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THE

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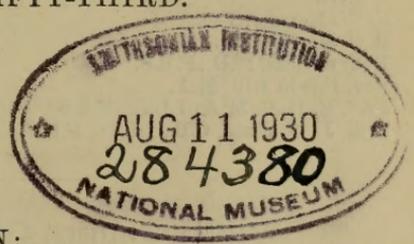
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Quod si cui mortalium cordi et curæ sit non tantum inventis hæerere, atque iis uti, sed ad ulteriora penetrare; atque non disputando adversarium, sed opere naturam vincere; denique non belle et probabiliter opinari, sed certo et ostensive scire; tales, tanquam veri scientiarum filii, nobis (si videbitur) se adiungant.  
—*Novum Organum, Præfatio.*

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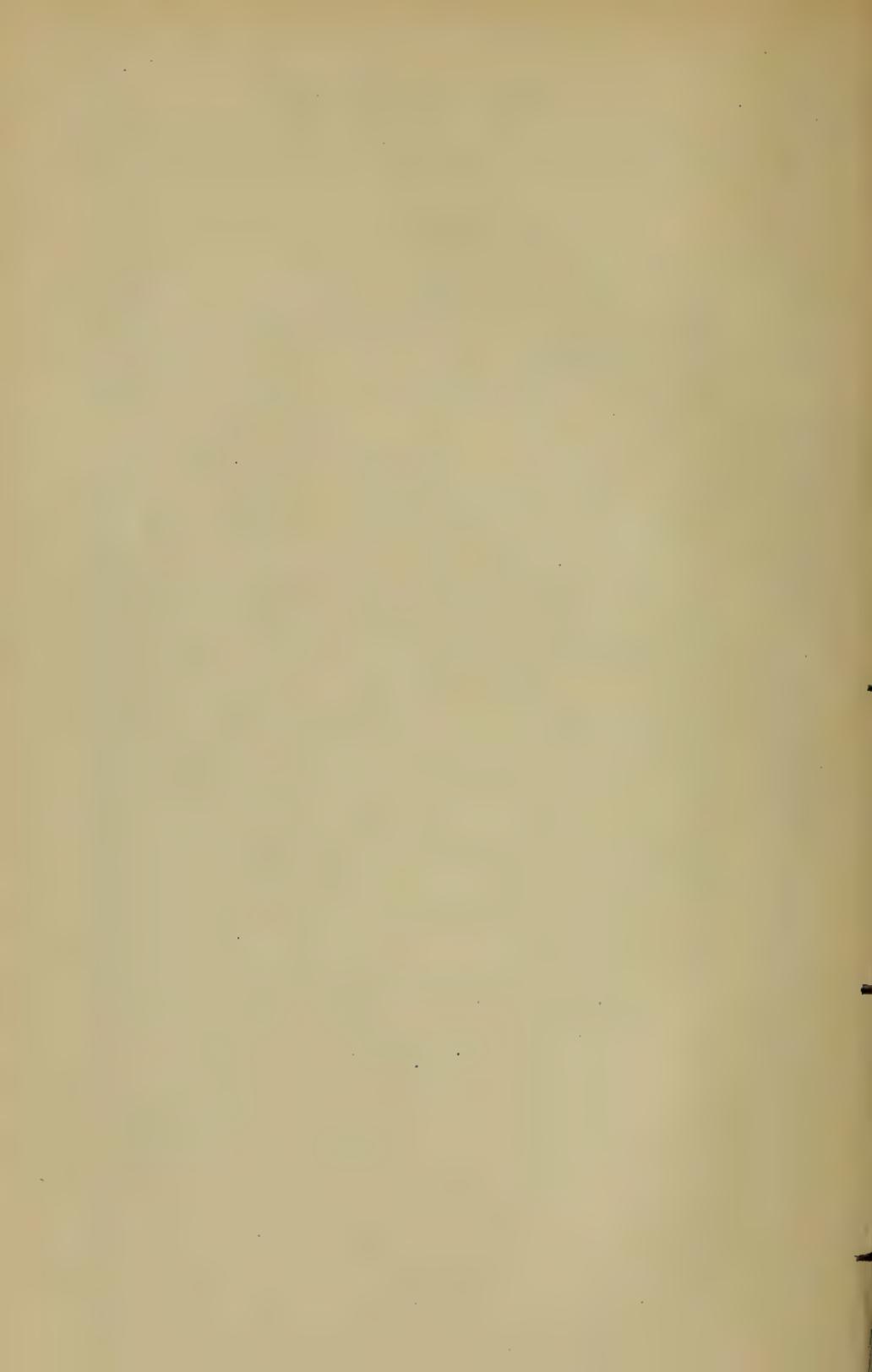
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SESSION 1896-97.

1897.

Wednesday, February ( <i>Anniversary</i> , Feb. 19) .....	3-24
"    March .....	10-24
"    April .....	7-28
"    May .....	12-26
"    June .....	9-23

[*Business will commence at Eight o'Clock precisely each Evening.*]

THE  
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VOL. LIII.

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1. *On the DISTRIBUTION in SPACE of the ACCESSORY SHOCKS of the GREAT JAPANESE EARTHQUAKE of 1891.* By CHARLES DAVISON, Sc.D., F.G.S., King Edward's High School, Birmingham. (Read November 4th, 1896.)

I. INTRODUCTION.

1. The complete history of the Mino-Owari, or great Japanese, earthquake of 1891 has yet to be written; but several important contributions to it have already been made. Prof. Koto, in an admirable memoir,<sup>1</sup> has traced the course of the extraordinary fault-scarp and discussed the origin of the earthquake; Prof. Ōmori,<sup>2</sup> with equal care and thoroughness, has investigated the unrivalled record of after-shocks; and Prof. Milne, in his invaluable catalogues of Japanese earthquakes,<sup>3</sup> has provided the materials for detailed analyses from many points of view.

My object in this paper is to consider the geographical distribution of the numerous shocks which preceded and followed the great earthquake. Prof. Ōmori has discussed the distribution of the after-shocks of this and other Japanese earthquakes, chiefly with regard to time; but, in an interesting section of his memoir,<sup>4</sup> he studies the distribution in space of the after-shocks of the Mino-Owari earthquake. In order to show the difference between Prof. Ōmori's method of treatment and that adopted in the present paper, I will first give a brief summary of this part of his work, though it is difficult to do justice to it without reproducing his maps.

<sup>1</sup> 'The Cause of the Great Earthquake in Central Japan,' 1891, *Journ. Coll. Sci., Imp. Univ., Japan*, vol. v. (1893) pp. 295-353 & pls. xxviii.-xxxv.

<sup>2</sup> 'On the After-shocks of Earthquakes,' *Journ. Coll. Sci., Imp. Univ., Japan*, vol. vii. (1894) pp. 111-200.

<sup>3</sup> 'A Catalogue of 8331 Earthquakes recorded in Japan between 1885 and 1892,' *Seismol. Journ. Japan*, vol. iv. (1895) pp. i-xxi, 1-367 (especially pp. 134-243), with maps.

<sup>4</sup> *Op. supra cit.* pp. 141-147.

## II. METHODS OF REPRESENTING THE DISTRIBUTION OF THE SHOCKS.

2. The great earthquake occurred on October 28th at 6<sup>h</sup> 38<sup>m</sup> A.M. (mean time of 135° E.), and during the first few days the after-shocks were so numerous and were separated by intervals of time so short that the identification of many of those observed at different places was nearly, if not quite, impossible. But at the meteorological station of Gifu, and at thirty-two other places in the provinces of Mino, Owari, and Mikawa, careful records were kept of all the shocks observed. Plotting on a map the numbers corresponding to the different stations, Prof. Omori has drawn curves through all places where equal numbers of shocks were felt during given intervals of time—namely, 1892, 1893 (omitting the months of January and September), January 1894, and also during the four years 1887 to 1890. In the first of these maps,<sup>1</sup> the marked expansion of the curves in four directions indicates the existence of as many axial lines which radiate from a point near Koori, and along which the seismic activity exceeded that in the adjoining districts. In the second and third maps, the axial lines proceeding towards Ibi and the Isé Gulf become insignificant, the other two, extending towards the E.N.E. and E.S.E., being still distinct; while in the fourth map no trace of any one of the axial lines exists. One interesting result which these maps bring out very clearly is that in the central part of the Neo Valley, which formed the principal epifocal tract of the great earthquake, the after-shocks were much less numerous than in the regions to the north and south.

3. The maps (figs. 2-8, pp. 4-7) which illustrate this paper are founded entirely on Prof. Milne's catalogues. These give, with comparatively few exceptions, the following elements of each earthquake:—the time of occurrence, the length, breadth, and extent of the disturbed area, the course of its boundary, and the approximate position of its epicentre. For the latter purpose, the whole country is divided by north-south and east-west lines into rectangles, each  $\frac{1}{6}$  degree in length and breadth; and the position of an epicentre is represented by the number of the rectangle in which it occurs, or, if under the sea, by its distance from the nearest rectangle on land.

The area included within the maps is bounded by the parallels 34° 40' and 36° 20' lat. N., and by the meridians 2° 10' and 3° 50' long. W. of Tokio, so that ten of Prof. Milne's rectangles adjoin each side of the map, and the whole area contains one hundred such rectangles.

In constructing the maps, the number of epicentres lying within each rectangle has been counted. Sometimes an epicentre is defined as lying between two consecutive rectangles, and such cases are divided equally between them.<sup>2</sup> Curves are then drawn through the centres of all rectangles within which the number of epicentres is the same, or through points which divide the line

<sup>1</sup> A reduced copy of this map, showing its essential features, is given in 'Natural Science,' vol. vi. (1895) p. 393.

<sup>2</sup> It thus happens sometimes that the number of epicentres allotted to a rectangle is not integral.

joining the centres of two rectangles in the proper proportion. Taking, for example, the curve marked 5, if the numbers in two consecutive rectangles are 3 and 7, the curve bisects the line joining their centres; if the numbers are 1 and 6, the line joining the centres is divided into five equal parts, and the curve passes through the first point of division reckoned from the centre of the rectangle in which six epicentres are found.

4. In Prof. Ōmori's maps, the meaning of the curves is obvious. At every point of the curve marked 100, for instance, one hundred shocks were, or would have been, felt during the period embraced by the map.

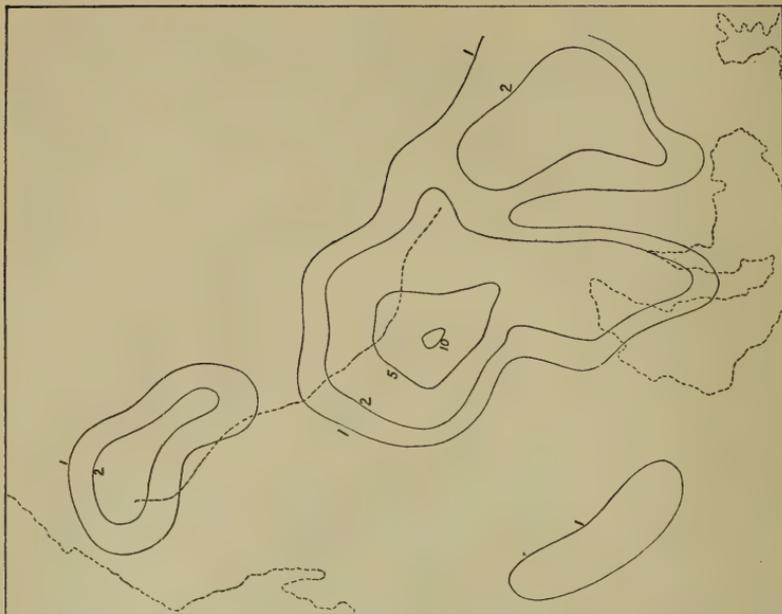
The meaning of the curve marked 100 in the accompanying maps (pp. 5, 6, & 7) is as follows:—Let any point in the curve be imagined as the centre of a rectangle whose sides are directed north-south and east-west, and are respectively  $\frac{1}{6}$  of a degree of latitude and longitude, then the number of epicentres within this rectangle is at the rate of 100 for the time considered.

If all of the Mino-Owari after-shocks had been exceedingly weak, so that each was felt at one station only, that place might be regarded as the centre of the shock, and the two methods would be the same, except in one slight detail. Some shocks, however, were strong or violent,<sup>1</sup> and must have been felt at a large number of stations, and in these cases Prof. Ōmori's method of counting the shock at each station is equivalent to drawing the disturbed area of that shock. Thus, the difference in principle between the two methods is nearly the same as that between Mallet's map of the world, in which the disturbed areas are coloured, and Milne's map of Japan, in which the epicentres only are marked. But, as a matter of fact, so large a number of the Mino-Owari after-shocks were weak or feeble that the two series of maps bear a certain resemblance one to another. The features in which they differ are due mainly, I believe, to the difference in principle noticed above and to the shorter intervals of time adopted in this paper.

5. It is important to point out a source of possible error in the maps, due, however, not to defects in the method so much as to the approximate character of the available data. In a map of all Japan which I have prepared, the number of rectangles is so great, and their size is so small compared with that of the whole country, that the errors may be neglected except in minute details. But in the present case the number of rectangles in each map is only 100, and the number to which the epicentres are principally confined is very much smaller, and therefore the errors may be of greater consequence. If the epicentres are connected with lines of fault, it is unlikely that they should be distributed evenly between the centres of adjacent rectangles. Thus, some error is unavoidably introduced into the curves by regarding the epicentres as

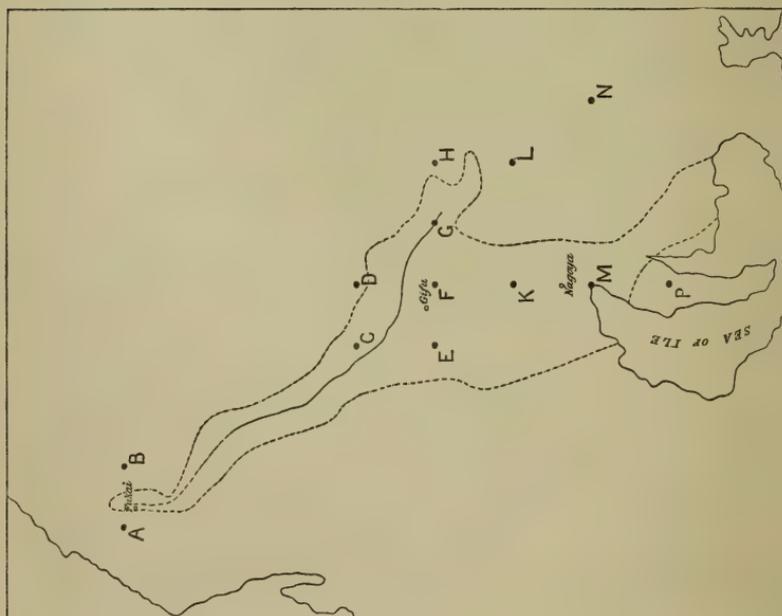
<sup>1</sup> 'Of the 3365 after-shocks recorded at Gifu during the first two years, 10 were 'violent,' 97 'strong,' 1808 'weak,' and 1041 'feeble,' while in the remaining 409 only sounds were heard without shocks.'—Ōmori, *op. jam cit.* p. 113.

Fig. 2.



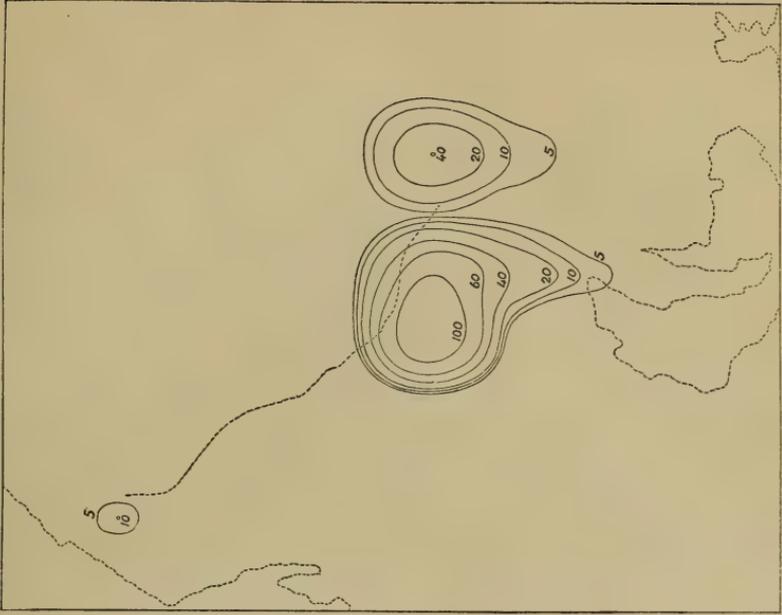
1 January 1890—27 October 1891.

Fig. 1.



[For 'Fukai' read 'Fukui,' and for 'Sea of Ile' read 'Sea of Isé.']

Fig. 4.



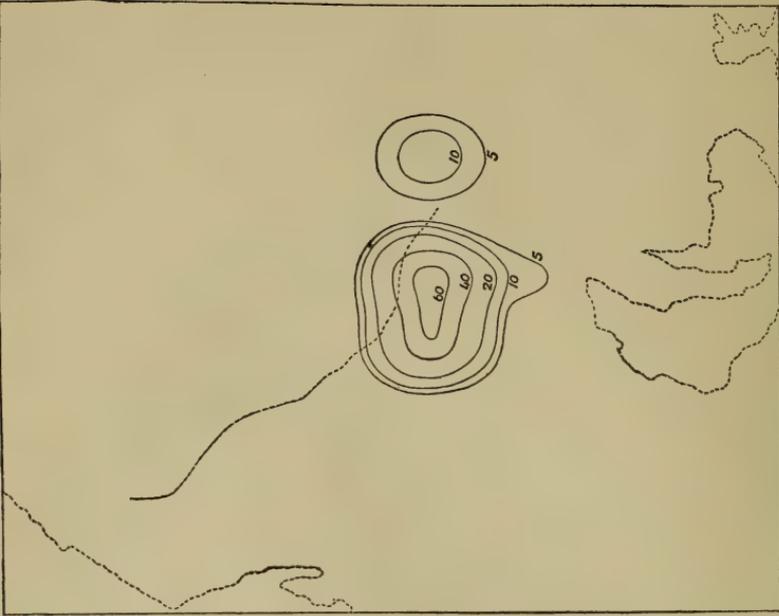
January—February 1892.

Fig. 3.



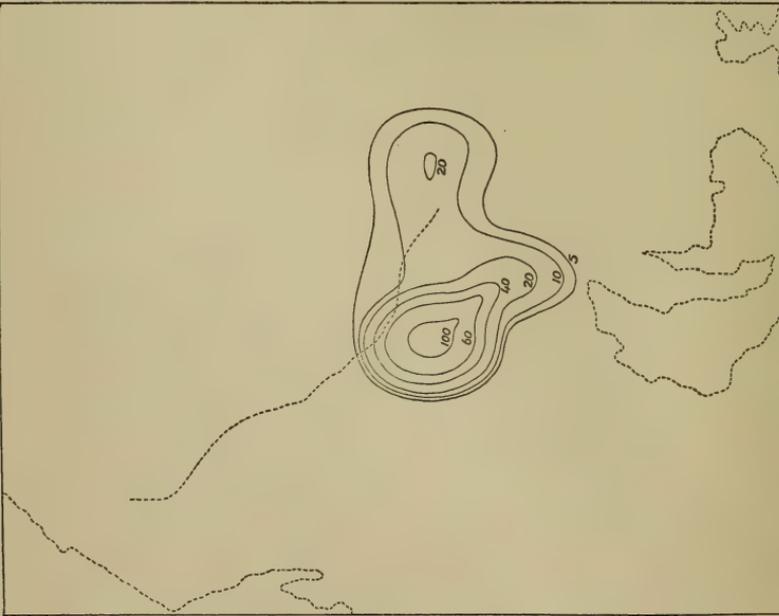
November—December 1891.

Fig. 6.



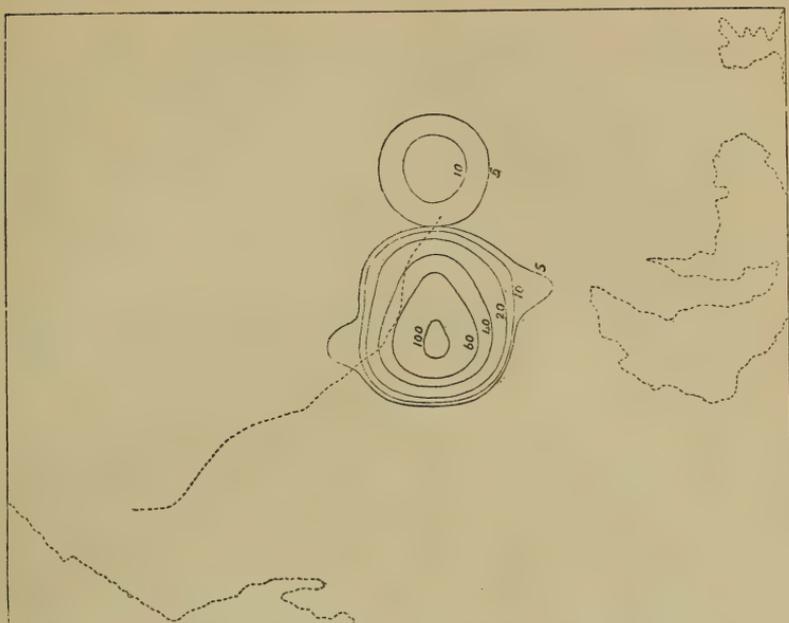
May—June 1892.

Fig. 5.



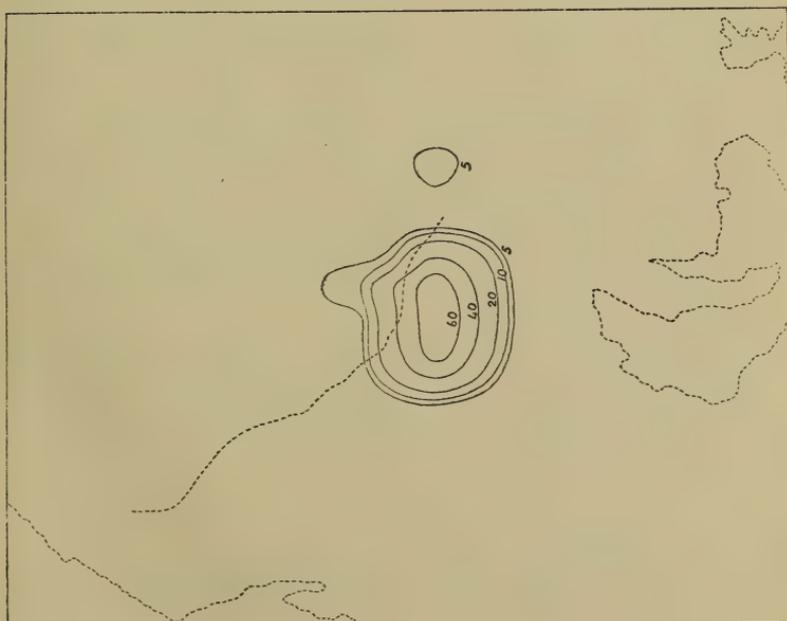
March—April 1892.

Fig. 8.



September—October 1892.

Fig. 7.



July—August 1892.

all collected at the centre of the rectangle, and the magnitude of the possible error increases with that of the rectangle. Supposing, however, the extreme case to occur in which all the epicentres are situated at one point close to a side of the rectangle, then the maximum deviation of any curve from its correct position would be equal to  $\frac{1}{12}$  of a degree, *i. e.* to  $\frac{1}{20}$  of a side of the complete map. The probable error is, of course, much less than this.

Another source, less of error than of misconception, should also be mentioned. This is due to the form of the rectangles, a degree of latitude being always longer than a degree of longitude, except at the equator. When a number of epicentres lie within a single isolated rectangle, the resulting curve is a small ellipse whose length is less than  $\frac{1}{3}$  of a degree, but the direction of the longer axis has no physical meaning, for it is necessarily parallel to the longer side of the rectangle.

Again, when a curve is founded on the occurrence of epicentres in two adjacent rectangles alone, its axis will generally be parallel to the line joining their centres; and its direction need not, though it may, correspond with that of some physical feature, for it is possible that all the epicentres might be grouped close to the common side of the two rectangles. It is only when the longer axis of the curve exceeds in length the sides of several rectangles that we can make any probable inference as to the connexion between the distribution of after-shocks and the geological structure of the district.

6. Turning now to the maps themselves, fig. 1 (p. 4) shows the outline of the coast within the Mino-Owari district. The dotted lines represent the boundary of the area over which the principal shock was felt most severely. The continuous line between them marks the course of the great fault-scarp, the northern part of which, not having been actually followed on the ground, is indicated by a dotted line.<sup>1</sup> The points A to P denote the centres of the rectangles,<sup>2</sup> within which the majority of the after-shock epicentres lie; this group of rectangles, as will be seen from the last column of Table I., contains sometimes all, and never less than  $\frac{9}{10}$  of the total number of epicentres within the district contemplated. In the succeeding maps, the coast-line and fault-scarp are indicated by dotted lines, the boundary of the meizoseismal area being omitted in order to avoid confusion.

The remaining figures are selected from a large number of maps. Fig. 2 represents the distribution of earthquakes during the period (January 1st, 1890, to October 27th, 1891) immediately preceding the great earthquake. The others illustrate the distribution of after-shocks for every two months from November 1891 to October 1892.

<sup>1</sup> The course of the fault-scarp and the boundary of the meizoseismal area are reduced from plate xxix. in Prof. Koto's memoir.

<sup>2</sup> They correspond in alphabetical order to the rectangles in Prof. Milne's map numbered 1237, 1238, 1352, 1353, 1401, 1402, 1403, 1404, 1457, 1459, 1512, 1515, and 1567.

TABLE I.

	No. of Epicentres.	A	B	C	D	E	F	G	H	K	L	M	N		A-P
1885 .....	29	...	...	...	31.0	...	3.4	...	3.4	...	3.4	...	3.4	...	44.6
1886 .....	19	...	...	...	5.3	21.1	...	...	...	...	...	...	10.5	...	36.9
1887 .....	16	...	...	...	...	12.5	...	...	...	...	...	...	...	...	25.0
1888 .....	33.5	...	...	3.0	...	26.9	...	6.0	3.0	3.0	...	9.4	3.0	3.1	44.9
1889 .....	27.5	...	...	5.5	3.8	25.5	7.3	...	...	5.7	5.5	7.3	...	...	51.1
1890 .....	52.5	1.0	5.7	3.8	3.8	9.5	4.0	4.8	2.9	2.9	2.9	5.7	...	...	61.2
Jan. 1st-Oct. 27th, 1891	28	5.4	...	3.6	3.6	21.4	3.6	...	...	3.6	5.4	7.1	7.1	5.7	60.8
Nov. 1891 .....	1139.5	0.6	0.7	0.1	0.1	7.3	5.6	1.9	4.4	65.3	0.6	2.1	0.4	...	94.1
Dec. " .....	495.5	...	1.0	...	...	3.9	0.4	18.4	...	83.0	...	8.5	1.2	1.3	96.7
Jan. 1892 .....	284.5	3.5	...	...	0.4	33.0	35.5	1.1	5.9	7.1	2.3	0.7	0.4	0.8	92.9
Feb. " .....	140.5	0.7	...	...	...	62.6	...	...	12.1	14.2	2.8	3.9	0.7	...	97.0
Mar. " .....	121.5	1.6	...	...	...	59.3	0.4	0.4	9.5	18.1	2.1	0.8	1.6	...	93.8
Apr. " .....	123	...	...	...	...	54.5	10.6	13.0	8.1	7.7	...	...	...	...	97.2
May " .....	96	2.1	...	...	3.3	54.5	36.5	0.4	10.4	6.2	...	...	...	...	100.0
June " .....	72	...	...	...	1.0	43.8	55.6	...	9.7	5.6	...	...	...	...	100.0
July " .....	84	...	...	...	1.4	27.8	52.4	...	3.6	4.8	...	...	...	...	97.7
Aug. " .....	95	...	...	...	3.6	32.1	32.1	1.2	3.6	3.2	...	...	...	...	96.9
Sept. " .....	156	1.3	...	0.6	1.3	50.5	30.1	0.5	4.2	2.6	...	...	...	1.1	96.8
Oct. " .....	98.5	...	...	7.1	...	5.8	20.4	5.1	5.1	5.1	...	1.0	...	...	90.8
Nov. " .....	103	...	...	3.9	...	34.0	34.5	1.0	13.1	9.2	...	...	...	...	95.7
Dec. " .....	86	...	...	1.2	...	39.0	39.0	2.3	3.5	5.8	1.2	...	...	...	92.0

[For Explanation, see p. 10.]

7. The maps do not, however, give a complete idea of the relative frequency of earthquakes in different parts of the district, just as contour-lines drawn at wide intervals do not determine with certainty the relative heights of the peaks which they enclose. The preceding Table (p. 9) supplements the maps in this respect. The letters A to P correspond to the rectangles whose centres are so denoted in fig. 1 (p. 4). The figures for each rectangle indicate the percentage of the whole number of epicentres in the Mino-Owari district which lie within that rectangle for the month or period mentioned.

8. It will be noticed in fig. 1 that the meizoseismal area is forked. The more important branch proceeds towards the south, while the fault-scarp apparently follows only the shorter branch to the south-east. From this figure alone it is difficult to avoid the impression that a considerable displacement, though perhaps not superficially visible, must have taken place along a fault passing somewhere near the axis of the southern branch, and this impression will be strengthened by a glance at the other maps, especially those in figs. 2 to 6. Without having any geological evidence of this second fault, I shall assume throughout the remainder of this paper that it does exist. Travelling first in a north-westerly direction from the sea, it probably bends towards the north somewhere near the point M (fig. 1). But whether it continues to the north joining the visible fault near the points E and F or turns again to the north-west about the point K, that is, whether it is a branch-fault or one of a system of faults, is not clear from the seismic evidence. The isolated curve in the south-western corner of fig. 2 would seem to indicate the existence of another fault of such a system, but the foundation for the inference is not very strong. For the sake of clearness, however, I will give provisionally the name of the 'main fault' to that which is visible on the surface, and of the 'secondary fault' to that whose existence along the southern branch of the meizoseismal area is inferred from the testimony of the earthquakes.

9. The central points C and D (fig. 1), and possibly also E and F, seem to be connected with the main fault; A and B with the northern end of the fault-scarp; G and H with its southern end; and L and N with a probable continuation of the main fault to the south-east. The points K, M, and P appear to be related to the secondary fault.

If we measure the seismic importance of a rectangle during a given interval by the number of epicentres which lie within it, the order of importance of the lettered rectangles will be evident from Table II., the corresponding number of epicentres being affixed.

TABLE II.

1885-1889.		Jan. 1, 1890—Oct. 27, 1891.		Nov. 1, 1891—Dec. 31, 1892.	
E	22	E	11	K	1168·5
D	10	M	} 5	E	749·5
M	3·5	N		K	475
N	} 3	K	4	H	199
F		} 2·5	B	} 3	G
C	} 2		C		M
L		} 0·5	D	A	24
G	} 0		F	L	21
H		} 0	L	P	20·5
P	} 0		P	D	18
K		} 0	G	N	15
A	} 0		A	C	14
B		} 0	H	B	12·5

### III. THE PREPARATION FOR THE GREAT EARTHQUAKE.

10. According to Prof. Milne, the last severe earthquakes at and near Gifu took place in 1826, 1827, and 1859.<sup>1</sup> On May 12th, 1889, a rather strong earthquake occurred, disturbing an area of about 48,700 square miles, and having its centre within or near the rectangle F.

The average yearly number of shocks in the district from January 1st, 1885, to October 27th, 1891, is 30. During the five years 1885-1889, the annual percentage of epicentres falling within the rectangles A-P lies between 25·0 and 51·1, the average being 42; in 1890 and 1891 (until October 27th) it rises to a little over 60; while, during the fourteen months succeeding the great earthquake, the monthly percentage is never less than 90 and twice is as much as 100.

11. During the first five years, the numbers of epicentres lying inside the rectangles A-P are respectively 13, 7, 4, 15, and 14; and the numbers occurring outside them are 16, 12, 12, 18·5, and 13·5. Thus, the number of epicentres lying within the fault-region increases and decreases with the total number of epicentres in the Mino-Owari district, showing that the great faults are to a large extent, though not entirely, responsible for the excess or defect in the average number of earthquakes.

It is remarkable that, during these five years, only one epicentre lies within the rectangle K, which is by far the most prominent seat of after-shocks in November and December 1891, while in the rectangles M and P there were only three epicentres during the same period. At this time, therefore, the secondary fault was almost inactive.

At the northern end of the main fault (rectangles A and B) there are no epicentres at all during the five years; at the south-eastern (rectangles G and H) there are four; and 6·5 in the continuation of the main fault to the south-east (rectangles L and N). The

<sup>1</sup> Seismol. Journ. Japan, vol. i. (1893) p. 149; Brit. Assoc. Rep. (1892) p. 128.

chief seat of earthquakes is in the rectangle D in 1885 and E in 1886, 1888, and 1889; the latter being the second in numerical importance, and the most persistent, in the district throughout the eight years considered.

Remembering that the rectangles A-P form only 13 per cent. of the whole area, it is thus clear that the frequency of earthquakes was relatively greater within the fault-region,<sup>1</sup> and that the seismic importance of the region increased considerably within about two years before the great earthquake.

12. The distribution of epicentres during the interval, January 1st, 1890, to October 27th, 1891, is illustrated in fig. 2 (p. 4). The total number is, however, so small comparatively that the essential features of the distribution are only brought out by adding curves 1 and 2. While the rectangle E is still the chief seat of seismic activity, it will be seen at a glance how the curves follow the lines of the main and secondary faults. In this as in other maps, there is a discontinuity in the curves in part of the main fault between the points B and C. Otherwise, earthquakes seem to have occurred along the whole fault-system, especially in the secondary fault and the supposed continuation of the main fault towards the south-east. A noteworthy feature is the uniformity in the distribution of epicentres throughout the fault-region; the marked concentration of effort which characterizes the after-shocks is hardly perceptible here. And this uniformity (as will be seen from Table I., p. 9) is still more noticeable in the earthquakes of the year 1890 alone.

13. An important point to be decided is how far this remarkable distribution is a result of the strong earthquake of May 12th, 1889. The number of shocks in the district in 1890 was 52·5, but in 1889 was only 27·5, of which 13 occurred before May 12th, and 13·5 after. Indeed, the earthquake of May 12th seems to have been almost unattended by after-shocks, the number of earthquakes felt in the district during the last eight months of 1889 being respectively 1, 1, 1, 2, 3·5, 4, 0, and 1. I think, then, that we may conclude that the distribution of earthquakes in 1890 and 1891 was in very small measure, if at all, the result of the shock of May 12th, 1889, but is rather to be regarded as a preparation for the great earthquake, the consequent relief at numerous and widely-distributed points equalizing the effective stress along the whole fault-system, and so clearing the way for one or more almost instantaneous slips throughout its entire length.

This outlining of the fault-system by the frequency-curves of 1890-91 points, therefore, to the previous existence of the faults, and implies that the great earthquake was due, not to the rupturing of strata, but probably to the intense friction called into action by the sudden displacement.<sup>2</sup>

<sup>1</sup> As 53 epicentres were situated during 1885-89 within these 13 rectangles, and 72 in the remaining 87 rectangles, it follows that the average frequency in one of the rectangles of the fault-region was five times as great as in one of those outside it.

<sup>2</sup> It would be interesting to determine in future studies whether this uniformity in distribution along a fault is a common feature of preparatory shocks. If so, it would form some rough indication of the approach of a great earthquake.

## IV. DISTRIBUTION OF THE AFTER-SHOCKS IN SPACE.

14. Prof. Ōmori has shown how the after-shocks decline in frequency, rapidly at first and more slowly afterwards. This decline is accompanied by more or less periodic fluctuations, and is occasionally interrupted (as on September 7th, 1892) by strong or violent earthquakes, each of which is followed by its own series of after-shocks, which may cause a temporary rise in the total number.

That a somewhat similar law governs the area over which shocks originate is evident from figs. 3-8 (pp. 5-7). During the first two months the epicentres occur over nearly the whole fault-region, but afterwards they are distributed over a more limited district, which does not, however, continually decrease in size.

In order to ascertain roughly the rate of diminution of the area of seismic action, I have made use of a series of monthly maps from November 1891 to December 1892, and have in each case determined the area included within the curve 5, which may be regarded as an approximate, though not an accurate, measure of the area in question. The results are given in the following table :—

TABLE III.

Month.	Area within Curve 5 in square miles.	Number of Epicentres.
Nov. 1891 .....	1741	1139.5
Dec. " .....	935	495.5
Jan. 1892 .....	930	284.5
Feb. " .....	633	140.5
Mar. " .....	572	121.5
Apr. " .....	728	123
May " .....	543	96
June " .....	444	72
July " .....	432	84
Aug. " .....	473	95
Sept. " .....	546	156
Oct. " .....	622	98.5
Nov. " .....	727	103
Dec. " .....	467	86

The monthly number of after-shocks, already stated in Table I. (p. 9), is repeated here for convenience of comparison. The figures in both columns exhibit a fluctuating decline, but the area of seismic action is not proportional to the number of shocks. We should not, however, expect this to be the case, any more than we should expect the area of the horizontal section of a hill made by the 500-foot contour to be proportional to the total volume of the hill above that plane.

15. Not only does the area of seismic action on the whole decrease in size, but the seat of principal activity is subject to almost continual change. Thus, the remarkable centre in the rectangle K sinks into

comparative insignificance after the first two months, and gives place to others in the rectangles E and F, the order during the first fourteen months being the following :—

K, K, F, E, E, E, E, F, F, E, E, E, F, E and F (equal).

The maps themselves furnish the most interesting evidence of this continuous displacement of the epicentres, though for details Table I. should be consulted. One or two points may be referred to. Thus, it will be seen that the rectangles C and D are more or less complementary; when one is the seat of action, the other is generally in repose. So also, but to a much less extent, are the rectangles E and F, one being as a rule much more active than the other, though they approach equality in this respect during the last three months.<sup>1</sup>

Perhaps the most interesting result of all is the distribution of epicentres along the main fault. A glance at the maps shows that this is not continuous. In the two rectangles which intervene diagonally between B and D there was almost complete repose, except for the great earthquake, during the whole time considered, there being only three epicentres within them in November 1891 and one in January 1892.<sup>2</sup> Again, in the rectangle G there is another, though far less strongly-marked, break, which does not occur, however, in December 1891 and April 1892, as will be seen in figs. 3 & 5 (pp. 5 & 6). Thus, the distribution along the fault may be summed up as follows :—a nearly central region of extraordinary activity, and two more or less isolated districts near or surrounding the extremities of the fault.

The seismic activity of these terminal districts was not only less marked, but also of shorter duration, than that of the central district. At the northern end of the main fault, as well as at the south-eastern end of its assumed continuation, all action practically died out before April 1892. In the southern terminal region of the fault-scarp it lasted until, if not after, the close of the same year.

A similar withdrawal of action from its southern extremity characterizes the secondary fault, only two epicentres lying in its neighbourhood after March 1892.

The after-shocks of the Mino-Owari earthquake for the first fourteen months were thus subject to the following conditions :—decline in frequency, decrease in the area of seismic action, and a gradual but oscillating withdrawal of that action to a more or less central district.

<sup>1</sup> These and other facts seem to show that the main fault is a system of two or more rather than the single fault indicated by the scarp.

<sup>2</sup> On September 7th, 1892, a strong earthquake occurred, which disturbed an area of nearly 44,000 square miles. The rectangles most shaken lie along a line passing immediately south-east of the B point and approximately at right angles to the direction of the main fault. A transference of strain from the latter to a possible longitudinal fault along the line indicated may perhaps account for the comparative quiescence along this part of the main fault.

## POSTSCRIPTUM.

[In the discussion which followed the reading of this paper, it was stated that 'where the maps showed blank spaces, in many cases the country was mountainous, and there were no observers.' This probably affords a partial, but not, I think, a complete explanation of the paucity of epicentres in the district referred to herein, for it would only apply to very slight earthquakes. It is obvious that the stronger shocks (if there were any) originating within the mountainous region would be observed in the surrounding country, and the resulting records would enable the positions of the epicentres to be determined.—Nov. 20th, 1896.]

## DISCUSSION.

Prof. MILNE said that the Mino-Owari earthquake had furnished a greater number and a more varied series of seismic phenomena for analysis than had been noted in connexion with any disturbance previously recorded. When this earthquake took place an enormous fault, which can be traced over a length of more than 40 miles, appeared upon the surface, and it was usually supposed that the sudden rupture and displacement of vast masses of material along this line were the cause of the earthquake.

On account of a peculiar distribution of shocks which took place prior to 1891, Dr. Davison argued that the fault or faults in the Mino-Owari district were outlined before the occurrence of the great earthquake, which was, therefore, only the result of their extension. This may have been so, but it must be remembered that before 1891 the number of shocks occurring in the Mino-Owari plain were not numerous; and as we pass from 1889 to 1891 we cannot say that they increased in number, while their distribution, as exhibited by maps, was largely dependent upon the observing-stations. Where the maps showed blank spaces, in many cases the country was mountainous, and there were no observers. The present Author's method of treatment of the statistics relating to 'after-shocks' no doubt possesses advantages over that previously used by Prof. Ōmori, but the results arrived at, so far as they are comparable, closely accord. It was at the speaker's suggestion that the study of after-shocks was undertaken, and he must congratulate Prof. Ōmori on having obtained results far beyond and of greater importance than anything anticipated at the outset. Prof. Ōmori added to our knowledge respecting the expiring efforts in a seismic area; while Dr. Davison, among other things, has thrown new light upon the change in subterranean conditions which culminated, on October 28th, 1891, in a shaking which could be recorded from pole to pole.

The Rev. EDWIN HILL remarked upon the extreme interest of the earthquakes described.

Mr. D. PAUL also spoke.

2. ADDITIONAL NOTE on the SECTIONS near the SUMMIT of the FURKA PASS (SWITZERLAND). By T. G. BONNEY, D.Sc., LL.D., F.R.S., V.P.G.S., Professor of Geology in University College, London, and Fellow of St. John's College, Cambridge. (Read November 4th, 1896.)

IN 1894 I gave an account<sup>1</sup> of certain sections in the valley of the Reuss (Switzerland) where a somewhat schistose white marble is associated with phyllites and limestones of Jurassic age. But of that on the Furka Pass, as then stated, the description was incomplete, as I had been compelled, owing to unfavourable weather, to be content with a hurried glance at that part of the infold which is on the western side of the summit. Here the road, curving round from a W.S.W. to W.N.W. direction, cuts across the apparent strike of the sedimentary rocks, and then quits them to run over the gneiss. It was the western end of the triangle thus formed, a piece measuring perhaps 400 yards in length by 250 at the widest part, which I had been unable to examine. But in the summer of 1895 I walked up to the top of the pass from the valley of the Rhone, in company with my friend the Rev. E. Hill, whose kind help I gladly acknowledge, and completed the examination of the western side, besides going over parts of the area which I had visited on the former occasion. A few additional facts were obtained, which may be worth bringing to the notice of the Society, for, although they are not conclusive as to the relation of the marble to the Jurassic rock, they throw, I think, some light upon the question.

On the western side of the pass, to speak first of the part left unexamined on the previous occasion, the live rock in many places is completely hidden by débris and turf. We have to make the best of various outcrops, which become more isolated as we go westward. The following account, however, I trust, is fairly correct. The great mass of slabby marble,<sup>2</sup> mentioned in my former paper as crossing the pass at the back of the 'dépendance' of the Furka Inn and forming a crag above the road, appears to descend gradually towards and run beneath the latter, and is lost under turf and talus on the steep slope below. It is overlain<sup>3</sup> by a greyish subcrystalline limestone, also rather slabby, with darker, more argillaceous bands, which do not look at all crystalline. This rock in general aspect corresponds with No. 3 of the section on p. 295 (*op. cit.*), and reveals traces of organisms under the microscope. Higher up comes a small outcrop of a rock which presents more resemblance to a very crushed condition of the marble than to one of the ordinary

<sup>1</sup> Quart. Journ. Geol. Soc. vol. 1. (1894) p. 285.

<sup>2</sup> No. 2 in the description given on p. 294 (*op. cit.*).

<sup>3</sup> I speak throughout this paper of the apparent succession of the outcrops on the mountain-slopes.

Jurassic limestones. Thus I believe that the opinion expressed in my former paper, as to a recurrence of the marble, is correct. I was not, however, able to trace this second mass farther west. The very rough diagram appended (fig. 1), a reproduction of one

Fig. 1.



1 = Jurassic.  
 2 = (Probably) crushed marble.  
 3 = Small patch, probably crushed marble.

4 = Quite typical Jurassic: 12 to 15 feet exposed.  
 5 = Marble (end of crag by road).  
 6 = Road.

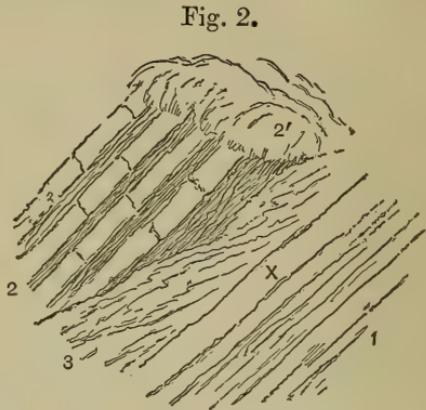
[Intervening spaces mostly turf-covered. Rock, if any visible, Jurassic.]

drawn in my note-book to indicate the general relation of the rocks on the western side of the top of the pass, may make the matter clearer than copies of more detailed sections. Next comes more limestone, grey or dark blue in colour, in one place having some sandy bands, in another becoming clayey. The details, however, are without interest, and the rock is undoubtedly Jurassic. Lastly, we found a pale-grey porphyritic gneissoid rock, with indications of having been crushed; not improbably a modified granite. It belongs, however, to the crystalline series of this part of the Alps, and is much older than the Jurassic period. So far as one can judge, the succession, which we observe close to the top of the pass,<sup>1</sup> continues towards the west, except that the upper bed of marble seems to disappear. The lower and larger mass is masked, after passing beneath the road, by turf and talus, and, so far as I could see, does not reappear. It is not indicated on the maps, and I think no conspicuous outcrop occurs on the slopes of the glen west of the pass.<sup>2</sup> The dip of the above-mentioned rocks is variable in amount and in direction, but something like 45° for the one and W.N.W. for the other may serve as a rough approximation. The marble at the top of the pass was more steeply inclined, having a dip nearer 70°; this, so far as I remember, was, however, rather exceptionally high.

<sup>1</sup> *Op. cit.* p. 295, *cf.* fig. 3.

<sup>2</sup> The slopes are steep and grassy, and exposures of rock mostly small. I found at one place about 1400 feet above the Rhone Glacier Hotel a very small outcrop which might possibly represent the marble in a greatly crushed condition. But in this part I have not attempted to make a minute examination.

At the time of my last visit the junction of the main mass of marble with the overlying Jurassic rock could be seen at three places. One is in a very small opening on the western side of the pass, just beyond the end of the crag of marble overhanging the road. Here we found in descending order (fig. 2) a subcrystalline limestone weathering bluish-grey, banded with a blackish slaty rock, about 18 inches; 'black messy stuff' (the above slaty rock crushed), about 6 inches; the slabby marble (crushed). The two other sections are on the eastern side of the pass, and were exposed in small quarries which had been opened by the roadside since my visit in 1894. The first was about 120 yards from the 'dépendance.' Here we see (1) a slabby, dull-coloured, subcrystalline limestone, parted by darker and more argillaceous bands; (2) a foot or so of 'dark messy stuff' corresponding with that in the last section; (3) the marble,<sup>1</sup> which rose to a height of about 15 feet



- 1 = Marble, rather crushed.  
 x = Top slab: specimen taken.  
 2 = Subcrystalline limestone with argillaceous slaty partings.  
 2' = Crushed slaty or shaly rock ('black messy stuff'), about 6 inches thick at most.  
 3 = Débris.

above the road. Its surface has a somewhat wavy outline, and its upper part is evidently in a rather crushed condition. This is the top of the mass of marble, which in 1891 we traced up the slope of the valley below, and which passes behind the 'dépendance,' forming the crag by the roadside farther west. Two other small pits, near together, are found about 40 yards east of that just described, each showing a similar section. In all these exposures two rocks of very different mineral character appear in close sequence, and suggest by their aspect some amount of faulting.

On previous visits I had observed certain macroscopic differences between the marble and the admittedly Jurassic limestone, but on this occasion became more than ever convinced of their existence. The most important may be stated as follows:—The marble, if unstained, is lighter in colour on a freshly-broken surface; on weathered surfaces it turns to a pale fawn colour, with occasional browner bands. These are more micaceous and project a little from the rest of the rock. The Jurassic limestone is darker in colour, becomes greyish-blue or bluish-grey in weathering, and

<sup>1</sup> No. 2 of the section described on p. 294 (*op. cit.*).

loses even its subcrystalline character in the more argillaceous bands. Both rocks are 'slabby,' but this character seems due, in the marble to pressure, in the limestone more immediately to the presence of soft shaly layers, though it may have been augmented by pressure. Moreover, to fracture a slab of the marble requires a hard blow with the hammer. The other rock breaks more easily and splits up into thinner slabs. In other words, the marble, except perhaps within a few inches of the junction, in the zone of exceptional crushing, is the less fissile of the two rocks. These remarks apply especially to the most crystalline variety of the Jurassic limestone, which appears, as stated in my former paper, to come immediately above the marble. The rest of it is so totally different from the latter rock that no confusion can arise.

The distinctions which are observed in the field are confirmed by study with the microscope. I collected some additional specimens last year, which have been compared with those obtained on former occasions. As regards the marble, I have really nothing to add to my previous description. If allowance be made for the effects of crushing (which are more conspicuous near the exterior), this rock everywhere has marked characteristics of its own. The mica, when it occurs, is usually well developed, seemingly authigenous, varying from colourless to a pale brown tint; the grains of quartz (with no hint of a fragmental origin) are larger than in the other rock; so also are those of calcite, as well as being more uniform in size and aspect. This rock, in short, corresponds very closely with the marble and the purer parts of the calc-mica schists, which are so abundant in association with various crystalline schists in many parts of the Pennine Alps, not to mention other districts. Even the most crystalline variety of the Jurassic rock is altogether less regular, and generally is more fine-grained in structure than it; the mica is in smaller flakes and of doubtful origin; the calcite-grains vary much in size, several certainly are fragments of organisms, among which crinoidal structure occasionally can be recognized: here and there dark films and small lenticles mark the presence of 'earthy' carbonaceous material, as in any ordinary impure limestone. Some mineral changes have undoubtedly occurred; the quartz, for instance, in its present form, does not indicate a clastic origin, but the alteration never exceeds, if indeed it equals, that in the matrix of the Jurassic 'knotenschiefer' near the Nufenen Pass.<sup>1</sup>

Omitting for the moment one character, which has no immediate bearing on the present question, we may thus sum up the differences: that while both rocks have been affected to some extent by pressure, the marble always seems tending to ally itself with a thoroughly crystalline rock, such as elsewhere in the Alps would be associated with typical mica-schists, quartz-schists, etc., and the limestone with the ordinary members of the Jurassic system.

The subcrystalline limestone seems to occupy the same position in regard to the marble, so far as it can be traced in this district,

<sup>1</sup> *Op. cit.* p. 288, and vol. xlv. (1890) pp. 213-221.

and a second thinner and apparently more limited band of the latter rock occurs above it. In the section at Realp<sup>1</sup> a rather similar limestone overlies the slabby marble, but the second mass of that rock is not seen. It may occur, however, for there is a considerable interval of covered ground just where it ought to crop out.

The possibility that this subcrystalline Jurassic rock might contain small fragments of the marble has more than once occurred to me, but on this point I have failed to obtain conclusive evidence. Here and there one detects with the microscope single grains of calcite, or associated groups of a few grains of calcite and quartz, which present an approach to a definite boundary and resemble small fragments of the marble; but, as the principal constituents of the two rocks are the same, anything like a boundary-line is not easily distinguished, and it may be that the agent, to which such metamorphism as the rock has undergone is due, has operated a little sporadically. Still I think that this possibility should be kept in view by anyone studying the rock. But the composition and condition of the band in immediate contact with the marble, and the state of the upper part of the latter, strongly suggest the existence of a thrust-fault. That might follow, however, the direction of the junction-surface between two rocks of different strength. But whether the present succession of the rocks be the original one or be only due to faulting, the result of this examination and of further study of the rocks in the great trough of the Upper Rhone valley convinces me that it is more probable that the marble is not a member of the Jurassic system, but a much more ancient rock, than that metamorphism has acted in a way unaccountably sporadic and capricious.

#### POSTSCRIPT.

This paper was completed shortly before I left England early in July 1896. Most of my holiday was devoted to examining, in company with my friend Mr. J. Eccles, F.G.S., sections between Ilanz and Splügen and the district south of the Rheinwald-Thal. Hereabouts 'slabby' marble is an unusually abundant constituent of the group of calc-mica schists (including quartz-schists and 'green schists'). The distinctive characters of the marble, and the marked differences between this group of crystalline schists and the slaty or calcareous rocks of Mesozoic age in the Alps, were impressed, if possible, more strongly than ever, upon my mind.

#### DISCUSSION.

The Rev. EDWIN HILL said that he could speak only of the Furka section. The two rocks seemed always in conformity, but always with signs of crush between, and always showed marked differences in strength, pointing to difference in age.

<sup>1</sup> *Op. cit.* p. 293, 3' in the section.

Dr. J. W. GREGORY thought that Prof. Bonney's maintenance of his former conclusion after a third study of the relations of the saccharoidal and the Jurassic limestones would lessen the value attached to the difficulties of his theory. Neither explanation is free from difficulty, but the constant differences now found between the two rocks greatly increase the probabilities in favour of the fault-theory.

The AUTHOR said that he quite agreed with Dr. Gregory that we had a dilemma before us. We must either assume very peculiar faulting or very sporadic and inexplicable metamorphism—seeing that the marble was totally different from the adjacent Jurassic rocks, was exactly like the marbles elsewhere members of the crystalline schists, and evidently had been affected by pressure after it had become a marble, while the other was simply a limestone affected by pressure. Hence he thought that the hypothesis of faults offered the fewer difficulties.

3. On CYCADEOIDEA GIGANTEA, a new CYCADEAN STEM from the PURBECK BEDS of PORTLAND. By A. C. SEWARD, Esq., M.A., F.G.S., University Lecturer in Botany, Cambridge. (Read November 18th, 1896.)

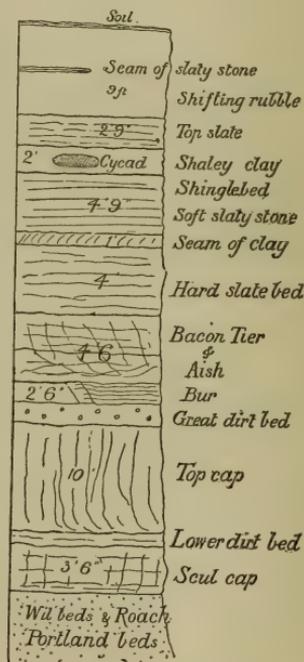
[PLATES I.-V.]

THE Isle of Portland has long been famous for the silicified Coniferous and Cycadean plants which occur in the surface-soils of Purbeck age. Buckland,<sup>1</sup> Carruthers,<sup>2</sup> and others have described the manner of occurrence and structure of the plant-remains from this horizon, and the fossil "crows' nests," or short, thick stems of Cycads, have long been familiar to geologists. The plant which forms the subject of the following description was acquired by Dr. Woodward in 1895, and is now one of the most remarkable specimens in the Fossil Plant Gallery of the British Museum.<sup>3</sup> It is probably the largest fossil Cycad hitherto recorded, and although the internal structure has been for the most part very imperfectly preserved, the cast of the stem is in some respects unusually complete. The specimen was found lying in a horizontal position in a bed of shaly clay, 2 feet thick, and about 17 feet higher in the Purbeck series than the Great Dirt-bed, from which most of the Portland plants have been obtained.

The position of the fossil is shown in fig. 1; the section is drawn from a photograph of the rock-face in one of Mr. Barnes's quarries close to St. George's Church on the west side of the old Portland Wide Street.

In Pl. I. the stem is represented about  $\frac{1}{8}$  natural size; it measures 1 metre 18.5 cm. in height (nearly 4 feet), and at the broadest part has a girth of 1 m. 7 cm. At the base it is somewhat narrower and thinner, and the surface-features

Fig. 1.—Section of the quarry in which the Cycadean stem was found.



[Drawn by Miss G. M. Woodward from a photograph.]

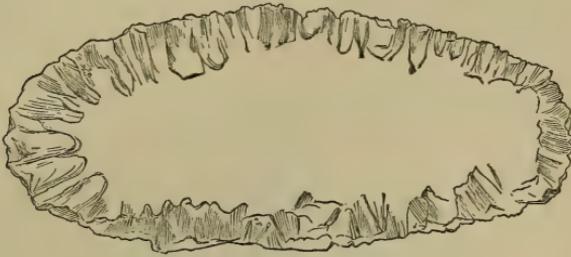
<sup>1</sup> W. Buckland, 'Geology and Mineralogy considered with reference to Natural Theology,' Sixth Bridgewater Treatise, vol. i. (London, 1836) p. 490, pls. lx.-lxii.; also Trans. Geol. Soc. ser. 2, vol. ii. pt. iii. (1828) p. 395.

<sup>2</sup> W. Carruthers, 'On Fossil Cycadean Stems from the Secondary Rocks of Britain,' Trans. Linn. Soc. vol. xxvi. (1870) p. 675.

<sup>3</sup> No. V. 3454.

are less clearly shown than in the other portions of the stem. A short distance above the base the preservation is particularly good, and much of the internal structure of the peripheral tissues is fairly well preserved. A transverse section has an elliptical outline (fig. 2),

Fig. 2.—*Transverse section of the stem of Cycadeoidea gigantea, sp. nov.*



measuring 41 cm. along the greater diameter, and 19 cm. along the smaller. The section, as drawn in fig. 2, is taken from about the middle of the stem; one side is almost flat, while the other has a more distinctly convex form. The present shape of the stem is no doubt largely the result of pressure, but it is possible that the trunk was originally rather broadly oval than circular in section.

Covering the surface of the specimen there is the characteristic Cycadean armour of the persistent bases of spirally-arranged leaf-stalks. Among recent Cycads, the majority of species present an appearance practically identical with that of the fossil, but in a few living forms the surface of the stem has a very different appearance, the regular petiole-bases being replaced by irregular transverse ridges and corky protuberances. This less known and more uncommon form is well illustrated by such plants as *Zamia Skinneri*, Warsz., *Z. Loddigesii*, Miq., and several others.<sup>1</sup> In most Cycads, however, after the fronds have withered, they become detached and the lower portion of the petiole remains for a longer time on the stem; finally the ragged petiole is cut off by a clean surface covered with corky tissue. The surface of the old stem in certain recent genera is thus covered with the regularly-disposed persistent bases of the large leaves. In the genus *Cycas* the stem shows a distinctly marked alternation of large persistent bases of fronds, and smaller bases of old bud-scales; while in such a genus as *Encephalartos* the bases of bud-scales and fronds present no such regular alternation, and cannot be readily distinguished in the older portion of a large stem. The surface of the fossil trunk is completely covered with rhomboidal leaf-bases, approximately of the same size, and it is impossible to draw any definite distinction between those of bud-scales and the larger foliage-leaves.

<sup>1</sup> See A. C. Seward, 'Annals Bot.' vol. x. no. xxxviii. (1896) p. 218, pl. xiv. figs. 1 & 2.

Passing to the apex of the trunk, we find that the leaf-bases become smaller in size (Pl. II. fig. 1), and finally at the extreme tip there is a conical bud surrounded by several long and narrow bud-scales (fig. 3). Covering the apex of the bud there is an irregularly-shaped cap of whitish colour, of which the surface is marked by numerous wavy lines suggestive of fine scaly or hair-like structures. The bud has a height of about 3 or 4 cm., and the scale-leaves which are best seen are about 1.5 cm. long and 6 mm. broad. The appearance of this terminal bud is shown in Pl. I., and more clearly in Pl. II. fig. 1, and in fig. 3. The lighter-coloured cap gives a flat-topped appear-

Fig. 3.—*Apical bud of Cycadeoidea gigantea, sp. nov.*



ance to the bud, and hides the tips of the uppermost scale-leaves; the form of the scales is, however, clearly seen in the lower portion of the bud. It is important to note that the stem at the base of the bud is almost circular in outline, thus confirming the opinion that the flattened appearance shown in fig. 2 (p. 23) is in great measure due to crushing. In the neighbourhood of the stem-apex the surface-features are imperfectly preserved, but the leaf-bases are distinctly visible in many places, and their gradual increase in size as we pass down the stem is easily recognized.

The material of which the specimen consists is highly siliceous; as shown in fig. 2, the central portion exhibits no trace of plant-structure, and is composed of cherty rock, while at the periphery the basal portion of the petioles and the interpetiolar substance are more or less clearly seen, and are represented in the sketch by radial lines extending inward a short distance (4 to 5 cm.) from the surface. There are no traces on the stem of any large lateral buds such as form so striking a feature in some fossil Cycadean plants, as, for example, in *Bennettites Gibsonianus*, Carr., and in some of the large specimens from North America and Italy.<sup>1</sup> An example figured by McBride,<sup>2</sup> from Dakota, shows a number of lateral shoots

<sup>1</sup> Capellini & Solms-Laubach, 'Tronchi di Bennettitee,' Mem. Real. Accad. Sci. Istit. Bologna, [5], vol. ii. 1892, p. 3.

<sup>2</sup> 'The American Geologist,' vol. xii. (1893) p. 248, pl. xi.

with remarkable distinctness; he named this stem *Bennettites dacotensis*, but Lester Ward has substituted the generic term *Cycadeoidea*.<sup>1</sup> The distal ends of the persistent petiole-bases have the form of rhomboidal areas, and the more internal portions extend for a short distance towards the centre of the stem in a slightly upward direction. This is, at all events, the case in the middle and lower portion of the specimen, but this position of the petioles is probably to a large extent the result of the pressure of overlying fronds, which has imparted to the bases a slightly downward direction.

A closer examination of the surface-features and of the facts revealed by microscopic sections of such peripheral tissues as have been preserved brings out some interesting points, which enable us to institute a comparison with recent plants and other fossil Cycads. In Pl. II. fig. 2 a portion of the surface towards the lower part of the trunk is shown on a larger scale. The appearance is that of a strong and prominent network with rhomboidal or elliptical meshes; the upper and lower sides of each mesh assume in some places the form of an arc of a circle, and laterally each mesh is bounded by the upper and lower walls meeting at an acute angle. The meshes shown in the figure (on a reduced scale) have a breadth of about 3 cm. and a height of 2 cm. In many cases the spaces in the network are occupied by a plug of cherty rock which can occasionally be extracted without difficulty; in others there is a mass of crumbling brown dust, while some are empty and extend for a short distance into the stem, as cavities marking the position of the lowest portion of the petioles. In some of the plugs occupying the meshes several small pits or dots may be seen towards the periphery; these are, no doubt, the remains of the vascular bundles of the leaf-stalk. In most cases, however, the actual structure of the petioles has not been preserved in any detail. The projecting framework frequently shows a marked tendency to weather into flakes, and this is simply an expression of the fact that the ridges separating the petiole-bases are largely made up of laminar structures, which are arranged in a direction parallel to the surface of the petioles. These interpetiolar structures are diagrammatically shown in Pl. V. figs. 14 r, 16-18 r, and more highly magnified in Pl. III. fig. 1 r, and figs. 4 & 8. Sections cut through some of the projecting ridges, of which the structure has been preserved by the infiltration of siliceous solutions, enable us to make out some of the anatomical characters of the petioles and the surrounding tissue composing the greater part of the framework of the net. The petioles consist in the main of fairly large-celled parenchymatous tissue, traversed by numerous secretory canals and scattered vascular bundles. The position of the secretory sacs or canals is indicated by the occurrence of dark brown or almost black patches which represent the mineralized contents of the secretory tissue. In Pl. V. figs. 16-18 the manner of

<sup>1</sup> Proc. Biol. Soc. Washington, vol. ix. (1894) p. 86.

occurrence of the secretory tissue is shown by the black dots; and in the parenchyma of the petiole *a*, shown in fig. 14, the sacs are seen in longitudinal section as obliquely-running and occasionally anastomosing cavities. The parenchymatous tissue of the leaf-stalk is usually crushed and imperfect, but in places the preservation is sufficiently good to show that the cells were of the ordinary type, such as characterizes the fundamental tissue of recent Cycadean petioles. In several of the parenchymatous cells of the ground-tissue, and especially well seen in longitudinal sections, there occurs a light-coloured vacuolated, or in some cases a darker granular substance. A few of the cells enclosing such contents are shown in Pl. IV. figs. 11-13; in the cell *b* (fig. 11) the brown contents have a granular appearance, and lie in the cell-cavity as a slightly contracted mass. In the cell *c* the apparent granular substance under a high magnifying power resolves itself into a fine reticulate structure, the framework of the net being marked out by lines of dark granules, and the meshes occupied by a brown substance. In fig. 13 the whole cavity is filled with a lighter and more transparent and delicate network, having rather the appearance of a number of more or less spherical cells with clear contents. In fig. 11 *d* the cell contains a spherical mass bounded by a delicate granular border, and consisting of a brown material possessing a vacuolated or frothy structure.

Again, in the neighbourhood of the larger sac (fig. 12) containing the petrified secretion, the cells are occupied by a distinct reticulum. The appearance presented by such a cell as *d* in fig. 11 and in fig. 13 suggests the spores or cells of an endoparasitic organism, but a careful comparison of several cells leads to the conclusion that these various forms of vacuolated, frothy, and granular material are merely different conditions of cell-contents. Prof. Marshall Ward pointed out to me the very striking resemblance, or indeed identity, between the contents of the fossil cells and the vacuolated and frothy substance found in the parenchymatous tissue of many recent plants. In a series of drawings of such cell-contents in some recent members of the *Rubiaceæ*, made by Prof. Ward from material which he investigated in Ceylon, it is possible to recognize the several forms assumed by the cell-substance of the fossil parenchyma. In the recent tissues these appearances are due to the various forms assumed by tannin, oily and protoplasmic substances in the cells, and in the fossil cells there can be little doubt that we have an illustration of the preservation of similar cell-contents. The chief importance of these facts is to emphasize the danger of regarding such structures as the cells of foreign organisms. Among recent plants this kind of cell-contents has been described as a parasitic fungus, and the extraordinary manner in which some portions of the vacuolated and frothy substance simulate the rounded cells of a fungus, renders it easy to be misled by the deceptive appearance. Precisely similar contents occur in the cells of the ground-tissue in the petioles of *Bennettites Gibsonianus*.

It has recently been shown that the 'spot disease' of orchids is

of a non-parasitic nature<sup>1</sup>; the contents of the leaf-cells of diseased plants agree very closely with those in the fossil tissue. In a paper contributed by Prof. Williamson in 1888 to the 'Annals of Botany' several examples are described of 'anomalous cells' within the tissues of Coal-Measure plants.<sup>2</sup> Some of the figures of these structures are practically identical with the appearance presented by the vacuolated contents in the cells of the Cycadean petioles. A comparison, for example, of Williamson's fig. 1 (pl. xviii.) with figures 11-13, Pl. IV. of this paper, and again with Masee's figure of the leaf-cells of a recent orchid, brings out an exceedingly close agreement in both these cases. There is very little doubt that many of these so-called 'cells' in the tissues of fossil plants are in reality vacuoles, granules, and other structures which are probably pathological in their origin. Some may be normal cell-contents, but others are more probably the expression of some abnormal condition of the plant in which they occur.

In some of the parenchymatous cells in the petioles of the Portland fossil there are preserved small oval or spherical bodies which stand out fairly conspicuously in the cell-cavity, as at *n*, Pl. IV. fig. 11. It is not improbable that these are examples of fossil nuclei.

At the periphery of the petioles the ground-tissue passes gradually into a parenchyma composed of somewhat smaller cells (Pl. III. fig. 1), which assume a distinct radial arrangement. External to these innermost radially disposed cells the tissue is frequently broken across, but in places it has been left intact, and is then seen to have the form of a zone of smaller, thinner-walled, and flattened cells, which is evidently a band of meristematic tissue. Beyond the cambium layer there is a succession of flatter and often crushed cells in regular series, limited by a layer of indistinct and partially disorganized cells (*e*) representing the remnants of an epidermis. In some parts of the section a light yellow-coloured line (*c*) may be seen outside the epidermal cells, and this is in all probability the imperfectly preserved and broken cuticle which has in many places been detached from the cells of the epidermis. The dark bands (*p*) at the margins of the petioles in Pl. V. figs. 16-18, and the band (*p*) in fig. 14, are made up of radial rows of tangentially-flattened cells.

In Pl. III. fig. 1 the lowest and largest cells *g* are part of the parenchymatous ground-tissue of the petiole; next to these occur rather smaller and radially-arranged cells, with cell-contents of a bright sherry-colour, which may be described as phelloderm (*phd.*) formed on the inner side of the cork-cambium or phellogen (*phl.*). The break in the tissues represents approximately the position of the cambium-cells, which would form a natural line of weakness. External to this, we have the lighter-coloured and flatter cells *ck.*, which constitute the cork-tissue developed from the phellogen. The rich brown contents of the phelloderm-cells no doubt consist of the silicified protoplasmic contents of this recently developed

<sup>1</sup> G. Masee, 'Annals Bot.' vol. ix. (1895) p. 421, pl. xv.

<sup>2</sup> W. C. Williamson, 'Annals Bot.' vol. i. (1888) p. 1, pl. xviii.

secondary tissue, while the absence of such infilling-material in the cork tissue is in accordance with air-containing periderm-cells. The epidermal cells are shown at *e* in Pl. III. fig. 1, and what is probably the remains of the cuticle at *c*. In fig. 3 the cork-cambium cells are shown under a higher power. From the relative position of the partially disorganized epidermis and its underlying periderm, it would seem that the phellogen arose in the subepidermal cell-layer. In Pl. III. fig. 2 is shown, on the same scale as fig. 1, a section through the peripheral portion of a petiole of *Macrozamia Denisoni*, Moor & Muell., cut from the persistent base of a leaf-stalk which has remained attached to the stem after the fall of the frond. The larger phelloderm-cells in the lower part of the section, *phd.*, pass gradually into the parenchyma and the ground-tissue, *g*, and on the left of the figure are seen four thick-walled sclerenchymatous cells, *s*. External to the phelloderm there is the cork-cambium, followed by the regular rows of flattened and somewhat crushed elements of the cork, *ck*; finally the torn epidermis and thick cuticle are found in the petiole-surface (*e* & *c*). In another part of the longitudinal section, shown in Pl. V. fig. 14, the epidermis of the petioles has been bent in such a manner as to appear in some places in surface-view, in precisely the same way as, in a badly-cut transverse section of a fresh leaf or twig, the epidermal layer is often bent over instead of being cut through transversely. Where the epidermis has been thus folded over, the component cells are seen to be polygonal or square in form and to have straight walls, as in most recent Cycads.<sup>1</sup> Several stomata stand out clearly, their position being readily recognized by the occurrence of comparatively large and dark-coloured guard-cells. In Pl. V. fig. 15 a stoma and some of the neighbouring epidermal cells are represented; the two conspicuous guard-cells, *gd*, .055 mm. in length, have somewhat shrunken cell-contents, and the oval brown-coloured bodies in the lower cell bear a striking resemblance to the chloroplasts in the guard-cells of recent stomata. It is by no means impossible that the substance of the chlorophyll-corpuscles has been preserved by the mineralizing material in such a way as to retain in the fossil condition the original form and arrangement of these constituents of the living cell.

The forms assumed by siliceous or calcareous substances in the tissues of fossil plants are, however, often difficult to interpret, and one cannot always determine how far the original cell-contents have been the cause of the form assumed by the material in the petrified cells. Between the two guard-cells, a small elliptical median aperture is clearly seen, especially on focussing down to a slightly lower level; this is the entrance to the respiratory cavity. On either side of this there appears to be a subsidiary cell (*s*). As no stoma is cut through vertically, it is difficult to be quite certain as to the structures observed in surface-view; possibly the apparently lower cells, *s*, are really part of the inwardly curved guard-cells.

<sup>1</sup> See Bornemann, 'Ueber organische Reste der Lettenkohlen-Gruppe Thüringens,' Leipzig, 1856; and Kraus, Pringsh. Jahrb. vol. iv. (1865-66).

Kraus has figured a stoma of *Ceratozamia mexicana*<sup>1</sup> in which the guard-cells are curiously curved in such a manner as to present an appearance in surface-view similar to that of the fossil stoma. Probably, however, the cells *s* are really separate from the guard-cells, and in transverse section would appear very similar to the stoma-cells of *Cycas revoluta*<sup>2</sup> as figured by Kraus, and later by Strasburger.<sup>3</sup> The latter points out that Kraus's section is neither median nor vertical. On the whole the appearance in surface-view and the size agree closely with those of the stomata of *Dioon edule* and other Cycads; in *Dioon* there are two subsidiary cells accompanying the guard-cells, and it is probable that there are two in the stomata of the fossil petioles. So far as it is possible to decide, it would appear that in the fossil the stomata are not much below the level of the epidermis.

Scattered through the ground-tissue of the portion of the petiole *i*, shown in fig. 16, there are twelve imperfectly preserved vascular bundles.<sup>4</sup> The structure of the bundles appears to agree with that described by Carruthers<sup>5</sup> and Lignier<sup>6</sup> in species of *Bennettites*. A single vascular bundle of *Bennettites Gibsonianus* is shown in Pl. IV. fig. 10, drawn from one of the sections of this plant in the Jodrell Laboratory of the Royal Gardens, Kew. At *cp* there is a group of tracheids without any regular arrangement, representing the centripetal part of the xylem; the probable position of the protoxylem elements is shown at *px*. External to this there are other tracheids more perfectly preserved and arranged in radial series (*cf*), with a few separating rows of medullary-ray cells (*m*). This portion of the bundle constitutes its centrifugally-developed xylem. Beyond this the tissues are as a rule less perfectly preserved, but in some of the sections of *Bennettites* it is easy to make out a line of thin-walled cambium-cells succeeded by the crushed elements of the phloem. Next to the zone of crushed phloem, there is a group of more clearly preserved cells (*s*), which may have been sclerenchymatous; they correspond to the thick-walled elements which Bertrand and Lignier have designated the 'fibres primitives'<sup>7</sup>; probably, however, these cells do not form part of the true vascular bundle, but belong to the ground-tissue of the petiole. In Pl. IV. fig. 9, one of the vascular bundles of the Portland stem is represented; although the preservation of the tissues is imperfect, the structure is sufficiently good to enable us to recognize a close agreement with the bundles of *Bennettites Gibsonianus*. The line *c* marks the external limit of the centrifugal xylem and the position of the cambium. External to this is the crushed phloem (*ph*), and finally a few cells, *s*, corre-

<sup>1</sup> Kraus, 'Ueber den Bau der Cycadeenfiedern,' Pringsh. Jahrb. vol. iv. (1865-66) pl. xxi. fig. 20.

<sup>2</sup> *Ibid.* pl. xix. fig. 5.

<sup>3</sup> Strasburger, 'Ein Beitrag zur Entwicklungsgeschichte der Spaltöffnungen,' Pringsh. Jahrb. vol. v. (1866-67) p. 331, pl. xli. fig. 143.

<sup>4</sup> Not shown in the figure.

<sup>5</sup> Trans. Linn. Soc. vol. xxvi. (1870) pl. lx. fig. 7.

<sup>6</sup> 'Structure et Affinités du *Bennettites Morierei* (Sap. & Mar.),' Mém. Soc. Linn. Normandie, vol. xviii. (1894) p. 21, pl. i. fig. 18, etc.

<sup>7</sup> Lignier, *op. supra cit.* p. 21.

sponding to those on the outside of the *Bennettites*-bundle (Pl. IV. fig. 10). The dark radial lines, *m*, are no doubt rows of medullary-ray parenchymatous cells. Below the radially-disposed tracheids, the tissue is very indistinct and disorganized, but probably there was in this position a group of centripetal tracheids corresponding to those shown at *cp* in fig. 10. In longitudinal section the imperfect xylem elements are seen to have scalariform thickenings on their walls.

It has already been pointed out that the spaces between the petiole-bases are occupied by a mass of scaly structures or ramenta. In transverse section the ramenta have the form of short and tapered cell-rows, more or less closely crowded together between the petioles. Longitudinal sections through the petioles show the ramenta attached here and there to the epidermal layer, from which they arise as laminar outgrowths. In Pl. V. fig. 14 the ramenta are seen to curve towards the leaf-stalk surfaces at *x*, whereas in the greater part of the space between the petioles they occur as closely-crowded laminæ, *r*, parallel to the petiole-bases. In Pl. III. figs. 1, 4, & 8, some ramenta are shown in transverse section; they have the form of a single layer of cells, or in the median portion they may be two, three, or more cells thick. The largest in fig. 4 has a length of .75 mm. and a breadth in the middle of .1 mm. In the longitudinal section the cells of the ramenta are long and narrow, with fairly square ends. Precisely similar structures have been previously described and figured by Carruthers and others, as forming a kind of interpetiolar packing in *Bennettites*.<sup>1</sup> The ramentum shown in Pl. III. fig. 7 was drawn from a section of *B. Gibsonianus*; it is shorter and broader than most of these structures, which are practically identical in form in the Portland stem, in *Bennettites Gibsonianus*, and *B. Moriëri*.<sup>2</sup> No doubt the compact and crowded arrangement of these epidermal structures between the petiole-bases has been partly brought about by the development of cork, and the consequent increase in thickness in the persistent leaf-bases. The projecting network shown in the photograph, Pl. I. and Pl. II. fig. 2, is chiefly made up of silicified ramental tissue, and exactly the same is the case in *Bennettites Gibsonianus* and other fossil trunks. The crowded and narrow cellular plates apparently absorbed the mineralizing-solution more readily than the tissues of the petioles, and so resisted decay, while the substance of the petioles has been for the most part destroyed. The comparatively loose mass of ramenta probably acted like a sponge, and sucked up the siliceous solutions with avidity. In speaking of these scaly outgrowths covering the basal portions of the petioles in *Bennettites*, Graf Solms<sup>3</sup> has called attention to the striking resemblance which they bear to the ramenta or paleæ so abundant on the leaf-stalks of many ferns.

<sup>1</sup> Cp. Carruthers's figures (*op. jam cit.*), pl. lx. figs. 7 & 11.

<sup>2</sup> Lignier, *op. cit.* pl. i. figs. 10-13.

<sup>3</sup> Solms-Laubach, 'On the Fructification of *Bennettites Gibsonianus*, Carr., *Annal. Bot.* vol. v. (1890-91) p. 423.

Carruthers thus describes the occurrence of the interpetiolar scaly structures in *Bennettites*:—‘A very dense ramentum clothed the under-surface of the base of the petiole, which was developed to such an extent as to separate very considerably each petiole from its neighbour. The petrifying material, having obtained speedy access to these delicate scales, has preserved them in a remarkably perfect condition.’<sup>1</sup>

In Pl. III. fig. 5 a single ramentum from the petiole of *Cyathea excelsa*, Sw., is shown in transverse section. This is a typical example of a fern-ramentum, and the resemblance to the corresponding structures in the fossil Cycad is obvious. The ramenta of ferns are occasionally more than one cell thick, as in those of the fossil Cycadean petioles. In a few ferns, e. g. *Dicksonia antarctica*, Lub., and *Osmunda regalis*, L.,<sup>2</sup> the paleæ have the form of cell-filaments, but this is exceptional. In recent Cycads, on the other hand, the woolly covering which is conspicuous on the bud-scales and leaf-stalk bases of some species consists of very long hairs composed almost entirely of a single cell. Buckland, in the sixth ‘Bridgewater Treatise,’ figured a section through the basal portion of a recent Cycad, showing the woolly epidermal hairs, comparable to the outgrowths from the fossil leaf-stalks (pl. lxii.). In Pl. III. fig. 6 a portion of one of the long hairs of *Dioon edule*, Lind., is represented; it consists of a short, thick-walled stalk-cell with a very long terminal cell. In the bud-scales and carpophylls of the cone of the same species, the dense covering of woolly hairs is very conspicuous. Similar hairs occur also in *Macrozamia*, *Encephalartos*, and other recent Cycads.<sup>3</sup> These ramental hairs of Cycads and the chaffy scales of fern-petioles are used in New South Wales as stuffing for cushions and known as ‘pulu.’

Reverting to the terminal bud of the fossil stem, it has already been pointed out that the apex is covered by an irregularly-shaped cap of ramental tissue. In fig. 4 (p. 32) is represented the apical bud of a large plant of *Encephalartos Altensteinii*, Lehm., in the Royal Gardens, Kew; in the lower portion the narrow and pointed bud-scales are clearly shown, but the summit is capped by a loose woolly mass of long brown hairs.<sup>4</sup> The resemblance between the bud of the recent and fossil stems is particularly striking. A few months after the photograph, reproduced in fig. 4, was taken, the hairy covering and bud-scales were seen to be pushed aside by the elongation and expansion of a large male flower. Whether the fossil bud, at the time of the plant’s death, contained a crown of unde-

<sup>1</sup> Trans. Linn. Soc. vol. xxvi. (1870), p. 696.

<sup>2</sup> Campbell, ‘The Structure and Development of the Mosses and Ferns,’ 1875, p. 353. See also De Bary, ‘Comparative Anatomy,’ p. 64.

<sup>3</sup> For other instances of the occurrence of hairs or cell-laminæ on the leaves of fossil Cycadean plants, see ‘The Wealden Flora,’ vol. ii. (Brit. Mus. Cat. 1895), ‘*Bennettites*,’ passim. See also Eichler on *Cycadaceæ*, in Engler & Prantl’s ‘Die natürlichen Pflanzenfamilien,’ pt. ii. (1889).

<sup>4</sup> My thanks are due to the Director of the Royal Gardens for permission to have photographs prepared for comparison with the fossil plant.

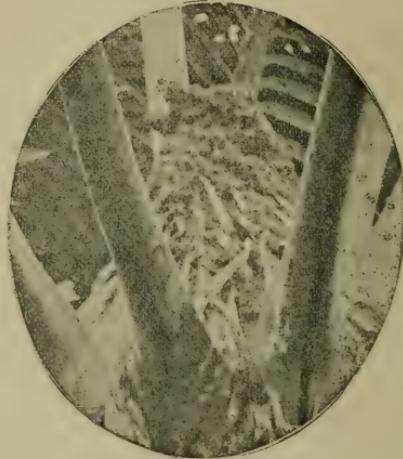
veloped fronds or a floral shoot must unfortunately remain a matter for speculation.<sup>1</sup>

It remains for us to consider more fully the affinities of the Portland fossil stem. Externally it would be difficult to discover any real difference between the fossil and many large trunks of recent Cycads, especially some species of *Macrozamia* and *Encephalartos*. In recent stems, the older petiole-bases may be frequently seen to have rotted away internally, while a peripheral band of more resistant material, periderm or sclerenchyma, has remained as a projecting ridge.<sup>2</sup> In the fossil stem it is more particularly the interpetiolar tissues that have remained as the prominent surface-feature.

Passing to the internal structure, there is a close correspondence between the fossil petioles and those of living Cycads. In a transverse section of a recent petiole taken some inches above the base, there is a well-developed hypodermal mass of sclerenchyma inter-

perspersed with groups of thin-walled parenchyma. If a series of sections be cut from a petiole until the base is reached, the sclerenchymatous hypoderm is found to gradually decrease in amount, and is finally almost or entirely absent. A cork-cambium arises in the persistent basal portion, either in the subepidermal layer or in a deeper layer of cells, and a ring of periderm is developed. This increase in the diameter of the old leaf-bases of Cycads has been alluded to by Saporta,<sup>3</sup> Renault,<sup>4</sup> Solms-Laubach,<sup>5</sup> and others. In the fossil stems we have an exactly similar formation of periderm in the petiole-bases. The leaf-bases of *Dioon edule*, as well as those of the species of *Macrozamia* (*M. Denisoni*) figured in Pl. III. fig. 2, illustrate very clearly the disappearance of the sclerenchyma and the formation of cork. In *Dioon edule* the phellogen occurs internal

Fig. 4.—The apical bud of *Encephalartos Altensteinii*.



[From a photograph of a plant in the Palm House, Royal Gardens, Kew.]

<sup>1</sup> Lester Ward has pointed out (U.S. Geol. Surv., 16th Ann. Rep. 1896, p. 487) that one of the specimens of *Bennettites (Cycadeoidea) Saxbyana* in the British Museum possesses an apical leaf-bud. This, however, is very much less distinct than the bud in the Portland stem.

<sup>2</sup> This is particularly well shown in a piece of a stem of *Macrozamia Moorei* in the Museum, Kew Gardens.

<sup>3</sup> Pal. Franç. vol. ii. (1875), Cycadées, p. 11.

<sup>4</sup> 'Cours de Bot. foss.' vol. i. (1885) p. 35.

<sup>5</sup> 'Die Sprossfolge der *Stangeria* u. der übrigen Cycadeen,' Bot. Zeit., Jahrg. xlviii. p. 12. See also Eichler in Engler & Prantl, *op. jam cit.* p. 7.

to the hypodermal sclerenchyma; in *Macrozamia Denisoni*, immediately underneath the epidermis. Some of the petioles seen on the polished tangential surface of a large block of *Bennettites Gibsonianus* in the British Museum possess a peripheral band of darker tissue, which is probably periderm. In the leaf-bases of *B. Gibsonianus*, in the immediate neighbourhood of the lateral inflorescences, there is no cork or sclerenchyma; in such cases the petioles would retain the power of further growth by cell-division.

The identity of the ramenta with those of *Bennettites* has already been emphasized, also the apparently close resemblance between the vascular bundles. Without discussing at length the comparative structure of the vascular bundles of recent and fossil Cycadean petioles, it is advisable to draw attention to one or two important features. In a transverse section of a Cycadean leaf-stalk, we find the vascular bundles are distinctly collateral in form, with the protoxylem elements on that side of the xylem next the phloem. The main portion of the xylem consists of tracheids internal to the protoxylem, which have been developed centripetally; external to the protoxylem, however, there occur a few isolated tracheids, or in some cases a fairly thick, crescent-shaped band, developed in a centrifugal direction.<sup>1</sup> Bundles in which the primary xylem is both centripetal and centrifugal have been termed mesarch. The nature of such bundles has been discussed by Solms-Laubach in his 'Fossil Botany' (p. 257), and more recently by Williamson and Scott (Phil. Trans. vol. clxxxvi. 1895, B, p. 713). If we examine a petiolar vascular bundle in the basal portion of a frond-axis, the centripetal portion of the xylem is found to be much more conspicuous than in the upper part of the petiole, and composed of radially-arranged tracheids. This is seen to be the case in *Macrozamia Denisoni*, and Mettenius figures a good example of such a bundle in the petiole of *Cycas revoluta*.<sup>2</sup> A comparison, therefore, of the fossil vascular bundles with those in the basal portions of recent petioles shows a fairly close agreement. There is still need, however, of a more accurate knowledge as to the anatomy of the recent Cycadean vascular bundle and its exact relation to that of *Bennettites* and other fossils. The chief difference between the fossil and recent bundles seems to consist in the more considerable development in the former of the centrifugal portion of the xylem.

The genus *Bennettites* has frequently been referred to in the description of the Portland stem; this generic name was proposed by Carruthers in 1870 for stems possessing the following characters:— 'Trunk ovoid, in transverse section elliptical, covered with the somewhat long permanent bases of the petioles. Medulla entirely cellular, with numerous gum-canals. Wood consisting of a thin interrupted

<sup>1</sup> These centrifugal tracheids are shown in a figure of *Cycas revoluta*, in De Bary's 'Comparative Anatomy' (1884), p. 336. See also Mettenius, 'Beiträge zur Anatomie der Cycadeen,' Abh. k. sächs. Gesellsch. Wissensch. 1860; Kraus, Pringsh. Jahrb. vol. iv. 1865-66, etc. The petioles of *Cycas media*, Br., and *Dioon edule*, show a larger development of these centrifugal tracheids than is found in some other species.

<sup>2</sup> Mettenius, *op. supra cit.* pl. i. fig. 7 (d).

cylinder of striated tissue everywhere penetrated by medullary rays. Fruits borne on secondary axis not protruding beyond the bases of the petioles.<sup>1</sup>

The elliptical form of the stem in transverse section is a character of somewhat doubtful value, and should not be regarded as a feature of primary importance, owing to the difficulty of determining how far such a form is due to secondary causes. In an important monograph on Italian Cycadean fossil stems, Solms-Laubach uses the generic name *Bennettites* for such stems as possess the lateral inflorescences, showing the characteristic features which have been so fully described in the case of *B. Gibsonianus*, Carr.<sup>2</sup> The important difference between the present fossil stem and *B. Gibsonianus* consists in the absence in the former of any lateral inflorescences. A careful examination of the surface of the trunk has failed to reveal any indication of the small flattened bracts which surround the inflorescence of *Bennettites*. In other respects there is the closest agreement between the large Portland trunk and *B. Gibsonianus*. Seeing that the surface-features are imperfectly preserved, it would be rash, on the strength of negative evidence, to assume that in the stem before us the flowers were produced at the apex as in recent species. The evidence, indeed, so far as it goes, tends to support such an assumption.

In such species as *B. Gibsonianus* and *B. (Cycadeoidea) portlandicus* (Carr.)<sup>3</sup> the lateral inflorescences are easily seen on the stem-surface, and if such existed in the present specimen one would certainly expect to find traces of them among the casts of the leaf-stalk bases.

Although no trace has been found of a lateral inflorescence of the Bennettitean type, a small bud was discovered in a tangential section taken from the lower portion of the stem. In Pl. V. fig. 16 a tangential section is shown, slightly enlarged, in which portions of three petioles are seen separated by the densely-packed ramenta, *r*. At *b* a smaller oval structure, 8 mm. in length, is cut across transversely; it consists in the main of parenchymatous tissue with numerous secretory sacs.

At the periphery of *b* the epidermis and cuticle are distinct, with some ramenta seen in connexion with the surface-cells. Below the epidermis the tissue consists of flat and crushed cells, which by their apparently radial arrangement suggest periderm. Next to this band *p'* there is parenchyma with numerous secretory sacs. At *p'* there is a band of tissue similar to *p'*, and consisting of radially-disposed cells. The centre is occupied by parenchyma containing numerous secretory cells with dark-coloured contents.

In the parenchymatous tissue occasional groups of smaller elements are seen, which may be vascular bundles. From this section alone it seemed impossible to interpret the meaning of the structure *b* embedded in the mass of ramental tissue. In figs. 17 & 18 two more sections are represented, which were cut parallel

<sup>1</sup> Carruthers, Trans. Linn. Soc. vol. xxvi. (1870) p. 694.

<sup>2</sup> For a general account of *Bennettites*, see Cat. Brit. Mus. 'Wealden Flora,' vol. ii. (1895) pp. 134 et seqq.

<sup>3</sup> Carruthers, *op. supra cit.* pl. lxi.

with, and slightly external to, that shown in fig. 16. In the second section, fig. 17, in place of the solid group of tissue, we find a number of long, narrow, and irregularly-shaped structures, more clearly seen in fig. 19, which are no doubt young leaves spirally arranged round the axis, *ax*. The whole group is 7 mm. in length. The leaf-sections consist of parenchyma containing many secretory cells, and external to these bract-like appendages there occur numerous ramenta. The entire structure is evidently a bud cut across somewhat obliquely. Finally, in fig. 18, the bud is no longer visible, but its position is indicated by the twisted and sinuous form of the ramenta, which suggests—to use a far-fetched simile—the swirling eddies of water over a sunken rock. The apex of the bud was no doubt clothed with ramental appendages, and it is these covering and protecting structures that are seen at *b'* in fig. 18. The oval section *b* in fig. 16 may be regarded, therefore, as the stalk of a small and apparently vegetative bud, of which the individual leaves are shown in fig. 17 *b* and fig. 19. The whole structure is evidently a dormant and aborted lateral bud. In recent Cycads such lateral shoots are often seen in species of *Cycas*,<sup>1</sup> and less commonly in *Encephalartos* and other genera. It is indeed possible that the bud may be that of an inflorescence, but there is no decisive evidence as to its exact nature.

A plant of *Encephalartos Altensteinii* in the Palm House at Kew shows a large lateral branch bearing a well-developed crown of leaves. *Zamia Skinneri*, Warsz., and other species of the same genus, afford striking examples of branched Cycadean stems.

In a recent revision of Buckland's genus *Cycadeoidea*, Lester Ward<sup>2</sup> has included in that comprehensive generic designation Carruthers's genus *Bennettites*. There are, however, certain reasons, as shown by Solms-Laubach, which favour his use of the genus *Bennettites*, according to which it is restricted to such stems as possess undoubted inflorescences of the type described in the case of *B. Gibsonianus*.<sup>3</sup> Without entering further into this question of nomenclature, there can be little doubt that *Cycadeoidea* is the most appropriate generic name for the stem described in the present paper. It is proposed to name the specimen *Cycadeoidea gigantea*.

The following diagnosis is necessarily incomplete, as the preservation of the specimen is not such as to permit of a thorough investigation:—

Genus CYCADEOIDEA, Buckland, 1827.

*Cycadeoidea gigantea*, sp. nov. Type specimen in the British Museum. (No. V. 3454.) Acquired Oct. 1895. From the Upper Purbeck, Isle of Portland.

Stem terminating in an apical bud, covered with long and narrow

<sup>1</sup> Göppert in 1844 figured a good example of such buds in a paper on fossil Cycads, Schles. Gesellsch. Denkschr. 1853, p. 251. In his figure of *Raumeria Schulziana*, Göpp. (pl. vii), the ramenta appear to be of the same form as those figured in Pl. III. of the present paper.

<sup>2</sup> Ward, Proc. Biol. Soc. Washington, vol. ix. (1894) p. 75.

<sup>3</sup> Cat. Brit. Mus. 'Wealden Flora,' vol. ii. (1895) p. 139.

bud-scales, and covered with ramental outgrowths. The older part of the stem is surrounded by an armour of persistent petiole-bases separated one from another by a dense mass of ramenta. The petioles composed of parenchymatous ground-tissue with numerous secretory cells, and traversed by scattered and comparatively large collateral vascular bundles; the centrifugally-developed xylem forms the most conspicuous part of each bundle, and consists of radially-arranged rows of pitted tracheids, with a few rows of medullary-ray cells. At the periphery of the petioles there is a fairly thick band of phelloderm and periderm, the phellogen being found in the subepidermal layer. The epidermis is provided with a distinct cuticle, and stomata consisting of two guard-cells and probably two subsidiary cells, slightly bent below the level of the epidermis. The ramenta arise as epidermal outgrowths in the form of plates of elongated parenchymatous cells; they may consist of a single layer of cells, or in the median portion they may be several cells in thickness. No trace of any lateral inflorescence such as occurs in *Bennettites*. Fronds unknown.

As already stated, the points of agreement between *Cycadeoidea gigantea* and *Bennettites* are very clear, with the exception of the absence, or apparent absence, in the former of any lateral inflorescence. It is unnecessary to recapitulate the characteristic features of *Bennettites* which mark it off as distinct in certain particulars from the recent family Cycadaceæ, but it is important to bear in mind that in speaking of fossil Cycads we include other forms than those which strictly conform to the characters of the present genera. It has been rightly said that we have as yet no well-authenticated case of a fossil stem which may with certainty be placed in the Cycadaceæ<sup>1</sup> as at present defined. As regards the exact affinities of *Cycadeoidea gigantea*, it is impossible to speak with certainty as to its natural position without more complete evidence. In the absence of the reproductive organs we must be content with such evidence as is afforded by the vegetative structures. There is no sufficient reason for regarding the stem as essentially distinct from such a type as is represented by *Bennettites Gibsonianus*, so far as concerns its position in a system of classification.

It is to be hoped that more material may be obtained which will enable us to supply some of the lacunæ in the above description, and to decide whether *Cycadeoidea gigantea* agrees in its floral structures with existing Cycads or with the true *Bennettites*, which can only be included among Cycadean plants if the term Cycad be used in an extremely wide sense. The point of contact between *Cycadeoidea gigantea* and species of *Bennettites* on the one hand, and recent ferns on the other, which is afforded by the ramental scales, although perhaps a small one, is of interest when considered in connexion with some other fossil genera. The genera *Lyginodendron*, *Heterangium*, *Myeloxydon*, of Palæozoic age, are good examples of plants in which Cycadean and Filicenean characters are combined

<sup>1</sup> Solms-Laubach, 'Annals Bot.' vol. v. (1890-91) p. 425.

in a striking manner, and they furnish undoubted evidence of a very close alliance of Ferns and Cycads in an earlier stage of plant-evolution. In all probability these synthetic forms warrant the conclusion that the characteristic features of existing Cycadean plants have been derived from an ancient fern-like stock.<sup>1</sup> It is of interest, therefore, to discover in the ramental scales of Mesozoic Cycadean species a remnant of this relationship between the two sets of plants; although in the structure of its reproductive organs the genus *Bennettites* has advanced a stage beyond that represented by recent Cycads. In describing a section of *Rachiopteris Williamsoni* in 1894,<sup>2</sup> I referred to the occurrence of a mass of parenchymatous tissue attached to the surface of the petiole, consisting of thin-walled and elongated parenchymatous cells. Probably this tissue is of the same nature as the paleæ on the petioles of recent ferns, and the laminar outgrowths in *Bennettites* and *Cycadeoidea gigantea*. *Rachiopteris Williamsoni*, as Scott and Williamson have suggested, should probably be included in the list of plants which occupy a position in the borderland between fern-like and Cycadean forms. Unfortunately we have as yet no evidence of the form of the fronds which crowned the stem of *Cycadeoidea gigantea*. The palæobotanist must often perforce be content to describe leaves and stems under separate names, and wait for additional evidence as to the connexion between the detached fossil portions of the same plant.

My thanks are due to Mr. Gepp, of the Botanical Department, British Museum, for the photographs reproduced in Pls. I. & II.; and to Dr. Henry Woodward I am indebted for facilities afforded me in the examination of the British Museum specimens. Mr. H. H. W. Pearson, of Christ's College, has rendered me valuable assistance in the preparation of sections of recent plants.

#### EXPLANATION OF PLATES I.-V.

(The sections of *Cycadeoidea gigantea*, twelve in number, are in the Geological Department of the British Museum, Natural History.)

##### PLATE I.

*Cycadeoidea gigantea*,  $\frac{1}{8}$  nat. size. (From a photograph by Mr. Gepp, of the British Museum.)

##### PLATE II.

Fig. 1. The apex of the stem shown in Pl. I. About  $\frac{1}{4}$  nat. size.

2. Leaf-bases and ramenta from the lower portion of the stem. (Both figures from Mr. Gepp's photographs.) About  $\frac{1}{2}$  nat. size.

<sup>1</sup> On this question see Williamson & Scott, Phil. Trans. vol. clxxxvi. (1895) p. 770. As regards the connexion between recent Cycads and Ferns, see Eichler, in Engler & Prantl's 'Die natürlichen Pflanzenfamilien,' pt. ii. (1889) p. 20.

<sup>2</sup> 'Annals Bot.' vol. viii. no. xxx. (1894) p. 209, pl. xiii. fig. 2 a.

## PLATE III.

- Fig. 1. Transverse section through the periderm of a petiole of *Cycadeoidea gigantea*. ( $\times 52$ ) *r*=ramenta; *c*=cuticle; *e*=epidermis; *ck*=cork; *phl*=phellogen; *phd*=pheloderm; *g*=ground-tissue.
2. Transverse section of the periderm of *Macrozamia Denisoni*. Lettering as in fig. 1. ( $\times 52$ ) *s*=sclerenchymatous cells.
3. Cells of the cork-cambium (phellogen) of fig. 1 more highly magnified. ( $\times 230$ )
- Figs. 4 & 8. Ramenta of *Cycadeoidea gigantea* in transverse section. ( $\times 52$ )
- Fig. 5. Single ramental layer of *Cyathea excelsa*. ( $\times 52$ )
6. Epidermal hair of *Dioon edule*. ( $\times 230$ )
7. Ramentum of *Bennettites Gibsonianus*, Carr. ( $\times 52$ )

## PLATE IV.

- Fig. 9. Vascular bundle of a petiole of *Cycadeoidea gigantea*. ( $\times 320$ ) *s*=sclerenchyma (?); *ph*=crushed phloem; *c*=cambium; *cf*=centrifugal wood; *m*=medullary rays.
10. Vascular bundle of *Bennettites Gibsonianus*. *px*=protoxylem; *cp*=centripetal xylem. Other lettering as in fig. 1. ( $\times 320$ )
- Figs. 11, 12, & 13. Cells of the parenchymatous ground-tissue of the petiole *a* shown in fig. 14. *n*=nucleus (?). Fig. 12 ( $\times 230$ ). Figs. 11 & 13 ( $\times 355$ ). Reduced one-half from the original drawing.

## PLATE V.

- Fig. 14. Longitudinal section showing portions of the petioles and an intervening mass of ramenta. ( $\times 17$ ) *a*=upper petiole, with parenchyma and secretory cells of the fundamental tissue. *p*=periderm, including pheloderm and cork; *x*=junction of ramenta with the epidermis; *r*=ramenta.
15. Stoma, with guard-cells and pore; also a few epidermal cells showing the form of the walls. *gd*=guard-cells; *s*=subsidiary cells.
- Figs. 16-18. Semi-diagrammatic sketches slightly enlarged (fig. 16—section  $1.6 \times 2$  cm., fig. 17— $2.1 \times 1.3$  cm., fig. 18— $2.3 \times 1.8$  cm.), showing portions of petioles, ramental tissue, and bud, *b*.
- Fig. 19. Section of the bud as shown at *b* in fig. 17. ( $\times 24$ ) *ax*=axis of bud, surrounded by leaves and ramenta. Reduced one-third from the original drawing.

## DISCUSSION.

Dr. D. H. SCOTT thought that this paper was of the greatest interest. Nothing was more remarkable in palæobotany than the prevalence during the Mesozoic period of plants which exactly resembled existing Cycadæ in habit and external characters, but which, in the best known cases, differed absolutely from them as regarded their fructification. This was the case notably with *Bennettites*, investigated by Carruthers, Solms-Laubach, and Lignier, which bore reproductive organs totally unlike those of Cycadæ or any other known gymnosperms, and approaching in some respects those of angiosperms. The existence of the Bennettitæ and certain other fossil groups showed that our recent Cycads form only a small surviving family, representing what was once an extensive and varied class of plants.

It was an interesting question, to which group of Cycad-like plants the fine specimen described by the Author belonged. The ramenta

afforded a minute but important character, strongly indicating Bennettitean affinities. Possibly the small lateral bud described by the Author might have been an abortive fructification.

The preservation of histological structure in the external tissues, as demonstrated by the Author, was astonishingly perfect, and had rarely been equalled in fossil plants. As regards the branching of recent Cycadeæ, it was well known that many of them branched far more freely in nature than when cultivated in our hot-houses.

Prof. TATE intimated that Australia might be thought to offer a field of investigation in the evolution of the Cycadeæ, but unhappily no such plants (at least none acceptable to the botanist) occur in the Kainozoic strata, which contain at various horizons extensive terrestrial formations. From field-observations on some Australian species of *Encephalartos*, notably *E. Macdonnelli*, he could not concur with the statement that the trunk was subject to furcation.

Prof. SEELEY stated that he had examined specimens of Cycad stems in the Isle of Portland and in the Wealden Beds, and one specimen from the Potton Beds, which appear to have been vertical, and were all more or less ovate in section; but there is no conclusive evidence of the cause of the external form.

Dr. WOODWARD referred to the interesting fact that the new *Cycadeoidea gigantea* came from a higher level than the old historical Dirt-bed described by Dr. Buckland. It is interesting as suggesting the persistence for a long period of land-conditions—a point of great interest to geologists. He bore testimony to the beauty of the photographs shown by the Author.

Mr. WHITAKER also spoke.

The AUTHOR expressed his thanks to the Fellows of the Society for the reception accorded to his paper. He did not wish to give too great prominence to the negative evidence as regards the position of the inflorescence, and admitted the possibility that the small bud found on the stem might be an aborted fertile shoot. He mentioned instances of branching Cycadean stems in the tropical house at Kew. There was no evidence, he believed, of the occurrence of *Bennettites* in English rocks in an erect position with an elliptical stem, and therefore he did not feel disposed to attach much importance to the shape of the stem as a generic character. In conclusion, the Author referred to his indebtedness to Mr. Gepp, of the British Museum, for the excellent photographs taken of the Portland fossil.

4. GEOLOGICAL and PETROGRAPHICAL STUDIES of the SUDBURY NICKEL DISTRICT (CANADA). By T. L. WALKER, Esq., M.A. (Communicated by J. J. H. TEALL, Esq., M.A., F.R.S., Sec. G.S. Read November 4th, 1896.)

[Abridged.]

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I. INTRODUCTION.

THE town of Sudbury is situated in Northern Ontario, 442 miles from Montreal on the transcontinental line of the Canadian Pacific Railway. When this railway was constructed some eight or ten years ago, the name Sudbury was given to a small station which was afterwards selected for the eastern terminus of the branch railway that follows the northern shore of Lake Huron and crosses the St. Mary River at Sault Ste. Marie. It is about 40 miles from the north-eastern shore of Lake Huron.

Shortly after the construction of the railway, considerable deposits of chalcopyrite were discovered in the neighbourhood, and an American company was organized to work them. Thus it was that Copper Cliff Mine was opened up for copper, although along with the chalcopyrite large quantities of nickeliferous pyrrhotite occurred. The pyrrhotite was considered worthless, as it was not known to contain nickel till the mine had been in operation for some little time, and sales had been made of the products. After the accidental discovery of the value of the pyrrhotite as a nickel ore, there was much prospecting in the district for nickel-deposits. This continued till 1891, by which time scores of nickel-deposits had been located. At that time the world's annual consumption of metallic nickel was not more than 1500 tons, and hence it was a more difficult task to dispose of nickel properties at remunerative prices than it was to discover them. For this reason, prospecting for nickel was abandoned in this region, though it is quite probable that, should a demand for larger quantities of nickel arise, many more deposits will yet be discovered.

The earliest geological descriptions of the country in the immediate vicinity of Sudbury were published by Selwyn in 1884. In 1888 Bonney published an account of the Huronian rocks exposed

in the cuttings of the Canadian Pacific Railway in the neighbourhood of Sudbury. During the seasons of 1888, '89, and '90, Bell and Barlow were appointed by the Canadian Geological Survey to explore the district. A collection of rocks was sent by Bell to the late G. H. Williams, whose petrographical studies were published along with Bell's report. During the summer of 1890 the late Baron von Foullon, of the Austrian Geological Survey, spent a few weeks in the district, and directed his attention particularly to the determination of the relative ages of the different rocks. A full statement of the literature bearing on the subject is appended (§ VIII. p. 65). I beg to acknowledge my indebtedness to the writings of all who have studied the geology of the Sudbury district, especially to the papers of Adams, Bell, Barlow, Bonney, von Foullon, Garnier, and G. H. Williams. Vogt's excellent descriptions of the Norwegian nickel-deposits and associated rocks have been freely consulted, as in many respects these descriptions are quite accurate when applied to the Sudbury district.

The nickel district is included in the great belt of Huronian rocks which extends from the northern shore of Lake Huron north-eastward to Lake Mistassini. In the neighbourhood of Sudbury this belt is barely 25 miles wide, and consists of quartzite, amphibolite, mica-schist, phyllite, volcanic breccia, and grauwacke. Inliers of later eruptives form a large part of the belt, and it is in connexion with one class of these that the nickel-deposits occur. The country north-west and south-east of the belt of Huronian rocks is composed of coarse granites and gneisses which are regarded as of Laurentian age.

The whole of this part of Canada has been subjected to glacial action, the general direction of ice-movement having been from north-east to south-west. The rocks in many places present well-polished surfaces, particularly where the protecting covering of clay, sand, or gravel has been only recently removed, as in railway-cuttings and along lake- and river-banks. The most lasting work of glacial agency is seen in the hollowing-out of innumerable depressions, which are now occupied by lakes and rivers. Archæan districts in Canada are characterized by innumerable rocky lakes with clear waters and swift eddying streams.

## II. THE GNEISS-FORMATION.

The larger part of Northern Ontario is occupied by gneisses of various kinds. In the immediate vicinity of Sudbury these rocks are not observed, though they form almost endless tracts on both sides of the Huronian belt. Good exposures, which are easily reached, occur in the cuttings of the Canadian Pacific Railway, near Wahnapiatae to the south-east, and about 3 miles west of Onaping to the north-west. Besides these gneisses, which may be regarded as Laurentian, there are gneissoid rocks geographically included in the Huronian belt, but as these are of very much later origin, and not true gneisses, it is proposed to deal with them in a later section.

## (i) The Gneisses near Wahnapiatae Station.

These rocks are well bedded, and show considerable folding on a large scale. Biotite is by far the most prominent constituent. Over large areas reddish almandine-garnet is so common that the Wahnapiatae rocks may be designated 'garnetiferous biotite-gneiss.' The garnets vary from  $\frac{1}{8}$  to  $1\frac{1}{4}$  inch in diameter, and are often so abundant as to constitute 20 per cent. of the rock. When in micaceous bands they are crystallized in rhombic dodecahedra  $\infty O$ , while when in quartzose or felspathic bands they are always icositetrahedra 2 O 2. As a rule, garnets are inclined to crystallize in rhombic dodecahedra when in schistose or basic bands, while when in acid or granular bands there is a tendency to take the form of icositetrahedra.

The microscope shows that the biotite is strongly pleochroic and nearly uniaxial. It occurs as comparatively large independent individuals, and never forms continuous films composed of innumerable small individuals. The biotite is sometimes altered to chlorite. Muscovite is occasional. The quartzes abound in liquid inclusions, which are often characterized by moving bubbles or small cube-like crystals. Felspar plays an important part, and is frequently perthitic or microclitic. Kyanite is often abundant, and presents in rock-sections long, highly-polarizing individuals which generally, but not always, conform to the schistosity. Inclusions of quartz and felspar are quite common. The colour is different in different individuals, and even in different parts of the same individual. Some are water-clear, while others are water-clear with irregular sky-blue flecks. No twinning could be detected. Sillimanite is frequent on slickensides. The long, colourless, acicular crystals show the effect of pressure in being broken into large numbers of short prismatic fragments which are drawn apart, so that the disjointed crystal is about twice as long as the original crystal. Zircon in rounded grains is frequent, and seems to be largely confined to the neighbourhood of biotite. When the zircon-grains are included in the biotite, they are usually surrounded by pleochroic areas ('pleochroitische Höfe').

## (ii) Gneiss near Onaping Station.

The gneiss exposed west of Onaping Station is largely composed of quartz and felspar, which form pinkish-white bands: these alternate with comparatively small bands of biotite. The Onaping gneiss is thus very much lighter in colour than the gneiss at Wahnapiatae. The microscope shows that these rocks are true gneisses and not crushed granites. Biotite occurs in large individuals, whose prismatic sections show a well-developed system of partings which form a cross-hatching, probably the result of pressure. The gliding-plane is apparently a pyramidal face, as has been proved to be the case for large mica-individuals by Tschermak. Biotite is sometimes changed to an aggregate of chlorite, epidote,

and spheue. Specimens collected farther south-west on the same gneiss-terrane contain almost equal quantities of biotite and muscovite, both of which are well preserved.

### III. THE HURONIAN ROCKS.

These are chiefly confined to the Huronian belt, which in the neighbourhood of Sudbury is about 25 miles wide. Inliers of different kinds are numerous, but these will be described in a later section. Quartzite, grauwacke, mica-schist, phyllite, and altered volcanic breccia are the chief constituents of the Huronian complex. They have all suffered extensive metamorphism, so that it is generally difficult to speak definitely as to their origin. Those which have been derived by the disintegration of still older rocks are to be regarded as among the oldest-known sediments. It is possible that some of the above rocks have been derived from acid tuffs, which in some cases may have been deposited in the primeval sea, as suggested by the frequently perfect stratification. Some may have been derived by the devitrification of flows of glassy, occasionally porphyritic eruptives. Metamorphism has advanced so far that the early history of these rocks is only very imperfectly revealed. All of the above-mentioned sources have doubtless contributed to the formation of the Huronian strata of the Sudbury district.

#### (i) Quartzites.

In the immediate vicinity of Sudbury, numerous exposures of these rocks are observed. In general the texture is very fine, the stratification obscure, and the colour ashen-grey. The microscope shows that the quartz-grains interlock as if much secondary enlargement had taken place, although no outline of original grains could be detected. Grains of perthitic felspar and scales of muscovite are mingled sparingly with the grains of quartz. Small clusters of brown mica and rounded spots of chlorite are often seen in thin sections. The general strike is N. 30° E. A short distance north of Sudbury, on the way to Blezard Mine, an evenly-stratified quartzitic rock occurs. Narrow bands of a few millimetres in width may be often followed for some score yards. A microscopic examination shows the presence of much muscovite and numerous small colonies of chlorite. This rock is also well exposed along the road to Copper Cliff Mine, about a mile from Sudbury. West of Sudbury, along the Canadian Pacific Railway, the quartzites are, as a rule, very thickly bedded, while in some cases bedding is scarcely discernible.

South-east of Sudbury, along the rocky shores of Ramsay Lake, conglomeratic phases of the above quartzites occur. The pebbles are in the main of reddish granite and vary much in size. As a rule, the south-eastern side of the Huronian belt is composed of the quartzitic rocks just described. The conglomeratic portions are undoubtedly derived from still older Archæan rocks, while the

evenly-bedded, very micaceous strata may represent altered acid tuffs which were deposited in shallow water. Bonney has suggested that some of the very fine-grained, indistinctly-bedded muscovite-quartzites may have been derived by devitrification of acid glassy or porphyritic rocks.

Exposures of highly-altered quartzite occur south of the Stobie Mine, and also on the main line of the Canadian Pacific Railway,  $1\frac{1}{4}$  mile west of Sudbury. At the former place, the altered rock becomes quite granitic in composition, and gneissoid in structure. The microscope shows that the component minerals are quartz, felspar, biotite, and a little muscovite. Quartz-grains abound in fluid inclusions, are irregular in outline, and generally interlock. Muscovite forms large separate individuals, while biotite usually forms approximately-parallel connected aggregates of small scales. The rock exposed on the railway west of Sudbury is of medium grain and peculiarly mottled: pale pink, roundish spots, from 1 to 4 inches in diameter, dapple a groundwork of a dark grey colour. On closer examination, it is seen that no sharp boundaries exist between the portions of different colour, and a microscopic examination shows that there is no important mineralogical difference. Gneissoid structure is altogether wanting. Crystals and grains of reddish garnet occur in addition to the minerals present in the rock south of Stobie Mine. Considering the mineralogical composition of these rocks, they may be referred to as biotite-granite. Bell has shown that these highly-altered clastics constitute a belt  $\frac{1}{2}$  mile wide and 6 miles long, extending from near the Stobie Mine south-west nearly to Copper Cliff Mines. Naturally, only a very impure quartzite could give rise to such rocks as these. We know very little as to the causes of this extreme and apparently selective metamorphism. Rocks of granitic composition and structure, when formed by the regeneration of clastics, may be called 'regenerated granites.' There is reason to believe that this is a more fruitful source of granitoid rocks than has been previously acknowledged.

#### (ii) Mica-Schists.

In the immediate vicinity of Sudbury these rocks, though occasionally present, play a very subordinate part. They generally dip at high angles, and are more frequent towards the centre of the Huronian belt. A very narrow band of silvery grey mica-schist crosses the railway about  $\frac{1}{2}$  mile east of Murray Mines. In thin sections the foliation is very distinct. Muscovite forms a network which surrounds the quartz-grains. Immediately east of Worthington Station a similar rock is exposed in the railway-cuttings. Farther south-west the Huronian belt is much richer in mica-schists, which are often hornblende and staurolitic. Between Blezard and Stobie Mines a dark, compact, schistose rock occurs, which the microscope shows to be a hornblende-epidote-schist; it is perhaps geologically an equivalent of the mica-schists.

## (iii) Phyllite.

This rock is very closely associated with the mica-schists, and may be examined in the railway-cuttings 3 miles east of Worthington Station. The rock dips at high angles, and is purple-brown in colour. On the cleavage-surfaces small yellowish-brown specks are observed which the microscope shows to be sagenitic aggregates of rutile-crystals: these are fairly transparent, and so large as to give polarization-colours resembling those of zircon.

## (iv) Clay-Slates.

These constitute an important member of the Huronian complex. They may be examined  $\frac{1}{2}$  mile west of Rayside Station, and also a short distance north of White Water Lake. In the former place they are in contact with the nickel-bearing rocks, and close to the junction the schistosity has quite disappeared. They are ashen-grey, drab to nearly black in colour, and probably represent detritus deposited in the deeper seas of the Huronian period.

## (v) Volcanic Breccia.

The western portion of the Huronian belt in the Sudbury district is occupied by a trough which is composed of the younger Huronian rocks. This trough extends nearly from Lake Wahnapietæ south-westward to the township of Trill, a distance of over 30 miles. The greatest width is a little over 8 miles. The central part of the trough is occupied by evenly-grained grauwacke, while the margin is composed of a highly-altered volcanic breccia. One of the most accessible exposures of this breccia is on the northern shore of Whitson Lake, where it is in contact with the nickel-bearing eruptive. The colour is ashen-grey, the stratification distinct, though interrupted and lumpy, and the strike is N. 70° E. The microscope discloses the breccia-structure. The volcanic fragments are quite angular, and sometimes show flow-structure, though they have been generally replaced by aggregates of secondary minerals—chlorite, quartz, felspar, muscovite, and calcite. Glass could be seen neither in the fragments nor in the matrix. An analysis of the breccia north of Whitson Lake gave the following results:—

SiO <sub>2</sub> .....	59·93	%
Al <sub>2</sub> O <sub>3</sub> .....	12·12	"
FeO .....	10·56	"
MnO .....	trace	
CaO .....	4·49	"
MgO .....	5·19	"
Na <sub>2</sub> O .....	3·80	"
K <sub>2</sub> O .....	0·97	"
Loss by ignition ...	1·57	"
Total .....	98·63	"

There are also good exposures of this rock along the north-western border, about  $1\frac{1}{2}$  mile south-east of Onaping Station.

## (vi) Grauwacke.

The central portion of the trough of younger Huronian rocks is occupied by an even-grained, ash-coloured, quartzose rock, in which conglomeratic fragments may be detected with the naked eye. This is the youngest member of the Huronian complex, and, as it is never cut by the nickel-bearing rocks, I am inclined to regard it as later than these. There is good ground for looking upon the nickel-bearing rocks as younger than the volcanic breccia, and hence the conclusion that the nickel-bearing rocks are of Huronian age, and that they occupy a position lying chronologically between the volcanic breccia and this youngest member. It may be mentioned, however, that Bell and Selwyn are inclined to regard the grauwacke as Lower Cambrian, although no fossils have been found in it.

Good exposures occur at several points along the railway, especially at Chelmsford and Larchwood Stations.

## IV. THE NICKEL-BEARING ROCKS.

## (i) General Observations.

These rocks have attracted much more attention than the other rocks of the district. The discovery of areas characterized by extensive deposits of nickel ores gave employment to large numbers of explorers from 1887 to 1891. It was soon remarked that valuable deposits of copper and nickel ores occurred only in connexion with greenish-coloured rocks of medium texture, which were conveniently referred to as trap, diorite, or greenstone. Early microscopic examination of the rocks in the immediate vicinity of the nickel-deposits showed that they were composed in general of hornblende and plagioclase, and in smaller proportions of quartz and biotite, with magnetite and apatite as accessories. Thus the microscope confirmed in a measure the prospectors' name 'diorite,' but it also showed the probability of the secondary nature of the chief constituents, and so the original nature of the country-rock of the nickel-deposits continued to be a matter of doubt. As the hornblende was probably derived from one of the members of the pyroxene group, the original rock was doubtless one of the gabbro family.

In the published descriptions these rocks are referred to as diorite, uraltic diorite, gabbro-diorite, and even occasionally as diabase. This uncertainty is in a measure accounted for by the fact that most of the specimens studied microscopically were collected quite close to the nickel-deposits, where the rock is as a rule completely altered, though in other parts of the 'greenstone' area the metamorphism has seldom advanced so far, and in some places the rock is practically unaltered.

It will be seen that the nickel-bearing rocks, taken as a whole and considered geologically, include not only these greenstone areas but also considerable areas of gneissoid and micropegmatiti

granite, which cannot be genetically separated from the greenstones. The geological map of the Sudbury district published by the Canadian Geological Survey contains nearly one hundred areas of greenstone. We will confine our attention to a very small number of these nickeliferous eruptives.

The nickeliferous rocks are included in or adjoining the Huronian belt already described. They commonly form long elliptical areas whose longer axis is more or less parallel to the stratification of the Huronian rocks. The largest of these areas extends from the township of Garson south-westward into the township of Creighton, having a width of nearly 4 and a length of at least 25 miles. It is crossed by the Canadian Pacific Railway between Murray and Rayside Stations. The area second in size is described by Bell as extending from the township of Lavack south-westward to the township of Trill. Its length is at least 18 miles, and its width between 3 and 4 miles. Onaping Station is situated near the south-eastern border of this eruptive area. As the former eruptive is well exposed in the vicinity of Whitson Lake, it will be convenient to refer to it as the Whitson Lake eruptive. For a similar reason, the second eruptive area will be referred to as the Windy Lake eruptive.

#### (ii) The Whitson Lake Eruptive.

The length of this area has been very moderately stated above; there is good reason for regarding it as much greater, and possibly connected with other nickeliferous areas which are now mapped as separate eruptives. The best exposures are to be found along the shores of the lakes lying within its bounds, and in the cuttings of the Canadian Pacific Railway. Along its north-western boundary it is flanked by the volcanic breccia previously described. It includes three parallel areas, which were mapped by Bell as greenstone, granite, and Huronian. It will be shown that the rocks which constitute these three terranes, though so different in appearance, are genetically a unit, that they are eruptive and younger than the enclosing rocks, and that in their apparent diversity they may rightly be referred to as nickel-bearing rocks.

##### *a. Exposures along the main line of the Canadian Pacific Railway.*

This eruptive is well exposed in the railway-cutting between Murray and Rayside Stations. Its width here is about 4 miles. As the rock is freshest towards the centre of the area, it will be advisable to consider in detail specimens collected there; then to study in order the specimens collected between the fresh central or type-rock and the Murray Mines contact, and finally the specimens from the north-western half, beginning at the centre, and proceeding towards the north-western contact near Rayside Station.

*The Type-rock.*—About  $1\frac{1}{2}$  mile north-west of Murray Mines,

near the point where the railway enters the township of Rayside, there are good exposures of a somewhat coarse-grained rock, which is greenish on the weathered surface, while the freshly-broken surfaces exposed in the railway-cuttings are nearly black, with a bluish tint. It is the diorite or greenstone of the prospectors, which the microscope shows to be norite. Hypersthene forms idiomorphic crystals, and seems to have been the first of the essential minerals to crystallize. Sections of this mineral when in the prismatic zone are stoutly rectangular, while sections parallel to the basis are octagonal and show indistinct prismatic cleavage. It is strongly pleochroic—rose-red, bluish-grey to nearly colourless. The crystals of hypersthene are generally bordered and veined with bastite, which often contains small grains of magnetite. In other cases the alteration has proceeded so far that one observes rectangular areas of bastite which contain only a few separated grains of hypersthene. Where the bastitic alteration-products border on plagioclase, a still further change occurs, in that bastitic fibres and magnetite-grains give place to a somewhat compact, strongly pleochroic, bluish-green hornblende. This latter change does not occur along borders between bastitic areas and biotite or magnetite. The felspar seems to participate, by contributing the alumina necessary for the formation of green hornblende.

Plagioclase is the most abundant mineral. The crystals are xenomorphic when in contact with hypersthene, which is thus seen to have crystallized earlier than the plagioclase. The broadly-twinning plagioclase-crystals are from two to three times as long as broad, and even in the thinnest sections are brownish, owing to the presence of innumerable dust-like inclusions, which are regarded as ilmenite, and are very characteristic of plagioclase in norites. Besides these brown inclusions, too small to admit of microscopic determination, there are colourless needle-like inclusions which form a network of three parallel systems. It is probable that these inclusions are parallel to the three edges formed by the pinacoidal faces. Measurements of extinction-angles lead to the conclusion that we are here dealing with bytownite.

Augite forms occasional, large, irregularly-bounded grains, which are non-pleochroic, and xenomorphic with respect to hypersthene and plagioclase. Inclusions parallel to OP give the appearance of basal cleavage when examined with a low power.

Besides the above-mentioned hornblende, which is of secondary origin, there is a small proportion of apparently primary nature. It never occurs alone in well-formed crystals, but mostly forms borders on crystals of hypersthene and on areas of bastite derived from these. This hornblende possesses well-developed cleavage, definite outline when bordering on felspar, is darker than the secondary hornblende, and is compact and not fibrous. Much might be said in favour of the secondary nature of this hornblende, where it could be regarded as the final product of the alteration represented by the change of hypersthene to a bastite-magnetite aggregate, this to bluish-green hornblende with no characteristic

outline or cleavage, and finally the hornblende in question with definite outline, strong pleochroism, and characteristic cleavage. Were this the case we should expect to find the largest amounts of this hornblende in rocks where alteration had advanced farthest. This, however, as will be seen later, is not the case, and hence it is preferable to regard this well-developed hornblende as primary, and as having formed borders on the pyroxene-crystals in the original unaltered norite. When so regarded, we find difficulty neither in explaining its presence as a border on perfectly fresh hypersthene-crystals, nor in its surrounding the bluish-green hornblende, which is undoubtedly of secondary nature.

Biotite is occasionally observed in well-developed scales, of whose primary nature there is no doubt. Secondary hornblende forms a very narrow border on biotite-scales when in contact with plagioclase.

Apatite, magnetite, and occasionally grains of iron sulphides are present, as is usually the case in such rocks. The very last mineral to crystallize was quartz, which is represented by a few irregular grains.

From this description it will be seen that the type-rock of the nickel-bearing eruptive exposed between Murray and Rayside Stations is a norite containing small quantities of biotite, hornblende, and augite. The slight alteration in no way obscures the original nature of the rock.

*East of the Type-rock.*—Eastward along the railway very little change is observed in the character of the greenstone for some distance. About  $\frac{1}{4}$  mile east of the type-rock two intrusions of granite occur. The broader of these has a width of about 100 yards. The later age of this granite may be concluded, as it sends apophyses into the norite, and where in contact with the latter rock it has changed the pyroxenes to hornblende and biotite. Similar action may be observed on fragments of norite included in the granite. This intrusive granite will be fully described later. It is enough here to know that we have sufficient ground for regarding the norite as a continuous area.

About  $\frac{1}{2}$  mile east of the type-rock the rock is macroscopically unchanged, except that it peels off in concentric layers when exposed to the weather, as is frequently the case with diabase, but not with norite. The microscope shows that it is more altered than the type-rock. Most of the hypersthene-crystals are so altered that generally only a few isolated grains can be detected in areas of secondary hornblende, whose areas are identical with those of the normal hypersthene-crystals. The secondary hornblende is the same as in the previous rock, except that there is relatively more pale bluish-green hornblende and less bastite.

A few needles of secondary pale-green hornblende occur in the plagioclase, as if the bastite-substance had been transported into the felspar, and had there produced the pale green hornblende, which in the type-rock occurred only where bastite bordered on felspar. The plagioclase constitutes two-thirds of the rock, and,

except for the presence of hornblende-inclusions, does not differ from that of the type-rock.

Passing eastward, the rock becomes slightly finer-grained, but does not differ materially from the type-rock. About 200 yards from the smelting-works at Murray Mines, the rock when examined microscopically is seen to differ from the former specimens in two ways: there are differences on the one hand which are due to metamorphism, and these may be regarded as of secondary nature; and on the other hand there are differences of a primary nature, and these are to be explained as due to the differentiation of the original rock-magma. Neither crystals of hypersthene nor even preserved remnants of the mineral, such as were noticed in the previous rocks, can be observed, and we are able to prove its presence in the original rock only by reference to the areas of bastite and secondary hornblende. The more or less regularly rectangular areas have been derived from hypersthene, while quite irregular areas have been probably derived from augite. Primary hornblende is not so abundant as previously, while biotite, which appears to be of primary nature, is more abundant. Plagioclase is characterized by brown dust-like inclusions, and by small colourless crystals which are probably zoisite or epidote.

The plagioclase-crystals contain numerous particles of secondary green hornblende, which is at times so plentiful as to somewhat conceal the original felspar-boundaries. The same indistinctness is often observed in connexion with the secondary products resulting from hypersthene and augite. Bastite-substance seems to have been transported in solution from the original hypersthene-areas, and to have produced the secondary hornblende in the plagioclase by reacting upon it. Generally the solution followed cleavage-planes in the felspar, but frequently the cleavage-paths cannot be traced. This process, whereby secondary hornblende is formed by the action upon plagioclase of solutions carrying bastite-substance, and the deposition of the hornblende distant from the bastite-areas, may be referred to as the 'migration of hornblende,' and hornblende so formed may be called 'immigrated hornblende.'

Between the smelting-works and the Murray Mines ore-deposits the rock is finer-grained and more altered. The microscope shows that the secondary hornblende is nearly all of the bluish-green type, bastite having almost disappeared. The migration of hornblende has become much more general, so that the old boundaries of the bisilicates are very imperfectly preserved in the areas of their secondary products. It is also worthy of note that a few of the areas of secondary hornblende seem to have suffered a still further change, and to have given rise to dark brown, fine, scaly biotite. This seems to be the final product of the alteration which changes hypersthene successively to bastite-magnetite aggregate, pleochroic bluish-green hornblende, and finally scaly biotite. The production of biotite from secondary hornblende seems to have been much more frequent in the small individuals included in the felspar. The plagioclase swarms with epidote-crystals and shows very irregular

boundaries. Grains of chalcopyrite and pyrrhotite are very frequent.

In the railway-cutting quite close to the Murray Mines deposit, which is very near the south-eastern border of the Whitson Lake eruptive, the rock contains a large amount of pyrrhotite and chalcopyrite. It has been much more altered than the rocks already described. Hypersthene and augite have entirely disappeared and have been replaced by green hornblende, which does not appear to be confined to any definite areas. Primary plagioclase cannot be detected, but seems to have given place to small individuals which are broadly twinned and water-clear. A few scales of biotite, a little primary hornblende, numerous small irregular grains of quartz, and swarms of pyrrhotite- and chalcopyrite-grains, complete the list of constituents. The rock has been almost entirely recrystallized, and its original nature is somewhat concealed. In composition it corresponds at present to an uralitic diorite, and has doubtless been derived from a rock of the gabbro family. For convenience, these altered norites or gabbros will be referred to in the following pages as 'greenstones.'

Although the rocks collected along the railway near Murray Mines indicate a total disappearance of hypersthene and a large increase of secondary hornblende, yet there is good ground for regarding these rocks as having been derived from norite. The late Baron von Foullon described a rock which was blasted out when the foundations were being prepared for the smelting-works at Murray Mines, not more than 100 yards from the contact. This rock is described as containing strongly pleochroic semi-idiomorphic hypersthene-crystals, along with a smaller amount of diallage. He observes that these minerals are often bordered with hornblende. The rock on the dump at Murray Mines is generally fine-grained and too much altered to show hypersthene, but in the lower workings, 10 to 20 yards removed from the contact, the ore occurs in a rock of medium grain, which contains an abundance of fresh hypersthene. This rock shows a large amount of diallage-like augite and secondary hornblende, while plagioclase is not so abundant as usual, and has been partly recrystallized.

The contact with the granite on the south-eastern side of the eruptive is not very sharp. Granite is mingled with greenstone for 100 to 150 yards and often forms breccias with it. The breccias have a granitic grained matrix, and sharply angular greenstone-fragments which vary much in size. The granite is very fine-grained near the contact, and is certainly younger than the greenstone. It seems to have been intruded along the wall between the greenstone and the original clastic, which was in contact with the eruptive greenstone before the intrusion of the granite. A narrow band of this clastic may now be seen along the railway about  $\frac{1}{2}$  mile east of the present contact of the Whitson Lake eruptive with the granite.

The nickeliferous pyrrhotite is intimately intermingled with the greenstone. Chalcopyrite is present in very much smaller

quantity. The pyrrhotite often contains crystals of magnetite and biotite, which are consequently older than the pyrrhotite containing them. By examining some specimens one might conclude that the ores had crystallized before the silicates, while an examination of other specimens would lead to the opposite conclusion. The ores are, in fact, to be regarded as constituents of the rock, which at a few places along the border of the eruptive have been concentrated by differentiation, so that the ore-deposits are norite or greenstone, which is rich enough in chalcopyrite and nickeliferous pyrrhotite to be of commercial value. The quantity of the ores in the rock increases gradually towards the border, till it often constitutes three-fourths of the rock. Sometimes the ores and silicates are finely intermingled, while at other times comparatively pure masses of pyrrhotite and chalcopyrite are included in the silicate-groundmass. These masses of pure ore vary from a few lines to a foot in longest diameter. In other cases the ores appear to form the groundmass in which the silicates are included. Near the contact the grain of the ores is fine, and the proportion of chalcopyrite and pyrrhotite is often so large as to form deposits of economic importance, while farther from the contact the ore becomes coarser-grained and the quantity of silicates increases till it can no longer be worked at a profit. The nickel percentage of the pyrrhotite varies greatly, but may be safely stated as ranging from 3 to 7 for the deposits which have been worked on a large scale. There are, however, many deposits which contain less than 3 per cent. of nickel, but these are at present of no special value.

Vogt, in describing similar nickel-deposits in Norway, regards the pyrrhotite and chalcopyrite as rock-forming minerals, and believes that they took their present form at the time of the solidification of the rock containing them. He refers to the rock rich in pyrrhotite as 'pyrrhotite-norite,' and observes that the ores generally diminish with the distance from the contact. He regards the ores as the most basic rock-constituents, and considers that the pyrrhotite-norite is related to the greenstone in the same way as basic borders on granite-stocks are to the granite. Both, he maintains, have been formed by differentiation of once homogeneous magmas. My observations lead me to think that the same relations obtain in the case of the Sudbury chalcopyrite-pyrrhotite deposits.

Occasionally small masses of titaniferous magnetite are associated with the pyrrhotite. An analysis of such a mass from Murray Mines showed the presence of 18.34 per cent. of titanitic acid. At other points along the border of the Whitson Lake eruptive similar masses of titaniferous magnetite occur. Portions of norite which are rich in titaniferous magnetite might well be so named as to indicate the presence of magnetite as an essential mineral. Similar peripheral separations of titaniferous magnetite are frequent in connexion with the gabbros of Minnesota, as Bayly has recently pointed out.

About 100 yards south of the office at Murray Mines a porphyritic facies of the greenstone occurs. The groundmass is

fine-grained and weathers to a greenish colour. Crystals of black hornblende, varying in size from peas to 'marbles,' are richly scattered through it.

*Rocks West of the Type-rock.*—We shall now examine in turn the rocks collected along the railway between the type-rock and the north-western contact.

About  $\frac{1}{4}$  mile north-west of the type-rock, there seems to be little change macroscopically. Small sapphire-blue grains of quartz are frequently observed in the dark rock. The microscope shows the complete alteration of hypersthene to bastite and green hornblende. The boundaries of the secondary products are fairly sharp, although there has been considerable migration of hornblende. Frequently the secondary hornblende is associated with scales of biotite, as if the latter had been produced from the former. Within the bounds of the old hypersthene-areas the hornblende extinguishes in two portions, and presents in some cases, between crossed nicols, the appearance of polysynthetic twinning on the orthopinacoid. There are occasional irregular areas of secondary hornblende, as if derived from augite. Primary hornblende and biotite are present in about the same proportions as in the type-specimen. Micropegmatite forms a few small areas, and seems to have been one of the last constituents to crystallize.

One mile east of Rayside Station the rock becomes quite coarse and gabbro-like. The dark minerals constitute only a third of the rock. Microscopically it differs from the last specimen in the total disappearance of the bastite stage of secondary hornblende, an increase in fine scaly biotite in association with immigrated hornblende, and an abundance of epidote-crystals in the plagioclases. The original rock was of a somewhat more acid character than those previously examined, as indicated by an increase in the quantity of quartz and micropegmatite. There are a few grains of a mineral which is strongly pleochroic—purple, rose, colourless—and which is generally associated with the bisilicates. It is probably orthite.

Westward the rock takes on gradually the appearance of a granite. The weathered surface is white to pink instead of green, while an indistinct parallelism is sometimes noticeable. Fine scaly biotite is more prominent, while the large, bright, black cleavage-surfaces of hypersthene, biotite, and hornblende are seldom observed.

A specimen collected about  $\frac{1}{4}$  mile west of Rayside Station represents the north-western border of the area. The weathered surface is pale pink. Parallelism in the constituents is very apparent, so that the structure is coarsely gneissoid. The texture is finer than in the central portion of the eruptive. The microscope shows that fine scaly biotite is the only bisilicate present, that orthoclase is much more abundant than plagioclase, and that quartz in small grains makes up about half the rock. This granitic rock has been subjected to considerable pressure, as indicated by the undulatory extinction of the quartz-grains and the bending and breaking of the plagioclase-crystals.

Quite at the contact, in a hill  $\frac{1}{2}$  mile north-west of Rayside

Station, the slate has been so altered by the eruptive as to lose its schistosity and to resemble the 'hornfels' so commonly produced by granite when in contact with slate. This rock is shown by the microscope to be composed of fine scales of biotite and muscovite and grains of quartz. The quartz-grains are bounded by polyhedral outlines, so as to produce the 'pavement'-structure which is so characteristic for contact-products. Roundish mica-scales are frequently included in the quartz-grains. These microscopic structures confirm the contact nature of the rock. Calcite-grains are so common that the rock-powder effervesces briskly with cold hydrochloric acid.

There are numerous inclusions of quartzose fragments in the eruptive near the junction. The presence of these quartzite-inclusions in the eruptive indicates that it has broken through quartzitic strata, which consequently underlie the slates at present observed in contact with the granite.

*β. Exposures north of Blezard Mine.*

The south-eastern contact is only a short distance south of Blezard Mine. The rocks are well exposed along the road north of the mine, while excellent opportunity is afforded for geological examination by the rocky shores and islands of Whitson Lake. The rocks of this cross-section of the Whitson Lake eruptive are quite similar to those studied in the previous one along the main line of the Canadian Pacific Railway.

The rock a short distance north of the mine is almost identical with the type-rock of the last series. It is dark, and of medium texture. The freshly-broken surface shows a few scales of biotite.

Specimens collected 200 yards south-west of the mine along the railway show that the rock has undergone considerable alteration. The original bisilicates and plagioclase have been replaced by secondary hornblende and irregular water-clear grains of plagioclase, which are generally accompanied by small grains of quartz.

Northward from Blezard Mine the rocks show an increase in acidity and alteration. By canoe one may visit the shores and islands of Whitson Lake, where further changes are observed. On an island about  $\frac{1}{2}$  mile south of the narrows the rock begins to show a granitic appearance, the quantity of quartz is much larger, brown scaly biotite and a little secondary hornblende represent the bisilicates, while untwinned orthoclase-felspar is present in about equal quantity with the narrowly-twinned plagioclase.

Areas of secondary hornblende generally extinguish more or less distinctly in two portions, but in sections of the above rock this manner of extinction is very plain. Moreover, in some cases hornblende twinned polysynthetically on  $\infty P \infty$  is connected with these areas, and one part of the hornblende-mosaic extinguishes with one series of twinning-lamellæ, while the other part of the mosaic extinguishes with the alternate series of twinning-lamellæ. This proves that the hornblende of the mosaic is oriented in the position for twinning on  $\infty P \infty$ . It differs, however, from the ordinary

twinning, in that there is complete interpenetration of the hornblende-individuals, which in the ordinary twinning are separated by straight lines, as is the case with plagioclase when twinned polysynthetically. It has been long remarked that areas of secondary hornblende extinguish in two portions, but the exact orientation of the one portion with reference to the other has not been previously determined.

Specimens from an island near the narrows of Whitson Lake show distinct parallelism, and appear to be gneissoid granite. The scaly biotite which occurred sparingly in the previous specimens is here a prominent constituent, and forms continuous films of small individuals, which give to the rock its parallel structure. Orthoclase is much more prominent than plagioclase, while micropegmatite constitutes nearly half the rock. It is interesting to note that the felspar present in the micropegmatite is well-twinning plagioclase.

Farther north the islands and shores present the same rock as that just described, except that scaly biotite, quartz, and orthoclase are almost the sole constituents. Micropegmatite nearly disappears in the northernmost specimens. Sometimes the rock contains numerous grains of calcite, which is well twinned and water-clear. This mineral is certainly not a decomposition-product of the granite, which is quite fresh. It may be a primary constituent, or more probably an infiltration into the small cavities of the originally somewhat porous rock. Similar calcite-granites have been reported by Hawes from New Hampshire, and by Törnebohm from Guömålo in Sweden.

The north-western contact occurs at the extreme north of the lake, near the mouth of a small creek. The rock to the north-west is the silicified breccia previously described.

This cross-section of the Whitson Lake eruptive shows that it extends from a short distance south of Blezard Mine to the northern end of the lake, a distance of  $3\frac{1}{2}$  miles, and that there is a gradual increase in acidity towards the north.

*γ. Exposures along the line between Lots 8 and 9 in the Township of Snider.*

A two days' trip was made through the woods along the line between lots 8 and 9 in the township of Snider, in order to study further and map the Whitson Lake eruptive. It was found that on the southern shore of the lake the rocks exposed were gneissoid granites similar to those seen near the narrows of Whitson Lake. The contact occurs about  $\frac{1}{2}$  mile north of the lake. Passing southward towards Meat Bird Lake, the granite gradually gave place to the normal greenstone. The southern contact was found to be near the boundary-line between concessions II. and III. Its width is therefore about 4 miles.

Thus it is seen that this section of the Whitson Lake eruptive is quite similar to the two sections already described.

While engaged as an assistant on the Canadian Geological Survey in 1890, and exploring south of White Water Lake with a view to determining the boundaries of the eruptive, I first observed that there was not a sharp boundary between the greenstone and the granite lying north-west of it, since there appeared to be everywhere a gradual transition from the one to the other.

In the previous pages it has been shown that such transitions occur along all the cross-sections of the Whitson Lake eruptive. The variations in chemical composition of these rocks are illustrated in the following series of analyses of specimens collected along the Blezard Mine crossing. The specimens range from south to north, from I to V. I am indebted for analysis IV to Mr. C. B. Fox, M.A., chemist of the Iron and Steel Company, of Hamilton, Ontario:—

	I.	II.	III.	IV.	V.
	%	%	%	%	%
SiO <sub>2</sub> .....	49.90	51.52	64.85	69.27	67.76
TiO <sub>2</sub> .....	1.47	1.39	.....	0.78	0.46
P <sub>2</sub> O <sub>5</sub> .....	0.17	0.10	0.24	0.06	0.19
Al <sub>2</sub> O <sub>3</sub> .....	16.32	19.77	11.44	12.56	14.00
Fe <sub>2</sub> O <sub>3</sub> .....	.....	.47	2.94	2.89	.....
FeO .....	13.54	6.77	6.02	4.51	5.18
CaO .....	6.58	8.16	3.49	1.44	4.28
MgO .....	6.22	6.49	1.60	0.91	1.00
MnO .....	trace	trace	trace	trace	trace
K <sub>2</sub> O .....	2.25	0.70	3.02	3.05	1.19
Na <sub>2</sub> O .....	1.82	2.66	3.92	3.12	5.22
H <sub>2</sub> O .....	0.76	1.68	0.78	0.76	1.01
Total .....	99.03	99.71	98.30	99.35	100.29
Specific gravity=	3.026	2.832	2.788	2.724	2.709

Several of the most important nickel-deposits occur along the south-eastern border of the Whitson Lake eruptive; among others the Blezard, Murray, Little Stobie, and Lady M<sup>c</sup>Donald mines.

### (iii) The Windy Lake Eruptive.

This eruptive is situated about 25 miles north-west of Sudbury, and is known to extend from the township of Lavack south-west to the township of Trill, a distance of 20 miles, though its total length is probably much greater. Exceptional opportunity is afforded for the examination of this eruptive by the cuttings of the Canadian Pacific Railway near Windy Lake, where the rock extends over a width of nearly 4 miles. Onaping Station is situated near the south-eastern border of the area.

About 3½ miles west of Onaping Station the railway passes through a ridge of greyish to pinkish, heavily-bedded gneiss, which was described at the beginning of this paper (p. 42). On travelling eastward a few hundred feet along the low margins of Windy Lake no rocks are observed, but a little farther east there are exposures of a medium-grained rock, in which the unaided eye distinguishes a black mineral occurring as separate grains, and a much more

abundant white mineral forming the groundmass for the dark mineral. Though a norite, this rock differs in appearance from the Whitson Lake eruptive in being coarser-grained and of a much lighter colour.

The microscope shows that here the hypersthene, though often quite fresh, is more frequently changed partly or even entirely to bastite or secondary hornblende. The plagioclase-crystals are quite free from the dusty-brown inclusions observed in the plagioclase of the Whitson Lake norite. This difference is largely responsible for the comparatively light colour of the Windy Lake norite as contrasted with the dark colour of the Whitson Lake norite.

A specimen collected  $\frac{1}{2}$  mile east differs from the last in being slightly more altered and of somewhat more acid character. Some crystals of plagioclase exhibit in an unusual degree zonal structure and wandering extinction. In some cases there is a difference of  $38^\circ$  between the extinction of the central and marginal portions of the same individual. Such plagioclase-crystals generally border on small areas of quartz and micropegmatite, and appear to have continued their growth till all the constituents except the quartz and micropegmatite had crystallized. The central portion is therefore composed of one of the most basic plagioclases, while the marginal portion represents one of the most acid of the series.

Eastward the rock becomes coarser in grain, and the greyish norite gives place to what might be taken macroscopically for a hornblende-syenite. A specimen collected  $2\frac{1}{4}$  miles west of Onaping Station, when examined microscopically, shows that secondary hornblende is the only bisilicate present. Micropegmatite and quartz are more abundant: the felspar of the micropegmatite is well-twinned plagioclase. There are a few grains of a yellowish pleochroic mineral, which has strong polarization-colours and a high index of refraction. As this mineral becomes much more abundant near Onaping Station, it will be more fully dealt with later: it seems to alter to radiating aggregates of pale lemon-yellow hornblende.

Towards Onaping Station there is a marked increase in the quantity of micropegmatite, which forms about half the rock. Well-defined felspar-crystals form the centres for radiating micropegmatite areas. Taking into consideration the prominent part played by micropegmatite and the porphyritic nature of the rock, it may be called a 'hornblende-porphyrity with a micropegmatitic groundmass.'

There is, moreover, another important constituent. This occurs commonly in groups of irregular grains, and is distinctly pleochroic—lemon, yellowish-green, and colourless. The index of refraction is high, and the surface appears to be quite rough when seen under the microscope. The double refraction is high, so that it polarizes in orange-green and red tints when quartz of the same thickness polarizes in grey. It is always associated with the radiating aggregates of secondary hornblende above mentioned. This mineral appears to have occupied a prominent place in the original rock, where it largely replaced the bisilicates. Having crystallized later than the quartz, it presents very seldom idiomorphic

forms. The same mineral is a very frequent accessory in the Norwegian zircon-syenites, though the secondary products are not so well developed there as in the Onaping rocks. This mineral has been identified in the zircon-syenites as wöhlerite, and it is possible that the associates of wöhlerite may be found in the Sudbury nickel-bearing rocks. A mechanical or chemical separation of this mineral was impossible.

The reddish granite at Onaping Station is composed of micropegmatite, orthoclase with a little free quartz, and about equal quantities of wöhlerite and secondary hornblende, which was probably derived from the former. Orthoclase has replaced plagioclase in the micropegmatite, which constitutes about two-thirds of the rock, and has attained a high degree of perfection. Wöhlerite is present as grains, which at times deserve the name of crystals, and may be seen to be optically biaxial, with a very large optic angle. The secondary hornblende derived from it contains numerous delicate feathery crystals of biotite, which are also probably of secondary nature.

South-eastward from Onaping, near the contact, the granite becomes fine-grained and darker in colour, while the microscope shows a slight increase in plagioclase and iron ores, and a decrease in free quartz.

In this eruptive, as in the one previously described, micropegmatite is characteristic for the granitic rocks connected with basic noritic borders. Harker has observed the same occurrence in his studies of the Carrock Fell gabbro in England. Elsewhere micropegmatitic rocks are generally muscovite-bearing, but in the Sudbury eruptives muscovite is very seldom found. A wider examination might show that micropegmatite is characteristic for all rocks which are midway between the more acid and the more basic portion of differentiated eruptives.

Some of the most important deposits of nickeliferous pyrrhotite discovered in the Sudbury district are situated along the north-western border of the Windy Lake eruptive. We have here to deal with an eruptive whose length is unknown, and whose width is nearly 4 miles. The gradual transition, from typical pyrrhotite-norite on the one hand to hornblende-granite on the other, shows that in most respects it is identical with the Whitson Lake eruptive. These eruptive areas, which are bordered locally with norite and pyrrhotite-norite, cannot properly be spoken of as basic eruptives, since the average acidity for the whole of the eruptives is at least 62 per cent. of silica. In this respect the Sudbury nickel-bearing eruptives differ from those of Norway as described by Vogt.

Bell's map shows a greenstone area extending from Lake Sagitchi-wai-a-ga-mog south-westward into the township of Morgan. This area is in all probability only a basic border of the Windy Lake eruptive. In this case the length of the eruptive is at least 25 miles, while further investigation may show that it is even longer.

Specific-gravity determinations, of a series of specimens collected along the railway where it crosses the Windy Lake eruptive, show a decrease from each border towards the centre, where the lightest and most acid rocks occur. The following numbers are averages of pairs of specimens, so that the error inherent in determinations made on small fragments is more or less eliminated:—

Eastern contact .....	2.714
"    " .....	2.746
"    " .....	2.690
Onaping Station .....	2.722
"    " .....	2.793
Western contact .....	2.851

#### (iv) The Travers Mine Eruptive.

This nickel-bearing area is situated in the townships of Drury and Denison, about 25 miles south-west of Sudbury. It is most easily reached from Worthington Station on the 'Soo' branch of the Canadian Pacific Railway. Bell maps it as being nearly a mile wide and 6 miles long.

The rock on the dump at Travers Mine is fine-grained, dark greenish-grey, and in some cases exhibits a schistose structure. The microscope shows that it is composed of fine granular felspar, uraltic hornblende, a very little hornblende-epidote, and iron ores. The schistosity is often very distinct, and is caused by the bisilicates forming lengthened, irregularly-pointed, elliptical areas, which alternate with granular felspar-epidote masses, that constitute two-thirds of the rock.

Farther south the rock is composed of the same minerals, but is often much coarser. Locally there are small patches which are nearly pure felspar-epidote aggregate, while in other places there are dark patches which contain very little felspar-epidote aggregate. A mile and a quarter south of the mine the rock becomes very much coarser.

The rocks of this area resemble the well-known flaser-gabbros of Rosswein, Saxony, and differ widely from the rocks of the two areas already studied. At present it is composed of saussurite flaser-gabbro, especially rich in saussurite. The flaser-structure has probably been caused by great pressure, which hastened the uraltization and saussuritization of the components, and may have produced the crushed granite north of the Travers Mine. I have not determined the relation of the gabbro to the granite north of the mine, but I think that the two are genetically distinct.

#### V. OTHER NICKELIFEROUS AREAS.

The Stobie Mine is connected with a long narrow area of somewhat schistose greenstone, which is only a few yards wide where crossed by the Blezard branch of the Canadian Pacific Railway. The specimens collected indicate an approach to amphibolite. The Huronian rocks have been metamorphosed by this now highly-altered

greenstone; garnet and biotite are the chief new minerals, while the whole rock has been rendered quite crystalline.

Copper Cliff Mine is also situated on a very narrow eruptive stock. The greenstone is so much altered that its original nature is quite concealed. The microscope shows that uralite, a little secondary hornblende, plagioclase, free quartz, and a little micropegmatite are the chief constituents. This rock is thus seen to be much more acid than that examined at any of the other nickel mines.

Worthington Mine is connected with an eruptive which is not more than 50 yards wide where the 'Soo' branch of the Canadian Pacific Railway crosses it at Worthington Station. The rock is very schistose, and greenish-grey in colour. Some of the fresher specimens might be called actinolite-schist, while others are largely changed to a fine aggregate of talc, which contains only a few slender actinolite-crystals. Pyrrhotite-grains are richly scattered through the rock.

There are a few areas of hornblende-schist in the Sudbury district, but it is difficult to determine whether they should be regarded as crystalline schists and proper members of the Huronian, or as altered greenstones. One of the largest and most accessible of these areas is cut by the main line of the Canadian Pacific Railway, about 3 miles west of Sudbury. The rock is rather compact, distinctly schistose, and nearly black in colour. The microscope shows that it is composed of long, slender crystals of bluish-green hornblende, a smaller quantity of quartz and water-clear grains of felspar.

Narrowly elliptical quartz-grains form parallel chains of inclusions in the hornblende-crystals. These inclusions occupy a definite plane, which, from the following observations, appears to be the positive orthodome  $+P\infty$ . (The face usually marked  $p$  is here taken to be the basis  $\infty P$ ):—

- (i) In sections of hornblende-individuals the inclusion-chains are at right angles to the cleavage—hence they lie in a plane of the orthodiagonal zone.
- (ii) The maximum extinction for sections parallel to  $\infty P\infty$  is  $13^\circ 55'$ . Such sections show that the chains of inclusions form an angle of  $75^\circ$  with the cleavage, and an angle of  $89^\circ$  with the axis of elasticity .
- (iii) Sections with smaller angles of extinction give larger angles between the cleavage and the inclusion-chains.

Similar disjointing of blade-like crystals by pressure is observed in many minerals, particularly in the piedmontite of Japanese piedmontite-schists. Parting of hornblende-crystals along  $+P\infty$  has been observed by Cross in actinolite-schists from Brittany, and also less perfectly in green schists from Zermatt in Switzerland.

The same amphibolite-area may be examined about  $\frac{1}{2}$  mile north of Copper Cliff Mine. The nickel-bearing rocks at Stobie Mine resemble these amphibolites, and it is possible that they are all connected.

It is worthy of note that most of the narrow areas of nickeliferous rocks have been acted upon by dynamic metamorphism with comparative ease, and as a result the original unaltered rock is seldom found in the smaller eruptives. The original rock was probably a massive norite or gabbro, which was changed into schistose hornblende-rock. This is seen in the rocks of the Stobie, Travers, and Worthington eruptives. On the other hand, large eruptives such as the two first described have retained their massive structure and to a large extent their pyroxene content.

As compared with the Norwegian nickeliferous rocks, the Sudbury rocks are decidedly more acid, for olivine, which is a frequent constituent of the former, has never been detected in any of the Sudbury nickeliferous rocks.

## VI. THE YOUNGER GRANITES.

We must now refer briefly to a class of granites which are younger than the nickeliferous rocks, and may be conveniently spoken of as 'Younger Granites.' The best exposures of these rocks occur on the main line of the Canadian Pacific Railway, about 2 miles west of Murray Mines. The nickel-bearing rocks are there cut by two separate eruptions of fine-grained, pinkish biotite-granite, which sends off apophyses into the surrounding greenstone. The wider of these intrusions is about 100 yards broad, while the smaller is less than 60 yards. The microscope shows that quartz, orthoclase, plagioclase, and biotite are the chief constituents.

Where the rock comes into contact with the norite, the hypersthene, hornblende, and augite of the latter are changed to fine scaly biotite, while the well-formed plagioclase is replaced by an aggregate of granular plagioclase, epidote, and quartz.

Another exposure of this rock occurs immediately south-east of Murray Mines, where it cuts through the nickeliferous greenstone, sometimes forming apparent inliers in the same. In other places breccias are formed by the inclusion of angular fragments of greenstone in a groundmass of fine-grained pinkish granite.

It appears as if there had been an intrusion of this granite along the contact between the nickel-bearing eruptives and the Huronian rocks south-east of them. The width of this granitic intrusion is over  $\frac{1}{2}$  mile. It contains numerous inliers of greenstone. A narrow strip of mica-schist 11 yards wide is exposed along the railway on the south-eastern border of the granite. The schist dips at very high angles, and doubtless represents the rock which was originally in contact with the nickel-bearing eruptive. Similar exposures of fine-grained granite are observed immediately south of Elezard Mine.

North of Copper Cliff Mine there is a large area of coarse gneissoid granite, which the late Baron von Follen considered to be Laurentian. It is essentially the same rock as that exposed east of Murray Mines, except that the latter has been so crushed as to present a much finer grain.

## VII. OLIVINE-DIABASE DYKES.

These dykes are the youngest of the Sudbury rocks, and are characterized by north-westerly direction with only very slight variations. All the other rocks of the district are intersected by them. The extensive area over which these dykes occur, taken in connexion with their general parallelism, points to a period of great dynamical action. The force that produced the cracks through which the diabase-magma ascended had doubtless a part in the production of amphibolites and fiaser-gabbros from massive pyroxene-rocks, in the metamorphism of the norites, and in the crushing of the Younger Granites and granitic borders of the nickel-bearing areas. As the dykes intersect all the other rocks, we may conclude their post-Huronian age, though it is impossible to say whether they were formed in early Palæozoic or in comparatively recent times.

One of the best representatives of this dyke-system is well exposed quite near the town of Sudbury, and can be followed for 7 miles. The easternmost exposure is on the southern shore of Ramsay Lake, near the north-western point of the peninsula which nearly divides the lake. It appears again on the north-western shore near the landing, and the dyke may be followed by frequent exposures past the town of Sudbury. All the exposures of diabase along the railway between Sudbury and Rayside Stations are portions of the same dyke.

Another dyke of this system crosses the railway 1 mile east of Worthington Station, and a third about  $\frac{1}{4}$  mile east of the station. A very large dyke is well exposed on the railway near Nairn Station. Many others might be mentioned, some of which are said to have other directions, but all those examined by the writer have a general north-westerly direction. In width they vary from a few feet to 50 yards.

Plagioclase is the chief constituent. It is generally quite fresh, but is occasionally somewhat clouded. Idiomorphic much-twinned crystals are characteristic. From measurements of the angles of extinction the felspar seems to be labradorite. The twinning is commonly of the albite law, but a combination of the albite and pericline laws is frequent. In a section from the large dyke near Murray Mines twinning was observed combining the albite, pericline, and Baveno laws. Twinning of plagioclase according to the Baveno law was first mentioned by Weiss, and more fully described by Brezina. The combination of this rare twinning law with the albite and pericline laws as exhibited in the diabase from near Murray Mines is very interesting, and probably has never been previously observed. Plagioclase being by far the earliest to crystallize, the ophitic structure is beautifully developed.

The quantity of monoclinic pyroxene varies. In the exposure near Murray Mines it forms about a quarter of the rock, while at other points on this dyke, as also in the dykes near Worthington Station, it does not constitute more than an eighth of the rock. Where there is most pyroxene there is least olivine, and *vice versá*,

so that the total quantity of pyroxene and olivine is nearly constant. The olivine forms more or less rounded, pale greenish-yellow grains, which are younger than the plagioclase, but older than the augite. Sometimes the olivine has given rise to small quantities of serpentine and swarms of minute grains of magnetite. The pyroxene shows no definite outline, and very seldom imperfect cleavage: it is reddish-brown to violet in colour, and distinctly pleochroic. The usual accessory minerals are present, and the rock is remarkably fresh.

One point characteristic of these dykes is the ease with which they are acted upon by hydrochemical agencies. Near the village of Murray Mines the Government road passes for some distance between high walls of granite, which have become prominent by the weathering-out of the diabase. The nickel-bearing greenstones resist the action of atmospheric agencies much better, and are generally greenish on the weathered surface. In this respect they stand in contrast to the rocks under discussion, which become quite rusty on exposure. Spheroidal weathering is characteristic.

One of the exposures on the railway immediately east of Worthington Station contains porphyritic crystals of plagioclase from 1 to 2 inches long. This porphyritic phase is confined to within 2 yards of the contact. No glassy borders were observed in connexion with these dykes, but this may be due to the ease with which the rock decays. The large dyke, where exposed on Ramsay Lake, exhibits a gradual change in texture from very fine at the borders to quite coarse in the central portions. A microscopic examination of the marginal and central portions shows that they are mineralogically identical, and that there has been no differentiation. This is confirmed by specific-gravity determinations of a series of specimens representing a cross-section of the dyke where its width is about 40 yards.

A quantitative analysis of a specimen from the big dyke near Murray Mines gave the following result:—

	%
SiO <sub>2</sub> .....	47·22
Al <sub>2</sub> O <sub>3</sub> .....	16·52
Fe <sub>2</sub> O <sub>3</sub> .....	3·32
FeO .....	12·40
MnO .....	0·04
CaO .....	9·61
MgO .....	3·33
K <sub>2</sub> O .....	0·67
Na <sub>2</sub> O .....	3·40
TiO <sub>2</sub> .....	3·62
P <sub>2</sub> O <sub>5</sub> .....	0·33
BaO .....	0·01
CuO .....	trace
NiO .....	0·0275
CoO .....	0·0055
Loss by ignition .....	0·30
<hr/>	
Total .....	100·803
<hr/>	
Specific gravity .....	3·01



The proportions of ferrous oxide and titanitic acid are unusually large. The latter doubtless occurs partly in the magnetite and ilmenite and partly in the augite, giving this last its peculiar violet colour. It has long been known that nickel is a frequent constituent of the heavy ferro-magnesian minerals, especially of olivine and pyroxene, and it is probable that the heavy metals contained in the diabase are constituents of these silicates. Whether the nickel, cobalt, and copper were primarily constituents of the diabase-magma or not would be difficult to say, as they may have been derived from the nickel-bearing greenstones which are intersected by these dykes. Fragments of the nickel-bearing rocks may have been absorbed by the diabase-magma. I am, however, inclined to regard the nickel content of the diabase as a constituent of the original diabase-magma. No nickel-deposits have been found associated with these dyke-rocks.

Had the nickeliferous diabase solidified more slowly and been richer in sulphur, the nickel would probably have separated as iron-nickel sulphides along the border, as it did in the case of the nickel-bearing greenstones, where these differentiations of pyrrhotite-norite now constitute the most extensive nickel-deposits in the world.

The map which accompanies this paper is founded on that issued by the Canadian Geological Survey. It differs, however, in two ways from the Government map. Firstly, I have omitted much of the detail both in topography and geology, and have reproduced only such features as are necessary to illustrate the present paper. The second difference is wholly geological, and consists in such changes as my own explorations showed to be necessary. These changes are principally connected with the Whitson Lake and Windy Lake eruptives, and with the Younger Granites.

The investigations reported in this paper were carried on under the direction of Herr Geheimrath Professor Zirkel. It affords me great pleasure to acknowledge my indebtedness to him for his friendly advice and encouragement.

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## DISCUSSION.

The PRESIDENT said that all additional information in regard to the Huronian rocks, which resemble so closely the volcanic rocks of pre-Cambrian age in Wales, was most useful at the present time. The Author's paper, therefore, was one in which British geologists would necessarily be much interested.

Prof. BONNEY said that, so far as he had seen the district, he doubted whether the ore was the result of differentiation. He believed that it was more likely to have been introduced afterwards, as is commonly the case with mineral ores. He thought also that the Author was pushing this idea of differentiation too far in regard to the rocks of the country. So far as he knew, there was a number of separate bosses of various kinds of rocks.

Mr. TEALL said that hyperites were associated with the Loch Dee granite in the South of Scotland, and that pyrrhotite occurred in some of the altered forms of these rocks. This pyrrhotite, however, in the specimen he had examined was certainly not nickeliferous to anything like the same extent as the Swedish and Canadian varieties. The association of nickeliferous pyrrhotite with hyperites and norites was now known from a very large number of localities in various parts of the world, and the differentiation-hypothesis had been advanced by Vogt to explain the association.

The paper was based on a large amount of field as well as laboratory work. Its main object was not to establish a theory, but to describe facts.

Gen. McMAHON referred to the theoretical portion of the paper, and commented on the difficulty of understanding how the law of gravitation could be appealed to as the explanation of the basic portions of slowly-cooling magmas concentrating in the centres of eruptive masses, combined with the formation of acid rocks on both margins.

The Rev. J. F. BLAKE also spoke.

5. *The FAUNA of the KEISLEY LIMESTONE.—PART II. CONCLUSION.*<sup>1</sup>  
By F. R. COWPER REED, Esq., M.A., F.G.S. (Read November  
18th, 1896.)

[PLATE VI.]

#### OSTRACODA.

OF the rich fauna of ostracods which Prof. T. Rupert Jones<sup>2</sup> has described from Kildare I have, after careful search, been able to determine only the following two at Keisley:—

##### PRIMITIA M'COYI, Salter.

This is the form which many previous observers have recorded as *Cythere phaseolus* (His.), but it is a mistaken identification, as Prof. Rupert Jones (*loc. cit.*) has shown. The species is as abundant at Keisley as it is at Kildare.

##### CYTHERE WRIGHTIANA, Jones.

This is a rare form at Keisley, only two or three specimens having so far been found.

#### BRACHIOPODA.

##### OBOLELLA *cf.* NITENS, Hisinger.

A small transversely-oval shell, with a longitudinal groove from the beak to the anterior margin, appears to belong to this Swedish species.<sup>3</sup> The shell is very thin, and marked with only a few concentric lines of growth; the brachial valve, which here is alone preserved, is much flattened, has a small pointed beak near the margin, an almost straight hinge-line, and a distinct longitudinal groove running from the beak to the front edge. The brachial valve of this species figured by Lindström<sup>4</sup> corresponds very closely in shape and other characters with our Keisley specimen, but the pedicle-valves there delineated are subcircular, and described as shield-shaped, though the breadth is given as twice the length. The species is found in the *Trinucleus*-schists of Sweden. Our specimen measures 2 millim. in length and 3 in breadth.

##### ORBICULOIDEA, sp.

A small circular pedicle-valve, ornamented with rather coarse concentric striæ, and possessing a central elevated umbo whence a narrow external pedicle-groove is traceable to the margin, is the only representative of the genus that I have seen from this rock. The specimen is in the Woodwardian Museum.

<sup>1</sup> For Part I., see this Journal, vol. lii. (1896) pp. 407-437 & pls. xx.-xxi.

<sup>2</sup> Ann. Mag. Nat. Hist. ser. 4, vol. ii. (1868) p. 54, pl. vii.

<sup>3</sup> Hisinger, 'Lethæa Suecica,' Stockholm, 1837, p. 77 (*Atrypa?* nitens).

<sup>4</sup> 'Fragm. Silur.' (1880) pl. xiii. fig. 34.

It cannot be identified with *Discina gibba* (Lindstr.) of the *Leptæna*-Limestone, for that species has two small nodules below the apical foramen, and the beak of the pedicle-valve is subcentral and nearer the posterior than the anterior margin. Davidson<sup>1</sup> figures a small species of *Orbiculoidea* (*Discina*, Dav.), from Keisley, which is apparently distinct from that above described.

LINGULA?, sp.

Prof. Harkness<sup>2</sup> records *Lingula brevis*? (Portl.) from the Keisley Limestone. I have seen the specimen thus identified at Carlisle, and am very doubtful about it. It might even not be a brachiopod at all, but a lamellibranch, like *Ambonychia? nux* (Lindstr.), which Lindström<sup>3</sup> figures and describes from the *Leptæna*-Limestone.

ORTHIS CALLIGRAMMA, Dalm.

This species is not common at Keisley.

ORTHIS CALLIGRAMMA, var.

In addition to specimens with the ordinary features of this well-known species, there has been found the imperfect brachial valve of an *Orthis* having the shape and appearance of typical individuals of this species, but furnished with thirty to forty rounded, straight, simple ribs of regular width, separated by interspaces which at the margin of the valve are more than double the breadth of the ribs, except near the hinge-line, where the last six or seven ribs are somewhat crowded together and of rather smaller size.

ORTHIS ACTONLÆ, Sowerby.

This is a rare species in the Keisley rock. Probably *Orthis Oswaldi* (Von Buch), which occurs in Stage F of the East Baltic provinces, is a synonym, as Schmidt<sup>4</sup> mentions. It is found also in the Kildare and *Leptæna*-Limestones.

ORTHIS (BILOBITES) BILOBA, Linn.

Though a characteristically Silurian species, this is not unknown from Ordovician beds, and Davidson<sup>5</sup> records its occurrence at Cefn Rhyddan and other places in Bala rocks. I have seen several well-preserved specimens from Keisley, two of which I found myself. It occurs in the *Leptæna*-Limestone.

ORTHIS (PLATYSTROPHIA) BIFORATA, Schlotheim.

A fairly common species at Keisley. The Kildare and *Leptæna*-Limestones and Schmidt's Stage F also contain it.

<sup>1</sup> 'Mon. Brit. Foss. Brach.,' vol. iii. (1864-71) pl. l. fig. 27.

<sup>2</sup> Quart. Journ. Geol. Soc. vol. xxi. (1865) p. 248.

<sup>3</sup> 'Fragm. Silur.' (1880) p. 17, pl. xiii. figs. 53, 54.

<sup>4</sup> 'On the Silurian (and Cambrian) Strata of the Baltic Provinces of Russia,' Quart. Journ. Geol. Soc. vol. xxxviii. (1882) p. 514.

<sup>5</sup> 'Mon. Brit. Foss. Brach.,' vol. iii. (1864-71) p. 206.

ORTHIS (DALMANELLA) TESTUDINARIA, Dalman.

Not very common at Keisley. It has not been recorded so far from the Kildare or the *Leptaena*-Limestone.

ORTHIS (DALMANELLA ?) cf. CONFERTA, Lindström.

Lindström<sup>1</sup> describes and figures a small species of *Orthis* from the *Leptaena*-Limestone under the name of *O. conferta*. Some specimens from Keisley appear to belong to it, agreeing in shape and surface-ornamentation.

ORTHIS cf. ARGENTEA, Hisinger.

I have but little doubt that this species of Hisinger's<sup>2</sup> occurs at Keisley, for several well-preserved shells show all the typical external features with the regular bifurcation of the ribs, but they are of rather large size. In Sweden it occurs in the *Trinuclous*-Schists.

ORTHIS (HEBERTELLA ?) KEISLEYENSIS, sp. n. (Pl. VI. figs. 1, 1 a, & 1 b.)

This species is founded on a single pedicle-valve of a small specimen, but it shows characters so peculiar and distinct that a new specific name is not uncalled for.

The valve is transverse, with a semicircular outline. The depth at the umbo is nearly one-third of the total length. There is a very faint indication of a median sinus; the beak is small, and not curved over the hinge-line.

The hinge-line is straight, and there is a high, triangular, steeply inclined hinge-area. The surface of the valve is ornamented with about sixteen simple, straight, unforked, narrow, rounded ribs extending from the beak to the margin, with interspaces of quite double the width of the ribs.

The ribs and interspaces are crossed by strong, rounded, raised, equidistant, concentric lines, not lamellose; these give a distinct cancellated appearance to the surface.

The length of the valve is 5 millim., and its width 6 millim.

In the shape of the pedicle-valve and the characters of the hinge-area, this Keisley form resembles the species belonging to the group *Hebertella* of Hall & Clarke,<sup>3</sup> but none of the species, so far as I know, have a precisely similar ornamentation.

In these respects also the common Wenlock species, *Orthis Bouchardi* (Davidson), is not unlike our specimen, but it has fewer ribs and the concentric markings are lamellose.

ORTHIS VESPERTILIO, Sowerby.

There is a specimen in the Carlisle Museum from Keisley, but it is a rare form. It probably occurs at Kildare.

<sup>1</sup> 'Fragm. Silur.' (1880) p. 26, pl. xiii. figs. 1-3.

<sup>2</sup> *Ibid.* pl. xiv. figs. 12-15; and Hisinger, 'Lethæa Suecica' (1837), p. 72, pl. xx. fig. 15.

<sup>3</sup> 'Pal. N. Y.,' vol. viii. Brach. pt. i. (1892) p. 198.

ORTHIS (DALMANELLA) ELEGANTULA ?, Dalman.

ORTHIS (HETERORTHIS) ALTERNATA ?, Sowerby.

ORTHIS (DINORTHIS) FLABELLULUM ?, Sowerby.

These three species have been doubtfully identified from fragmentary specimens.

STROPHOMENA ANTIQUATA, Sowerby.

A fairly common species at Keisley ; it is found in the Bala, as well as in the Silurian of Britain.

STROPHOMENA CORRUGATELLA, Davidson.

This is one of the commonest species at Keisley, and is also found at the Chair of Kildare and in the *Leptaena*-Limestone.

LEPTÆNA RHOMBOIDALIS, Wilckens.

This species, commonly but erroneously<sup>1</sup> called *Strophomena rhomboidalis*, is not abundant in the Keisley Limestone, but it has been recorded thence by Harkness, Marr, and Nicholson, and I have found good typical specimens of it myself. It occurs also in the Kildare Limestone and in the Dalecarlian Limestone.

PLECTAMBONITES SCHMIDTI, Törnquist.

It is of considerable importance that this species has been recognized at Keisley, for it appears to be nearly restricted to the horizon of the *Leptaena*-Limestone and Stage F of Schmidt. I have not seen any specimens from Kildare, but the Keisley examples show all the features described by Lindström.<sup>2</sup>

PLECTAMBONITES QUINQUECOSTATA, M'Coy.

Törnquist<sup>3</sup> compares a *Leptaena*-Limestone species with this one of M'Coy's, but it is not given in the 'List of the Fossil Faunas of Sweden' (Stockholm, 1888). It is fairly common at Keisley and Kildare.

PLECTAMBONITES TRANSVERSALIS ?, Wahlenberg.

I believe that this species occurs at Keisley, but the specimens are rather imperfect. It occurs also doubtfully at Kildare. It is known from Bala, Llandovery, and Wenlock rocks in the United Kingdom.<sup>4</sup>

RAFINESQUINA EXPANSA, Sowerby.

There is a well-preserved ventral valve of this species at Carlisle, and I have seen other fragments. Davidson<sup>5</sup> states that this form is found in the Caradoc and Lower Llandovery.

<sup>1</sup> Hall & Clarke, 'Pal. N. Y.', vol. viii. Brach. pt. i. (1892) pp. 250 & 276.

<sup>2</sup> 'Fragm. Silur.' (1880) p. 29, pl. xiv. figs. 25, 26.

<sup>3</sup> 'Öfvers. ö. Bergbyggn. inom Siljans. i Dal.' p. 26, Sveriges Geol. Undersök. ser. C, no. 57 (Stockholm, 1883).

<sup>4</sup> Davidson, 'Mon. Brit. Foss. Brach.', vol. iii. (1864-71) p. 320 (*Leptaena transversalis*).

<sup>5</sup> *Ibid.* p. 314 (*Strophomena expansa*).

## RAFINESQUINA DELTOIDEA, Dalman.

The typical form of this species occurs at Keisley, and perhaps at Kildare, but is rare. It is recorded from Stage F of the East Baltic provinces by Schmidt.<sup>1</sup>

## RAFINESQUINA (?) DELTOIDEA, var. UNDATA, M'Coy.

This variety is not uncommon at Kildare and Keisley. I strongly doubt whether it is really a variety of *R. deltoidea* and not a distinct species belonging to another genus. Lindström<sup>2</sup> figures and describes a variety of *Strophæodonta imbrex* (Pander) which seems to be almost identical with the Keisley form. The latter agrees best with fig. 23, pl. xxxix. vol. iii. of Davidson's 'Monograph of the British Fossil Brachiopoda.' The Swedish specimens, however, which are from the *Leptaena*-Limestone appear to be less suddenly geniculated and to possess a greater number of larger ribs than those from Keisley and Kildare.

## TRIPLECIA INSULARIS, Eichwald.

This species occurs at Keisley, Kildare, and in Stage F.

## STREPTIS MONILIFERA, M'Coy.

This form appears to be almost restricted to Keisley and Kildare, where it is abundant.

## CHRISTIANIA TENUICINCTA, M'Coy.

This is a very common species at Keisley, and is also found at Kildare. The peculiar internal structure and muscular impressions have recently led Messrs. Hall & Clarke to establish the new genus *Christiania* for the reception of this species, which previously was called a *Leptaena*.

## ATRYPA EXPANSA, Lindström.

This species<sup>3</sup> is very variable, but is distinguished from *A. marginalis* (Dalm.) by its subquadrate form and diminished prominence of the beak of the ventral valve. Three fairly distinct varieties occur in the Keisley Limestone. The first (var.  $\alpha$ ) is characterized by the almost obsolete fold on the brachial valve, while the sinus on the pedicle-valve is fairly strong. The marginal fringes to the valves, such as Davidson figured in the case of *A. reticularis*, are frequently preserved.

The second variety ( $\beta$ ) has the fold on the brachial valve distinct, but the ribs on the valves are much smaller and more numerous than in the type-form. Thus I have counted as many as ten ribs on the brachial fold of one specimen. The marginal fringes are often present in this variety also. The third variety ( $\gamma$ ) is characterized by the possession of a strong angular sinus in the pedicle-valve,

<sup>1</sup> 'Rev. d. ostbalt. Silur. Trilob.,' pt. i. Mém. Acad. Imp. des Sci. St. Pétersbourg, ser. 7, vol. xxx. (1881) no. 1, p. 38.

<sup>2</sup> 'Fragm. Silur.' (1830) p. 29, pl. xiv. figs. 27-32.

<sup>3</sup> *Ibid.* p. 22, pl. xii. figs. 6-10, 17-19.

furnished with a single median rib. The brachial valve has a low median fold, marked by two ribs and a somewhat wide interspace on each side between the fold and the lateral group of ribs. The cardinal angles of the shell are more rounded than in the type-form. I was at first inclined to remove this form into a new species, but perhaps it is safer at present merely to consider it a variety of *A. expansa*. It apparently occurs in the *Leptæna*-Limestone.

*ATRYPA MARGINALIS* (Dalman).

There is no reason to doubt that this species or a variety of it occurs in the Keisley Limestone, as its characters are sufficiently distinct from those of *A. expansa* in its typical form.

*ATRYPINA SIMILIS*, sp. n. (Pl. VI. figs. 2, 2a, 2b, 3, & 3a.)

Shell small, subcircular, retziform, flattened. Pedicle-valve more convex than the brachial valve, and furnished with a prominent beak pierced by a distinct circular foramen with a deltidium (of one piece?) in front. The surface of this valve is traversed by seven radiating rounded ribs extending from the beak to the margin; of these the median one bifurcates close to the beak into two strong rounded ribs, each of which again bifurcates at about half its length. The other ribs are simple, and decrease in strength near the hinge-line.

Brachial valve flattened, more convex posteriorly, with small inconspicuous beak and shallow mesial sinus, widening anteriorly. In this sinus lies a single rounded rib which arises at a point about half the length of the shell and bifurcates into two weaker ribs which reach the margin. On each side of the sinus is a strong rounded rib, arising from the beak and bifurcating, at about half its length, into two weaker contiguous ribs reaching the margin like the central one in the sinus. (In the young form, Pl. VI. fig. 2a, these ribs do not bifurcate.) On each lateral portion of the valve outside these ribs bordering the sinus are three simple ribs, those nearest the hinge-line being the weakest.

	millim.
Length of shell .....	5·5
Breadth „ .....	5·0

This species much resembles *Atrypa Barrandei* (Davidson)<sup>1</sup> in shape and general characters, as well as in the distribution of the ribs on each valve. But it differs in the bifurcation of certain of these ribs and in the absence of the concentric-growth ridges.

Hall & Clarke<sup>2</sup> have recently designated the group of shells to which *Atrypa Barrandei* belongs by the generic term of *Atrypina*. Our Keisley species is especially closely allied to *A. disparilis* (Hall)<sup>3</sup> of the Niagara Group, and also much resembles the type of the genus *A. imbricata* (Hall)<sup>4</sup> from the Lower Helderberg Group.

<sup>1</sup> Davidson, 'Mon. Brit. Foss. Brach.', vol. iii. (1864-71) p. 128, pl. xiii. figs. 10-13; vol. v. Suppl. Sil. Brach. (1882) p. 114, pl. vii. figs. 7-7 b.

<sup>2</sup> 'Pal. N. Y.', vol. viii. Brach. pt. ii. (1894) p. 161.

<sup>3</sup> *Ibid.* vol. ii. (1852) p. 277, pl. lvii. fig. 6.

<sup>4</sup> *Ibid.* vol. iii. (1859) p. 246, pl. xxxviii. figs. 8-13.

But the distribution and furcation of the ribs are shown by the figures of these American species to be slightly different.

*CAMERELLA* ? THOMSONI (Davidson).

This species, which Davidson<sup>1</sup> doubtfully put in the genus *Rhynchonella*, resembles in external characters Billings's *Camerella Vöborthi*<sup>2</sup> from the Black River Limestone of Canada and Törnquist's *Camerella angulosa*<sup>3</sup> from the *Leptæna*-Limestone. I think, therefore, that it is safer to assign it to the genus *Camerella* than to *Rhynchonella*, used in its old wide sense.

Davidson gives only Craighead Quarry and Penwhapple Glen as the localities in which this species has previously been found.

*SYNTROPHIA AFFINIS*, sp. n. (Pl. VI. figs. 4 & 4 a.)

Hall & Clarke<sup>4</sup> have recently established the new genus *Syntrophia* for a small group of brachiopods which externally resemble *Billingsella* and *Protorthis*, but in their internal structure are related to the genus *Stricklandinia* of a later date. A single pedicle-valve of a species of this genus *Syntrophia* from the Keisley Limestone is in the Woodwardian Museum, bearing a close resemblance to Whitfield's species *Syn. lateralis*, from the Calciferous formation of America. Our specimen is transversely elongate, strongly convex, with a straight hinge-line nearly equal to the greatest width of the shell. The valve is divided into two rounded convex lobes by a smooth sinus commencing a short distance in front of the umbo, and extending with increasing width to the anterior margin, which it gently sinuates. The umbo is small, not prominent, but incurved over the hinge-line. At the cardinal-lateral angles there is a slight flattening of the convexity of the lobes of the valve in the vicinity of the hinge-line. The surface of the valve is smooth, except for a few concentric striæ, of which the marginal ones are more strongly incised than the others.

As to the internal structure of the valve, the median septum is seen through the thin shell to extend forward from the beak for about two-thirds the length of the shell, but the spondylium formed by the dental plates is not visible.

The points in which our species differs from *Syn. lateralis* (Whitf.) are the inferior height and prominence of the umbo, and the more clearly defined and rounded median sinus.

	millim.
Length of shell .....	3
Breadth .....	5

*RHYNCHOTREMA* cf. *DENTATUM*, Hall.

The species *Rh. dentatum* occurs in the Trenton Limestone of

<sup>1</sup> 'Mon. Brit. Foss. Brach.,' vol. iii. (1864-71) p. 186, pl. xxiv. fig. 18.

<sup>2</sup> 'Canadian Naturalist & Geologist,' vol. iv. (1859) pp. 301, 302 & 445, figs. 23, 24.

<sup>3</sup> 'Om Lagerfölj. i Dal. undersilur Bildn.,' Lunds Universitets Årsskrift, vol. iii. (1866) p. 17; Lindström, 'Fragm. Silur.' (1880) p. 23, pl. xiii. figs. 14-19.

<sup>4</sup> 'Pal. N. Y.,' vol. viii. Brach. pt. ii. (1894) p. 216, pl. lxii. figs. 1-10.

America, from which it was first described by Hall<sup>1</sup> under the name of *Atrypa dentata*. Recently it has been assigned by Hall & Clarke<sup>2</sup> to the genus *Rhynchotrema*. The species much resembles *Rhynchonella*? *œmula* (Salter MS.) described by Davidson<sup>3</sup> from the Kildare Limestone, but in this Irish form the mesial fold of the brachial valve becomes biciplicated only near the front margin of the shell, and the two short rounded ribs on each side of it are confined to the edges of the valve. In *Rh. dentatum*, on the other hand, the mesial fold is strongly biciplicated nearly from the beak, while each lateral portion is furnished with three simple, slightly curved ribs, extending entirely from the beak to the margin. The 'zigzag filiform lines' which Hall describes in the American individuals are also distinguishable on the ribs of our specimen.

The American specimens appear to have rather sharper and more angular ribs than the Keisley form. This, however, is the only point of difference that I have been able to detect.

Davidson's *Rhynchonella decemplicata*,<sup>4</sup> from the Bala and Upper Llandovery beds, has more numerous ribs on the lateral portions, but otherwise, so far as external characters go, much resembles *Rhynchotrema dentatum*.

Length of shell .....	millim.
Breadth .....	4
	4

DAYIA PENTAGONALIS, sp. n. (Pl. VI. figs. 5, 5a, 5b, & 5c.)

Shell subpentagonal, broadest across the middle, biconvex. Hinge-line curved. No hinge-area. Pedicle-valve more convex than the brachial valve, especially near the beak; beak closely curved over the hinge-line, concealing foramen. Beak of pedicle-valve furnished with a longitudinal, broad, rounded keel; at about one-third the length of the valve a shallow median furrow begins on this keel or ridge, and extends to the front margin, increasing in width anteriorly and thus making a double keel on the anterior portion of the valve. The lateral portions of the valve on the slopes of the median keel are slightly excavated, and are bounded posteriorly on each side by a small narrow fold starting from the side of the beak and curving round in its outward course to the end of the hinge-line, so as to give the appearance of a false hinge-area between it and the hinge-line, as in some *Rhynchonellids*.

The brachial valve is more convex posteriorly than towards the front margin. A shallow groove begins close in front of the umbo, and extends forward, with a steadily increasing width and depth, to the anterior edge of the shell, where it has a smooth flattened floor with low, steep, and abrupt sides. The lateral portions of this valve are gently convex.

The anterior margin of the shell is broadly notched, owing to the meeting of the median sinuses of the opposite valves. In the umbonal cavity of the pedicle-valve are seen two short, divergent,

<sup>1</sup> 'Pal. N. Y.,' vol. i. (1847) p. 148, pl. xxxiii. fig. 14.

<sup>2</sup> *Ibid.* vol. viii. Brach. pt. ii. (1894) p. 182.

<sup>3</sup> 'Mon. Brit. Foss. Brach.,' vol. iii. (1864-71) p. 188, pl. xxiv. fig. 21.

<sup>4</sup> *Ibid.* p. 177, pl. xxiii. figs. 20-24.

dental plates; and a long, low, median septum or ridge extends for about two-thirds of the length of the brachial valve.

A brachidium with spiral cones of the type of *Dayia* is present, but its details have not been made out, owing to lack of material on which to experiment.

	millim.
Length of shell .....	8.5
Breadth „ .....	8.0

*Affinities.*—The extraordinarily close external resemblance of this species to Emmons's *Cyclospira bisulcata*<sup>1</sup> of the Trenton Limestone led me at first to the view that it must belong to the same genus. With the exception of the absence of the median fold in the sinus of the brachial valve, the resemblance appears to be complete. But on developing the interior of the shell I have been able to demonstrate that the brachidium is of the type of *Dayia navicula*, which is entirely different from the American genus *Cyclospira*, as Hall & Clarke have recently shown.<sup>3</sup>

I do not know whether Törnquist's species *Dayia pentagona* (MS.)<sup>4</sup> is synonymous, as no description or figure has been published. But the latter species is from the *Leptaena*-Limestone, and I have seen specimens of the form which I have above described from the same rock. There is a specimen of this shell from the Chair of Kildare Limestone, labelled *Atrypa navicula* (var.), in Sir R. Griffith's Collection in the Dublin Museum.

#### HYATTELLA PORTLOCKIANA (Davidson).

Davidson described this species more than 25 years ago from the Limestone of the Chair of Kildare,<sup>5</sup> and subsequently (in his Supplement to the Silurian Brachiopoda) from the Upper Llandeilo of Balclutchie, Girvan. The external characters of the shell were alone given, and it was assigned doubtfully to the genus *Rhynchonella*. Lindström<sup>6</sup> placed it in the genus *Athyris*, but does not mention his reasons for so doing. I have been able to expose the internal structure with some completeness, and to demonstrate the presence of spiral lamellæ, necessitating the removal of this species both from the genus *Rhynchonella* and from the genus *Athyris*.

There are two fairly distinct varieties of this species—a long one and a broad one. The elongated ovate form is that figured by Davidson; those illustrated by Lindström are rather broader and more globose, and pass into the transverse or broad variety. Inter-

<sup>1</sup> 'Geol. New York,' Rept. Second Distr. (1842) p. 395, fig. 4 (*Orthis bisulcata*); Hall, 'Pal. N. Y.,' vol. i. (1847) p. 139, pl. xxxiii. fig. 3 (*Atrypa bisulcata*); Hall & Clarke, *ibid.* vol. viii. Brach. pt. ii. (1894) p. 146 (*Cyclospira bisulcata*).

<sup>2</sup> Davidson, 'Mon. Brit. Foss. Brach.,' vol. iii. (1869) p. 190, pl. xxii. figs. 20-23; vol. v. Suppl. Sil. Brach. (1882) p. 96, pl. v. figs. 1-4.

<sup>3</sup> 'Pal. N. Y.,' vol. viii. Brach. pt. ii. (1894).

<sup>4</sup> E. Stolley, 'Die cambrischen u. silurischen Geschiebe Schleswig-Holsteins,' Archiv für Anthrop. u. Geol. Schl.-Holst., vol. i. pt. i. (1895) p. 88.

<sup>5</sup> 'Mon. Brit. Foss. Brach.,' vol. iii. (1869) p. 189, pl. xxiv. figs. 23-25; vol. v. Suppl. Sil. Brach. (1882) p. 159, pl. x. figs. 12-14.

<sup>6</sup> 'Fragm. Silur.' (1880) p. 22, pl. xiii. figs. 20-22.

nally, the characters of these varieties appear to be identical. The small subcircular, flattened forms which Davidson figures (*op. supra cit.* fig. 25), and which I have also found at Keisley, are probably only young individuals of the species. In these the median dorsal fold is more sharply defined posteriorly than in the other forms. The description of the species is as follows:—Shell longitudinally to transversely ovate, subglobose. Hinge-line curved. Cardinal angles rounded. Pedicle-valve the larger, with prominent beak incurved over the hinge-line; a weak median sinus is present in this valve—narrow near the beak, but increasing in width and depth anteriorly; a slight fold borders it on each side, and in some individuals a faint median ridge occurs in it. Brachial valve less convex than the ventral; beak small, and hidden beneath the incurved beak of the other valve. A low subquadrate fold with steep sides exists in this valve and corresponds to the sinus in the pedicle-valve; the fold is indistinct posteriorly in the adult and old individuals, but strongly developed on the anterior edge, where a deep sinus borders it on each side.

The surface of the valves is smooth, or decorated with very delicate radiating striæ (?).

A pair of short, subparallel, dental lamellæ is seen in the umbonal cavity of the pedicle-valve, and a strong muscular impression lies between them.

In the brachial valve a short septum exists, extending for about one-fifth of the length of the valve. The crural plates (seen in the course of developing one specimen) are triangular, and divided by a narrow deep median cleft exactly as figured in *Hyattella congesta* (Conr.).<sup>1</sup> The crura themselves are short, as in that species also. The primary lamellæ run forward with a steady divergence of from 25° to 30°, with no outward and only a slight upward curvature. The points and manner of attachment of these lamellæ have not been seen. They extend forward for more than two-thirds of the length of the valve, and then are coiled into the spiral cones. These cones consist of only four or five volutions, and form very loose coils. Their bases are subparallel to the longitudinal axis of the shell, and their apices are directed laterally and slightly backward and downward into the pedicle-valve.

The loop has not been satisfactorily or clearly exposed; but it seems to arise at a point about halfway along the primary lamellæ, and to make a very acute angle with them, running backward with an upward curvature. At the angle where its lateral branches unite a strong single median process—apparently tubular—is given off, and rises abruptly in an upward direction to the level of the primary lamellæ. The point of this process is seen as a central dot between them in grinding down the brachial valve.

	millim.	millim.
Length of shell .....	10	9
Breadth „ .....	15	8.5

<sup>1</sup> Hall & Clarke, 'Pal. N. Y.,' vol. viii. Brach. pt. ii. (1894) p. 61, pl. xl. figs. 23-28.

*Affinities.*—This species I would assign to the genus *Hyattella*, which Hall & Clarke have recently established (*loc. cit.*). In external characters *H. Portlockiana* agrees very closely with Conrad's *H. congesta* from the Clinton Group, and in its internal features the loose spiral coils, with their few volutions, position, and shape, the course of the primary lamellæ, the shape of the hinge-plate, with its narrow median cleft and short crura, the deep and striated pedicle-cavity in the pedicle-valve, with strong short dental plates, and the loop and process, so far as can be made out, are essentially similar. The chief points of difference are the presence of the short median septum in the brachial valve, and the greater length of the process of the loop.

This species (*H. Portlockiana*) is found in the *Leptæna*-Limestone in tolerable abundance.

#### POLYZOA.

*PTILODICTYA COSTELLATA*, M'Coy?

*PTILODICTYA RECTA*, Hall?

These two species are doubtfully recorded from Keisley.

*FENESTELLA ASSIMILIS*, Lonsdale.

Not very common.

#### MOLLUSCA.

##### Cephalopoda.

*ORTHO CERAS cf. SCABRIDUM* (Ang.).

Some fragmentary specimens from Keisley resemble this species of Angelin's<sup>1</sup> in their cylindrical shape, with a very slow rate of tapering, in the great distance apart of the septa (*i. e.* 1 to  $1\frac{1}{3}$  the diameter of the shell), in the deep cup-shape of the septa, in the central siphuncle, and, as far as can be seen, in the ornamentation of the surface of the shell.

*O. scabridum*, in Sweden, is found in the *Orthoceras*-Limestone.

Foord<sup>2</sup> mentions that, in addition to *O. cf. elongatocinctum* (Portl.), another species occurs in the Keisley Limestone, and he may be referring to *O. cf. scabridum*.

*ORTHO CERAS cf. ELONGATOCINCTUM* (Portl.).

Foord (*loc. cit.*) describes this species from Keisley, where it is the commonest *Orthoceras*, and in some parts of the limestone occurs in abundance almost to the exclusion of other fossils.

<sup>1</sup> Lindström, 'Fragm. Silur.' (1880) p. 4, pl. iv. figs. 6-9 & pl. vii. figs. 8-10.

<sup>2</sup> Quart. Journ. Geol. Soc. vol. xlvii. (1891) p. 526.

## Gasteropoda.

## LOXONEMA STRIATISSIMUM, Salter MS. (Pl. VI. fig. 6.)

Shell elongate, turriculate, consisting of nine or ten whorls. Apical angle about  $20^{\circ}$ . Whorls ventricose, about twice as broad as long, the successive whorls regularly decreasing in size towards the apex by one-third of their length and breadth. Upper whorls constricted just below the suture. The suture-line crosses the axis of the shell at an angle of about  $70^{\circ}$ . Surface of shell ornamented with fine longitudinal curved lines.

There are specimens of this shell from the Kildare Limestone, and it is one of these in the Jermyn Street Museum which bears the MS. name *L. striatissimum*. It was probably given by Salter. *L. sinuosum* (Sowerby)<sup>1</sup> is a closely-allied species, and so is *L. intumescens* (Lindström),<sup>2</sup> but they possess strongly-bent striae on the whorls. *L. dalecaricum* (Lindström),<sup>3</sup> of the *Leptæna*-Limestone, has whorls too globose and short to be considered identical with the Keisley form.

## HOLOPEA CONCINNA, M'Coy.

This species is found at Keisley, and is said to be very abundant at the Chair of Kildare.<sup>4</sup> There are specimens of it from the latter locality in Sir R. Griffith's Collection in the Dublin Museum.

## HOLOPEA STRIATELLA, Sowerby.

Casts of this species are not uncommon at Keisley. I have been unable to assign to it definitely any specimens from Kildare.

## CYCLONEMA RUPESTRE, Eichwald.

This species is found at Kildare, and I have seen a portion of a single shell from Keisley in the Carlisle Museum, where it was labelled *Holopea concinna*. It is not recorded from the *Leptæna*-Limestone, but Schmidt<sup>5</sup> gives it as *Trochus rupestris* in his list of fossils from the Lyckholm-bed (Stage F).

## CYCLONEMA SULCIFERUM, Eichw.

Of this shell I have seen only one imperfect specimen from Keisley. It occurs in the Kildare Limestone, and in the *Orthoceras*-Limestone of Esthonia.

## EUNEMA CARINATUM, Lindström, var.

The only point of difference between a specimen from Keisley and that figured by Lindström<sup>6</sup> from the *Leptæna*-Limestone is

<sup>1</sup> 'Sil. Syst.' pt. i. (1839) p. 619, pl. viii. fig. 15 (*Terebra*).

<sup>2</sup> 'Sil. Gastrop., etc. Gotland,' K. Svensk. Vetensk. Akad. Handl. vol. xix. (1884) no. 6, p. 143, pl. xv. fig. 6.

<sup>3</sup> 'Fragm. Silur.' (1880) p. 14, pl. xv. fig. 19.

<sup>4</sup> M'Coy, 'Syn. Sil. Foss. Irel.' Dublin, 1846, p. 13, pl. i. fig. 10.

<sup>5</sup> 'Rev. ostbalt. silur. Trilob.,' pt. i. Mém. Acad. Impér. d. Sci. St. Pétersbourg, ser. 7, vol. xxx. (1881) no. 1, p. 38.

<sup>6</sup> *Op. jam cit.* p. 14, pl. xv. fig. 20.

that the apical angle is rather larger, giving consequently a broader and shorter form to the shell. The seven ventricose whorls furnished with three revolving carinæ are apparently quite similar to those in the Dalecarlian individuals.

*EUOMPHALUS cf. OBTUSANGULUS*, Lindström.

There are several small specimens of an *Euomphalus* in the state of casts, which may well be compared with Lindström's species *E. obtusangulus*,<sup>1</sup> but they are not sufficiently well preserved to admit of any positive statement as to their specific identity. *E. obtusangulus* is a *Leptæna*-Limestone species.

*EUOMPHALUS NITIDULUS*, Lindström ?

I have little doubt that the fossil which is here referred with a query to Lindström's<sup>2</sup> species from the *Leptæna*-Limestone will ultimately be found really identical with it. It appears very similar to Billings's *Straparollus Hippolyta*.<sup>3</sup>

*EUOMPHALUS SUBSULCATUS* (His.) ?

There is a portion of a shell in the Carlisle Museum which may belong to this species, quoted by M'Coy<sup>4</sup> as common in the Chair of Kildare Limestone. The fragment that I have seen is merely part of a shell coiled in a flat spiral, with several carinæ running round the whorls.

*PLATYCERAS VERISIMILE*, sp. n. (Pl. VI. figs. 7, 7 a, & 7 b.)

Shell neritiform, transverse, about twice as broad as high; spire low and short; of three or four whorls rapidly decreasing in size. Body-whorl very large, twice as broad as high, and nearly three times as large as the succeeding whorl. Suture only slightly impressed. Surface of shell ornamented with fine longitudinal lines which are rather irregular in size and very slightly sigmoidal.

This species much resembles the Swedish form *Pl. caniculatum* (Lindström),<sup>5</sup> but its sutural line is not so deeply impressed nor is its body-whorl so long. The mouth of the shell is not preserved. The ornamentation is different from that of *Pl. cornutum* (Hisinger),<sup>6</sup> which it otherwise resembles. The American species *Platyostoma niagarensis*<sup>7</sup> appears to show much the same characters.

*PLATYCERAS cf. CORNUTUM*, Hisinger.

This very variable species is held to be synonymous with *Natica parva* (Sowerby), and with several other British species. Our specimen resembles most closely the species of Sowerby's just

<sup>1</sup> 'Fragm. Silur.' (1880) p. 12, pl. xvii. figs. 19-20.

<sup>2</sup> *Ibid.* p. 12, pl. xv. figs. 24-26.

<sup>3</sup> 'Geol. of Canada: Palæoz. Foss.,' vol. i. p. 160, fig. 144.

<sup>4</sup> 'Syn. Silur. Foss. Irel.' (1846) p. 14.

<sup>5</sup> *Op. jam cit.* pl. xvii. figs. 13-16.

<sup>6</sup> 'Lethæa Suecica,' (1837) p. 41, pl. xii. fig. 11 (*Pileopsis cornuta*).

<sup>7</sup> Hall, 'Pal. N.Y.,' vol. ii. (1852) p. 287, pl. lx. figs. 1 a-v.

mentioned. The ornamentation, so far as can be made out, consists of fine, longitudinal, sigmoidally-curved lines, with some faint continuous transverse lines running round the whorls, and better marked near the middle of the whorls.

#### PLEUROTOMARIA NOTABILIS, Eichwald ?

An internal cast of a *Pleurotomaria* appears to me to be referable to this Russian species described and figured by Eichwald.<sup>1</sup> The shell itself has not been figured or described, and the casts of species of *Pleurotomaria* are always somewhat unsatisfactory and difficult of identification. *Pl. notabilis* occurs in the Borkholm Limestone.

#### MURCHISONIA, sp. n. ? (Pl. VI. figs. 8 & 8 a.)

The cast of a small gasteropod from Keisley appears to belong to the genus *Murchisonia*, though some of the tall species of *Pleurotomaria* are not unlike it. It is a turriculate shell of six convex whorls, with an apical angle of 30°. Each whorl is very short, being less than half as long as broad. This gives a peculiar compressed appearance to the shell. The suture-line is almost at right angles to the axis. A faint, narrow, spiral band can be detected running round rather below the middle of the whorls. I am not acquainted with any species showing the above characters, and believe that this specimen belongs to a new species. Its length is 7 millim., and across the basal whorl the breadth is 4.5 millim.

### Pteropoda.

#### CONULARIA, sp.

A solitary specimen of *Conularia* in the Carlisle Museum has the following characters:—Shell short, triangular, rapidly tapering to the apex, with sides converging at an angle of about 50°. Surface with a median depression, and ornamented with simple, transverse, parallel raised lines, slightly sinuated in the middle, and more than their thickness apart. Length=3 millim.; width at front end=2.5 millim.

Harkness<sup>2</sup> records *Conularia elongata* (Portlock<sup>3</sup>) from the Keisley Limestone, and this specimen, to which I hesitate to give a specific name, is thus labelled. The ornamentation is certainly very similar, though I was not able to distinguish the fine longitudinal lines which Portlock figures. Portlock says of his species that it is 'characterized by the very gradual decrease in its thickness,' whereas our specimen is characterized by the very rapid decrease in its thickness, so as to resemble in shape Hall's species *C. trentonensis*.<sup>4</sup> For these reasons, I cannot hold that the identifi-

<sup>1</sup> 'Lethæa Rossica,' vol. i. (1860-61) p. 1170, pl. xlv. figs. 22 a-d.

<sup>2</sup> Quart. Journ. Geol. Soc. vol. xxi. (1865) p. 249.

<sup>3</sup> 'Rep. Geol. Londonderry' (1843), p. 393, pl. xxix a. fig. 2.

<sup>4</sup> 'Pal. N.Y.,' vol. i. (1847) p. 222, pl. lviii. fig. 4.

cation of our specimen with *C. elongata* is correct. It does not appear to agree with any of Holm's Swedish species.<sup>1</sup>

#### HYOLITHUS TRIANGULARIS ? (Portl.).

Prof. Harkness recorded this species from Keisley, and a specimen so labelled is in the Carlisle Museum. I am doubtful as to the correctness of this identification, for the rate of tapering of this specimen is more rapid, and, unless we regard it as the broken pointed end of the shell, it is a much shorter form than that figured by Portlock<sup>2</sup> and in Murchison's 'Siluria.'<sup>3</sup>

### Lamellibranchiata.

#### PTERINÆA SUBFALCATA, Conrad, var.

Shell obliquely oval, subfalcate, narrow, strongly convex; umbo gibbous, acute, projecting above hinge-line. Surface ornamented with regular, simple, radiating, straight, fine ribs, of which the anterior ones are slightly curved forward. Anterior ear small, flat, triangular, sharply marked off from the body of the shell, striated. Posterior wing not preserved, but apparently as abruptly defined from the body of the shell as the anterior ear.

	millim.
Length of shell (obliquely measured) .....	10·5
Width of same across middle .....	7·0

This shell, which is in the Carlisle Museum, was labelled, apparently by Harkness, as *Pterinæa tenuistriata*; its shape and ornamentation are, however, completely different. It differs from typical specimens of *Pt. subfalcata* (Conrad)<sup>4</sup> only by the absence of the concentric striae. The type-form of the species occurs in the Upper Ludlow.

#### ANODONTOPSIS, sp. (Pl. VI. figs. 9 & 9 a.)

Shell small, subcircular, gently convex, most convex near the beak; hinge-line slightly curved; beak near the anterior end, directed forward. The beak rises steeply above a small flattened portion immediately in front of it. No muscular scars or pallial line visible. Length 4·5 millim.

M'Coy's *Anodontopsis bulla*<sup>5</sup> appears to bear resemblance to this Keisley form, but it is with some hesitation that I refer the latter to the same genus, since it hardly shows sufficient structural features

<sup>1</sup> 'Sveriges Kambr. Silur. Hyolithidæ o. Conulariidæ,' Sver. Geol. Undersökn. ser. c. no. 112 (1893).

<sup>2</sup> 'Rep. Geol. Londond.' (1843) p. 375, pl. xxviii. A, figs. 3 a-c.

<sup>3</sup> 5th ed. p. 199, Foss. 41, fig. 2.

<sup>4</sup> M'Coy, 'Syst. Descr. Brit. Pal. Foss.' (1855) p. 263, pl. i. 1, fig. 3.

<sup>5</sup> *Ibid.* p. 271, pl. i. κ, figs. 11-13.

to allow of one's feeling sure of its affinities. Murchison's species *Lucina* ? *Hisingeri*,<sup>1</sup> from Gotland, also bears comparison with our form.

#### MODIOLOPSIS ?, sp.

Harkness recorded *Modiolopsis Nerei* (Münster) from Keisley.<sup>2</sup> There is a specimen in the Woodwardian Museum with that name attached to it, but it is a mere fragment, and, in addition to feeling sure that this identification is erroneous, I have grave doubts even about the genus to which it should be referred. The anterior portion of a left (?) valve, probably of a circular shape when perfect, with a small inconspicuous beak some distance from the anterior (?) border of the shell, with the surface ornamented with concentric striæ—these are all the characters visible, and they are quite inadequate for identification.

### ECHINODERMATA.

#### Cystidea.

##### SPHÆRONITES PYRIFORMIS (Forbes).

Forbes describes this species as *Caryocystites pyriformis*<sup>3</sup> from the Chair of Kildare, but none of his specimens showed the arrangement of the plates. Our specimen, though imperfect, shows distinctly five tiers of large pentagonal or hexagonal plates somewhat irregularly arranged, but it is too incomplete to allow of any certainty as to the number or position of the plates in each tier. There are, however, five basal plates to be made out, and these with three lateral tiers and the summit-plates compose the test. The length of our specimen is about 18 millim.

The species has also been recorded from Rhiwlas.<sup>4</sup>

#### Crinoidea.

Only portions of the stems of various crinoids<sup>5</sup> have so far been found in the Keisley Limestone. Consequently, it is impossible with this unsatisfactory material to determine the genera and species; as there are, however, several well-marked types of stems which

<sup>1</sup> Quart. Journ. Geol. Soc. vol. iii. (1847) p. 24, woodcut; F. Römer, 'Leth. Errat.', p. 87, pl. vi. fig. 7, & p. 101, pl. viii. fig. 2 (Palæont. Abhandl. ii. 1885).

<sup>2</sup> Quart. Journ. Geol. Soc. vol. xxi. (1865) p. 249.

<sup>3</sup> Mem. Geol. Surv. vol. ii. pt. ii. (1848) p. 515, pl. xxi. fig. 1.

<sup>4</sup> *Ibid.* vol. iii. 2nd ed. (1881) p. 476.

<sup>5</sup> Holm mentions crinoidal remains from the *Leptæna*-Limestone, Sver. Geol. Undersökn., ser. c, no. 115, pp. 14, 15 (Stockholm, 1890).

may at some future date be found associated with the calices, a brief description of them will be useful.

One type ( $\alpha$ ) consists of thin circular ossicles furnished with a strong rounded projecting ridge on the periphery, occupying rather more than one-third of the width.

Another common type ( $\beta$ ) is composed of large, plain, smooth ossicles, unornamented, and all of equal size, forming a regular, smooth, cylindrical column.

Yet another type ( $\gamma$ ) is quadrangular in section, and composed of alternating thick and thin ossicles with a large central canal.

A fourth type ( $\delta$ ) consists of circular ossicles, with a thickness of about one-fourth of the diameter of the stem, and all of the same size. A narrow, smooth, marginal ring surrounds the front edge, and a series of fine concentric lines with a single median circlet of tubercles adorn the rest of the periphery. There is a large central canal, with the margins radially striated.

Another type ( $\epsilon$ ) is composed of circular thick ossicles of equal size, with a rounded periphery ornamented with eight or nine longitudinally-elongated tubercles. The central canal is very small.

A sixth type ( $\zeta$ ) of stem shows a pentagonal section with a central canal of about one-fourth the diameter of the stem. And finally there is another type ( $\eta$ ), which has a circular section, and is composed of thin ossicles ornamented with encircling threads swelling into irregularly-disposed low tubercles.

## ACTINOZOA.

### STREPTELASMA EUROPÆUM, F. Römer.

This species seems to be the commonest coral at Keisley. It occurs also in the Borkholm<sup>1</sup> and Lyckholm zones,<sup>2</sup> in the Sadewitz drift-pebbles,<sup>3</sup> and is common in the Craighead Limestone.<sup>4</sup>

### HALYSITES CATENULARIA, L.

In England this species ranges from the Bala to the Silurian. I have seen only one specimen from Keisley. It occurs also in the Kildare Limestone, in the *Leptæna*-Limestone, and in the Lyckholm zone.<sup>5</sup>

<sup>1</sup> W. Weissermel, 'Die Korallen d. Silurgesch. Ostpreuss.,' Zeitschr. d. Deutsch. geol. Gesellsch. vol. xlv. (1894) p. 580.

<sup>2</sup> Fr. Schmidt, 'Rev. d. ostbalt. Silur. Trilob.,' pt. i. Mém. Acad. Imp. des Sci. St. Pétersbourg, ser. 7, vol. xxx. (1881) no. 1, p. 38.

<sup>3</sup> F. Römer, 'Die foss. Fauna d. Silur. diluv. Gesch. v. Sadewitz,' Breslau, 1861, p. 16, pl. iv. fig. 1.

<sup>4</sup> Nicholson & Etheridge, 'Mon. Silur. Foss. Girvan,' 1878, p. 76, pl. vi. figs. 1, 1 b.

<sup>5</sup> Weissermel, *op. supra cit.* p. 661.

**HELIOLITES DUBIA**, Schmidt?

As far as one can judge from the external aspect, size, and arrangement of the corallites in a small fragment of a corallum, this species occurs at Keisley. Schmidt<sup>1</sup> describes it from the Lyckholm Beds, Lindström<sup>2</sup> from the *Leptæna*-Limestone, F. Römer<sup>3</sup> from the Sadewitz pebbles,<sup>3</sup> and Weissermel<sup>4</sup> from those of Rosenberg.

**STENOPORA FIBROSA**, Goldf.

This species is of common occurrence at Keisley and Kildare.

**FAVOSITES ALVEOLARIS**, Goldf., *pars*.

The Geological Survey of Ireland record this species from the Chair of Kildare, and it may be identical with the variety of the allied *F. aspera* said by Schmidt to occur in the Borkholm zone. *F. aspera*<sup>5</sup> has smaller corallites with greater irregularity of size.

**PRASOPORA GRAYÆ**, Nich. & Eth.

Prof. H. A. Nicholson, to whom I am indebted for kind assistance in this group of organisms, informs me that he has found this species at Keisley. In his work 'Palæozoic Tabulate Corals,' he says (p. 327): 'The only known species of *Prasopora* [i.e. *Pr. Grayæ*] occurs commonly in the Craighead Limestone (Lower Silurian) of Craighead, near Girvan, Ayrshire.'

*Note.*—In addition to the above-mentioned species, there are several indeterminable zaphrentoid corals and monticuliporoids in the Keisley Limestone. Harkness recorded *Nebulipora lens* from this rock, but the specimen thus labelled in the Carlisle Museum is very indistinct and doubtful.

<sup>1</sup> 'Untersuch. üb. d. Silur. Form. Ehstland, etc.' (1858) p. 228.

<sup>2</sup> 'Fragm. Silur.' (1880) p. 32, pl. i. figs. 1-4.

<sup>3</sup> 'Die foss. Fauna d. Silur. diluv. Gesch. v. Sadewitz' (1861), p. 26, pl. iv. fig. 5.

<sup>4</sup> Zeitschr. d. Deutsch. geol. Gesellsch. vol. xlv. (1894) p. 666 & pl. liii. fig. 4.

<sup>5</sup> Edwards & Haime, 'Brit. Foss. Corals,' Monogr. Pal. Soc. (1850-1855) p. 257, pl. lx. figs. 3 & 3a.

## LIST OF FOSSILS FROM THE KEISLEY LIMESTONE

(showing also the species occurring in the Kildare Limestone, etc.).

GENERA AND SPECIES.	Kildare Limestone.	Leptana Limestone.	Stage F.	
			Borkholm Zone.	Lycckholm Zone.
TRILOBITA.				
<i>Agnostus</i> cf. <i>galba</i> , Billings .....				
<i>Ampyx</i> <i>binodulosus</i> , n. sp. ....				
<i>Tiresias</i> <i>insculptus</i> , M'Coy .....	*			
<i>Remopleurides</i> <i>Colbi</i> , Portlock .....				
" <i>longicostatus</i> , Portlock .....	*			
<i>Cyphoniscus</i> <i>socialis</i> , Salter .....	*			
<i>Calymene</i> <i>Blumenbachi</i> , var. <i>Caractaci</i> , Salter .....				
<i>Homalonotus</i> ? <i>punctiliosus</i> , Törnquist .....	*	*		
<i>Illenus</i> <i>Bowmani</i> , Salter .....	*			
"    "    var. <i>brevicapitatus</i> .....	*			
"    "    var. <i>longicapitatus</i> .....	*			
" <i>fallax</i> , Holm .....	*	*		
" <i>Ræmeri</i> , Volborth .....	?	*	*	*
" <i>cæcus</i> , Holm .....	?	...	...	*
" <i>galeatus</i> , sp. n. ....	*			
"    sp. (hypostome) .....	*			
<i>Cheirurus</i> <i>bimucronatus</i> , Murchison .....	*			
" <i>cancrurus</i> , Salter .....	*			
" <i>keisleyensis</i> , sp. n. ....	*			
"    cf. <i>glaber</i> , Angelin .....	?	*	...	*
?    "    cf. <i>clavifrons</i> , Dalman .....	*	*	*	*
"    ( <i>Pseudosphærexochus</i> ) <i>conformis</i> , Angelin .....	*	*	*	*
"    " <i>subquadratus</i> , sp. n. ....	?			
? <i>Sphærocoryphe</i> <i>granulata</i> , Angelin .....	?	*	?	
<i>Sphærexochus</i> <i>mirus</i> , Beyrich .....	*	*	*	*
" <i>latirugatus</i> , sp. n. ....	*			
<i>Staurocephalus</i> <i>Murchisoni</i> , Barrande .....	*			
<i>Acidaspis</i> <i>convexa</i> , sp. n. ....				
"    sp. ....				
<i>Lichas</i> <i>affinis</i> , Angelin .....	...	*		
" <i>bifurcatus</i> , n. sp. ....	?			
" <i>bulbiceps</i> , Phillips MS. ....	*			
" <i>conformis</i> , Ang. ....	...	*		
"    "    var. <i>keisleyensis</i> .....	*			
" <i>hibernicus</i> , Portlock .....	*			
" <i>laxatus</i> , M'Coy .....	*	*		
<i>Cyphaspis</i> ? <i>Harknessi</i> , sp. n. ....				
"    ( <i>Törnquistia</i> ) <i>Nicholsoni</i> , sp. n. ....	*			
<i>Phillipsinella</i> <i>parabola</i> , Barrande .....				
<i>Harpes</i> <i>Wegelini</i> , Angelin .....	*	*		
?    " <i>costatus</i> , Angelin .....	...	*		
"    sp. <i>α</i> .....				
"    sp. <i>β</i> .....				

## LIST OF FOSSILS (continued).

GENERA AND SPECIES.	Kildare Limestone.	Leptena- Limestone.	Stage F.	
			Borkholm Zone.	Lychholm Zone.
OSTRACODA.				
<i>Primitia M'Coyi</i> , Salter .....	*			
<i>Cythere Wrightiana</i> , Jones .....	*			
BRACHIOPODA.				
<i>Orthis calligramma</i> , Dalman .....	*	*		
"          "          var. ....	*			
" <i>Actoniae</i> , Sowerby .....	*	*	...	*
" <i>vespertilio</i> , Sowerby .....	*			
"    ( <i>Bilobites</i> ) <i>biloba</i> , Linné .....	...	*		
"    ( <i>Platystrophia</i> ) <i>biforata</i> , Schlotheim .....	*	*	*	*
"    ( <i>Dalmanella</i> ) <i>testudinaria</i> , Dalman .....	?			
"    ( ? " ) <i>cf. conferta</i> , Lindström .....	...	*		
"    ( ? " ) <i>cf. argentea</i> , Hisinger .....				
"    ( ? " ) <i>elegantula</i> , Dalman .....				
? "    ( <i>Heterorthis</i> ) <i>alternata</i> , Sowerby .....	*			
? "    ( <i>Dinorthis</i> ) <i>flabellulum</i> , Sowerby .....	*			
"    (? <i>Hebertella</i> ) <i>keisleyensis</i> , sp. n. ....				
"    2 spp. indet. ....				
<i>Strophomena antiquata</i> , Sowerby .....	*			
" <i>corrugatella</i> , Davidson .....	*	*		
<i>Leptæna rhomboidalis</i> , Wilckens .....	*	*		
<i>Rafinesquina expansa</i> , Sowerby .....	*	...	*	
" <i>deltoidea</i> .....	?	...	*	*
"    "    var. <i>undata</i> , M'Coy .....	*	?		
<i>Plectambonites quinquecostata</i> , M'Coy .....	*	*		
" <i>Schmidti</i> , Törnquist .....	...	*	*	*
? " <i>transversalis</i> , Wahlenberg .....	?			
<i>Atrypa marginalis</i> , Dalman .....	*			
" <i>expansa</i> , Lindström .....	*	*		
"    "    var. <i>α</i> .....				
"    "    var. <i>β</i> .....				
"    "    var. <i>γ</i> .....				
<i>Atrypina similis</i> , sp. n. ....				
<i>Christiania tenuicincta</i> , M'Coy .....	*			
<i>Streptis monilifera</i> , M'Coy .....	*			
<i>Triplecia insularis</i> , Eichwald .....	*	...	...	*
<i>Rhynchotrema cf. dentatum</i> , Hall .....				
<i>Syntrophia affinis</i> , sp. n. ....				
<i>Camerella</i> ? <i>Thomsoni</i> , Davidson .....				
<i>Hyattella Portlockiana</i> , Davidson .....	*	*		
<i>Dayia pentagonalis</i> , sp. n. ....	*	*		
<i>Obolella cf. nitens</i> , Hisinger .....				
<i>Orbiculoidea</i> , 2 spp. ....				
? <i>Lingula</i> , sp. ....				

LIST OF FOSSILS (*continued*).

GENERA AND SPECIES.	Kildare Limestone.	Leptena- Limestone.	Stage F.	
			Borkholm Zone.	Ljckholm Zone.
POLYZOA.				
<i>Ptilodictya costellata</i> , M'Coy? .....	..	..	*	
" <i>recta</i> , Hall? .....	*			
<i>Fenestella assimilis</i> , Lonsdale .....	*			
MOLLUSCA.				
<i>Orthoceras</i> cf. <i>elongatocinctum</i> , Portlock .....				
"    cf. <i>scabridum</i> , Angelin .....				
<i>Loxonema striatissimum</i> , Salter MS. ....	*			
<i>Holopea concinna</i> , M'Coy .....	*			
" <i>striatella</i> , Sowerby .....				
<i>Cyclonema rupestre</i> , Eichwald .....	*	..	*	?
" <i>sulciferum</i> , Eichwald .....	*			
<i>Eunema carinatum</i> , Lindström, var. ....		*		
<i>Euomphalus</i> cf. <i>obtusangulus</i> , Lindström .....		*		
? " <i>subsulcatus</i> , Hisinger .....	*	*		
? " <i>nitidulus</i> , Lindström .....		*		
<i>Platyceras verisimile</i> , sp. n. ....				
"    cf. <i>cornutum</i> , Hisinger .....				
? <i>Pleurotomaria notabilis</i> , Eichwald .....	..	..	*	
<i>Murchisonia</i> , sp.? .....				
<i>Conularia</i> , sp. ....	*			
? <i>Hyolithus triangularis</i> , Portlock .....				
<i>Pterinea subfalcata</i> , Conrad, var. ....				
<i>Anodontopsis</i> , sp. ....				
<i>Modiolopsis</i> , sp.? .....				
ECHINODERMATA.				
<i>Sphaeronites pyriformis</i> , Forbes .....	*			
Crinoid stems, 6 spp. ....				
ACTINOZOA.				
<i>Streptelasma europæum</i> , Römer .....	..	..	..	*
<i>Halysites catenularia</i> , Linné .....	*	*	..	*
? <i>Heliolites dubia</i> , Schmidt .....		*	..	*
<i>Stenopora fibrosa</i> , Goldfuss .....	*			
<i>Favosites alveolaris</i> , Goldfuss, <i>pars</i> .....	*			
<i>Prasopora Grayæ</i> , Nicholson & Etheridge .....				
? <i>Nebulipora lens</i> , M'Coy .....				

## GENERAL REMARKS ON THE FAUNA OF THE KEISLEY LIMESTONE.

I. TRILOBITA.—The Trilobita are unmistakably the predominant members of the assemblage of organisms which we meet with in the Keisley Limestone. Not only in the number and variety of the genera and species do they far exceed other groups, but also in the number of individuals. Yet all the genera are not equal in this latter respect, nor are the species. The *Illæni* are the most common of all the trilobites, and large slabs covered with the head-shields and pygidia of *I. Bowmani* and its varieties are of frequent occurrence. *I. galeatus* is the next most common species of *Illænus*, while *I. Rœmeri*, *I. fallax*, and *I. cæcus* are very rare.

Next in order of abundance come the genera of Cheiruridæ, and in species and individuals they hold the same place. The species of *Pseudosphærewochus* and of *Sphærewochus* are represented by numerous individuals. The genus *Lichas* has at least six species belonging to it in this rock, but the individuals are not numerous. *Cyphoniscus socialis* is fairly abundant. From the failure of many observers and collectors to find such trilobites as *Staurocephalus Murchisoni*, of which I have myself collected at least a dozen specimens in a few hours, I believe the occurrence of such forms is sporadic or limited to special bands in the rock. It should be remembered that the great majority of the fossils recorded have been collected from loose blocks in the adjacent stone walls, or hammered out of detached masses lying on the surface of the ground. Many of those which I found were obtained from the remains of an old lime-kiln close to the large quarry, but others were chipped out of the outcropping solid rock.

The peculiar features of the trilobitic fauna are:—(1) The absence of the genera *Phacops* and *Trinucleus*. Both these genera are so abundant in the Bala rocks of all areas, and are represented by species so characteristic, that their entire absence is very striking. In the *Staurocephalus*-Limestone and Ashgill Shales, as well as in the underlying Middle Bala, we find them making a marked feature in the fauna. The genera *Trinucleus* and *Phacops* are practically absent from the Chair of Kildare Limestone<sup>1</sup> and the *Leptæna*-Limestone. *Trinucleus* is very rare in the Russian Stage F,<sup>2</sup> and till recently was thought not to occur there. (2) The occurrence of certain peculiar genera of very limited range in time and space, as, for example, *Cyphoniscus* and *Tiresias*. (3) The occurrence of many peculiar species limited either entirely to this Keisley bed, or to it and the Chair of Kildare Limestone, or to both these beds and the *Leptæna*-Limestone of Dalecarlia, or to the Keisley and Dalecarlian beds, or to one of these beds and Stage F of the East Baltic provinces of Russia.

<sup>1</sup> Quite recently Mr. C. I. Gardiner, F.G.S., has shown me an eye of a *Phacops* and a fragment of a *Trinucleus*—possibly *Tr. seticornis* (His.)—from the Kildare Limestone; but these are the only specimens I know.

<sup>2</sup> Fr. Schmidt, 'Rev. ostbalt. Silur. Trilob.', pt. iv. Mém. Acad. Imp. des Sci. St. Pétersbourg, ser. 7, vol. xlii. (1894) no. 5, p. 71.

It will be seen on examining the list of fossils tabulated on p. 85 that, out of the total number of 40 species of trilobites in the Keisley Limestone, 20 are definitely known to occur in the Kildare Limestone, and 6 others are doubtfully recorded.

The following species also, so far as is known, are absolutely peculiar to these two limestones:—*Cheirurus keisleyensis*, *Ch. canerurus*, *Sphærexochus latirugatus*, *Lichas bulbiceps*, *Tiresias insculptus*, *Cyphaspis* (*Törnquistia*) *Nicholsoni*, and *Cyphoniscus socialis*.

In the *Leptaena*-Limestone 10 or perhaps 12 of the Keisley species are found, and in the Borkholm and Lyckholm zones 3 (or 4) and 6 have respectively been recorded. Only a very poor list of the fauna of the Borkholm zone is obtainable,<sup>1</sup> or probably the number of common species would have to be increased. Moreover, if we take into account the closely-allied but not identical species of these beds, the similarity of the trilobitic faunas is still more marked. Thus *Cheirurus bimucronatus* and *Ch. keisleyensis* are allied to *Ch. insignis* and *Ch. speciosus* of the *Leptaena*-Limestone; *Ch. (Ps.) subquadratus* to *Ch. (Ps.) Roemeri* of the Borkholm and Lyckholm zones; *Lichas bifurcatus* to *L. margaritifera* of the *Leptaena*-Limestone and Borkholm zone; *Acidaspis convexa* to *A. evoluta* of the *Leptaena*-Limestone; and *Illænus Bowmani* to *I. Linnarssoni*, of the *Leptaena*-Limestone and the Borkholm and Lyckholm zones.<sup>2</sup>

The occurrence of many peculiar species of trilobites is very noticeable. *Cheirurus* (*Pseudosphærexochus*) *conformis* occurs in the above-mentioned beds in each area, and it might well be taken as the zone-fossil of this horizon.

The following species which are found at Keisley also are markedly characteristic of, or limited to, the *Leptaena*-Limestone, and therefore deserve special notice:—*Cheirurus glaber*, *Ch. (Pseudosphærexochus) conformis*, *Sphærocoryphe granulata* (? Keisley), *Harpes Wegelini*, *H. costatus* (? Keisley), *Homalonotus? punctillosus*, *Illænus fallax*, and *I. Roemeri*.

The following species have been so far found only at Keisley; although two of them are doubtfully recorded from Kildare:—

*Cheirurus (Pseudosphærexochus) subquadratus* (? Kildare), *Lichas bifurcatus* (? Kildare), *Cyphaspis? Harknessi*, *Ampyx binodulosus*, *Acidaspis convexa*, and *Illænus galeatus*.

Turning now to the question of the degree of relationship of the trilobitic fauna of Keisley to that of the Middle and Upper Bala of Great Britain, we find the following species occurring in Middle Bala rocks:—*Cheirurus bimucronatus*, *Ch. clavifrons*, Dalm.?,

<sup>1</sup> Schmidt, 'Rev. ostbalt. Silur. Trilob.' pt. i. Mém. Acad. Imp. des Sci. St. Pétersbourg, ser. 7, vol. xxx. (1881) no. 1, p. 38; and Quart. Journ. Geol. Soc. vol. xxxviii. (1882) p. 514.

<sup>2</sup> Several of the Kildare trilobites, not hitherto found at Keisley, occur in Stage F of the Baltic provinces, thus linking these widely-separated beds more closely together; see S. H. Reynolds & C. I. Gardiner on 'The Kildare Inlier,' Quart. Journ. Geol. Soc. vol. lii. (1896) p. 587.

*Calymene Blumenbachi*, var. *Caractaci*, *Sphærexochus mirus*, *Ilænus Bowmani*, *Lichas laxatus*.

In the Upper Bala beds the following Keisley species are found:—*Cheirurus bimucronatus*, *Ch. clavifrons*, (?) *Sphærexochus mirus*, *Lichas laxatus*, *Ilænus Bowmani*, \**Remopleurides longicostatus*, \**Phillipsinella parabola*, *Staurocephalus Murchisoni*, and *Calymene Blumenbachi*.

Of these the two species marked \* are in Britain known only in the Upper Bala (excepting, of course the Kildare and Keisley Limestones). *Ch. bimucronatus*, *Sph. mirus*, *C. Blumenbachi*, and *St. Murchisoni* pass up into the Silurian. *Lichas hibernicus*, curiously enough, occurs elsewhere only in the Craighead Limestone of Scotland. *I. Bowmani* and *Sph. mirus* also occur in the Scottish Lower Bala.<sup>1</sup>

Thus, of the 10 species found in other British rocks, 3 occur in the Lower Bala, 6 in the Middle Bala, 9 in the Upper Bala, and 4 pass up into the Silurian. But in spite of this apparent great resemblance to the Upper Bala, we must remember that the absence of all species of *Trinucleus* and *Phacops*, especially *Tr. seticornis* and *Ph. eucentra*, characteristic forms of the Upper Bala,<sup>2</sup> marks an important difference.

Summing up, we obtain the following percentage results with respect to the species of trilobites from Keisley:—

- (i) 50 % occur in the Kildare Limestone.
- (ii) 25 % occur in the *Leptæna*-Limestone.
- (iii) 25 % occur in British Bala or Silurian beds, and of these about 99 % occur in Upper Bala beds.
- (iv) Over 70 % occur in no other British bed.
- (v) About 16 % are peculiar to the Keisley Limestone.

The peculiarity of the trilobitic fauna of this bed is thus plainly shown.

II. OSTRACODA.—Both the Keisley species occur at Kildare, and these are the only two localities in which one form (*Cythere Wrightiana*) is known to occur, while *Primitia M' Coyi*, the other species, is known elsewhere from the limestone of Aldeans on the Stinchar River.<sup>3</sup>

III. BRACHIOPODA.—The foregoing list of the fossils of the Keisley Limestone shows (p. 86) that out of the 37 species of brachiopoda, 19—or over 50 %—are also found at Kildare, and several others probably occur. In the *Leptæna*-Limestone<sup>4</sup> 12 of

<sup>1</sup> Nicholson & Etheridge, 'Mon. Silur. Foss. Girv.' 1879; Lapworth, Quart. Journ. Geol. Soc. vol. xxxviii. (1882) p. 537.

<sup>2</sup> Marr & Roberts, Quart. Journ. Geol. Soc. vol. xli. (1885) p. 476.

<sup>3</sup> Ann. Mag. Nat. Hist. ser. 4, vol. ii. (1868) p. 56.

<sup>4</sup> In the case of the *Leptæna*-Limestone I have made use of the specimens in the Woodwardian Museum, Törnquist's list in 'Öfvers. ö. Bergbygn. in Siljans. i Dal.' p. 26, Sveriges Geol. Undersökn. ser. c, no. 57, and the 'List of the Fossil Faunas of Sweden,' published by the Stockholm Museum in 1888.

the Keisley species, or over 30 % of the whole number of Keisley brachiopoda, have been recognized.

Schmidt mentions only 11 species of brachiopoda from the Lyckholm zone,<sup>1</sup> but of these 5 occur at Keisley. Out of the 10 species mentioned by him (*loc. cit.*) from the Borkholm zone, 4 occur at Keisley. Other species allied to British forms are recorded by him from these rocks. Thus we see that there is a considerable degree of similarity in the brachiopodal faunas.

*Atrypa expansa* and *Orthis conferta* appear confined to this horizon as represented at Keisley, the Chair of Kildare, Dalecarlia, and Western Russia. *Plectambonites Schmidtii* is highly characteristic of it, though also known from the *Trinucleus*-shales of Sweden, while *Hyattella Portlockiana* has elsewhere been recorded only from 'the Upper Llandeilo' of Balclutchie, Girvan.<sup>2</sup> *Streptis monilifera*, apart from Kildare and Keisley, is mentioned by Davidson only from the 'Middle Llandovery' of Woodland Point,<sup>3</sup> Girvan.

Three species are peculiar to the Keisley Limestone:—*Orthis keisleyensis*, *Syntrophia affinis*, and *Atrypina similis*.

The commonest species of brachiopoda at Keisley are *Atrypa expansa* (and its varieties), *Strophomena corrugatella*, and *Christiania tenuicincta*.

The following Keisley species are found also in the Middle Bala of England, Wales, and Scotland:—

*Orthis calligramma*, *O. Actonia*, *O. biforata*, *O. biloba*, *O. alternata*, *O. elegantula*, *O. flabellulum*, *O. testudinaria*, *O. vespertilio*, *Triplecia insularis*, *Strophomena antiquata*, *Str. corrugatella*, *Rafinesquina deltoidea*, *R. expansa*, *Leptæna rhomboidalis*, *Christiania tenuicincta*, *Plectambonites transversalis*, *Pl. quinquecostata*, (?) *Camerella ? Thomsoni*.

Thus over 50 % of the Keisley species occur in the Middle Bala.

Of the species occurring in the Upper Bala (*i. e.* the beds above and including the *Staurocephalus*-Limestone) it is difficult to draw up a satisfactory list, as the fossils have been by no means well investigated. From lists given by Mr. Marr and others<sup>4</sup> and from specimens at Cambridge we see that the following Keisley forms occur in the Upper Bala:—*Orthis Actonia*, *O. biforata*, *O. calligramma*, *O. elegantula*, *O. testudinaria*, *O. vespertilio*, *Christiania tenuicincta*, *Leptæna rhomboidalis*, *Plectambonites quinquecostata*.

This list is, I believe, much too short, and represents therefore imperfectly the degree of affinity of the brachiopodal faunas.

<sup>1</sup> 'Rev. ostbalt. Silur. Trilob.', pt. i. Mém. Acad. Imp. des Sci. St. Pétersbourg, ser. 7, vol. xxx. (1881) no. 1, p. 38; and Quart. Journ. Geol. Soc. vol. xxxviii. (1882) p. 514.

<sup>2</sup> Davidson, 'Mon. Brit. Foss. Brach.' vol. v. (1882-84), Sil. Suppl. p. 159.

<sup>3</sup> *Ibid.* p. 147.

<sup>4</sup> Quart. Journ. Geol. Soc. vol. xxxiv. (1878) p. 871, vol. xli. (1885) p. 476, vol. xlvi. (1891) p. 500; Geol. Mag. 1892, p. 97.

A very considerable number are found in British Silurian beds.

The following is a list of these species:—

*Orthis Actoniae*, *O. biforata*, *O. biloba*, *O. elegantula*, *O. calligramma*, *O. testudinaria*, *O. vespertilio*, *Strophomena antiquata*, *Str. corrugatella*, *Rafinesquina expansa*, *Plectambonites transversalis*, *Pt. quinquecostata*, *Leptaena rhomboidalis*, *Triplecia insularis*, *Streptis monilifera*, and *Atrypa marginalis*.

Thus 16 species, or over 44 %, occur in the Silurian. But none of these are characteristically Silurian forms,<sup>1</sup> and all of them are known from Bala Beds. Owing, therefore, to their long range, they are of comparatively little zonal importance, and cannot justly be used in support of the argument for the Silurian facies of the fauna. It is also specially noteworthy that such typically Silurian genera as *Stricklandinia* and *Pentamerus* (and its subgenera or allied genera) are conspicuous by their absence. There are, moreover, no species of *Spirifer* such as we should expect to find in Silurian strata.

In the *Leptaena*-Limestone, indeed, *Meristella? crassa* is found, but this species marks the conglomerate at the top of the Ashgill Shales in Britain, and this bed is on the border-line between the Silurian and Ordovician.

On the whole we must therefore say that the brachiopoda of the Keisley Limestone are an assemblage of species of a Middle and Upper Ordovician stamp, but that this assemblage possesses a certain uniqueness which can be most closely paralleled by that of the Kildare and *Leptaena*-Limestones, as in the case of the trilobitic fauna.

IV. POLYZOA.—Members of this group appear very rare at Keisley, whereas at Kildare and in the Dalecarlian and Russian assumed equivalent formations they are very common. In fact, the *Leptaena*-Limestone has the alternative name 'Fenestellenkalk,'<sup>2</sup> and a long list of polyzoa is known from Stage F of Schmidt.

All the Keisley polyzoa that I have seen are very imperfect and fragmentary specimens; all the species are doubtfully identified, but two of these (*Ptilodictya recta* and *Fenestella assimilis*) occur in the Kildare Limestone, and the third (*Pt. costellata*) is a Bala form. There is no Silurian species among them. Not one of the three species is recorded from the *Leptaena*-Limestone or Stage F except *Pt. costellata*, which occurs in the Borkholm zone.

V. MOLLUSCA.—Of the mollusca the cephalopoda are by far the most abundant group in the Keisley Limestone, but there appear to be only the two species of *Orthoceras* as the representatives of the group. Neither of these throw any light on the horizon of the limestone.

The gasteropoda are represented by a dozen or more species belonging to 9 genera, but they are by no means common. The most abundant form is *Loxonema striatissimum*, which shows close affinity with Silurian species. The only other species suggesting Silurian affinity is the form compared with Hisinger's

<sup>1</sup> Except *Atrypa marginalis* and *Orthis biloba*.

<sup>2</sup> Remelé, Zeitschr. d. Deutsch. geol. Gesellsch. vol. xxxii. (1880) p. 645, & vol. xxxiv. (1882) p. 651.

*Platyceras cornutum*. Of the others, *Holopea concinna* and *H. striatella* are typically Bala forms.

*Loxonema striatissimum*, *Euomphalus subsulcatus*, *Holopea concinna*, *Cyclonema rupestre*, and *C. sulciferum* are found also in the Kildare Limestone. *Loxonema striatissimum* is confined to the Keisley and Kildare Limestones. *Eunema carinatum*, *Euomphalus obtusangulus*, and *E. nitidulus* are *Leptæna*-Limestone species. *Cyclonema rupestre* and *Pleurotomaria notabilis* occur in Stage F of the Baltic provinces of Russia.

We thus see that the gasteropoda of the Keisley Limestone support the conclusions derived from a study of the brachiopoda and crustacea as regards the affinities of the fauna.

The pteropoda and lamellibranchiata are too indefinite to help us.

VI. ECHINODERMATA.—The only determinable form is a species (*Sphæronites pyriformis*) which occurs at Kildare and in the Upper Bala of Rhiwlas. It is also noticeable that this genus is particularly abundant in the *Leptæna*-Limestone, being there represented by 4 species.<sup>1</sup>

VII. ACTINOZOA.—Of the Actinozoa *Streptelasma europæum* and *Stenopora fibrosa*, with some indeterminate zaphrentoid corals, are the commonest forms at Keisley. But corals are decidedly scarce.

Three species—*Halysites catenularia*, *Stenopora fibrosa*, and *Favosites alveolaris*—occur at Kildare.

*Halysites catenularia* and *Heliolites dubia* are found in the *Leptæna*-Limestone and in the Lyckholm zone, with the addition of *Streptelasma europæum*, which also occurs in the Borkholm zone.

In Great Britain *Halysites catenularia* ranges from the Llandeilo formation to the Ludlow, *Stenopora fibrosa* occurs all through the Bala, and *Streptelasma europæum* and *Prasopora Grayæ* are found in the Craighead Limestone of Llandeilo age.

#### PALÆONTOLOGICAL EVIDENCE OF THE AGE OF THE KEISLEY LIMESTONE.

After removing from the list of fossils all those species which are either peculiar to the Keisley Limestone, or are found in no other bed in the British Isles save the Chair of Kildare Limestone, and in addition all the doubtful species, we find that there are 16 which occur in the Lower Bala beds, 28 in the Middle Bala, 20 in the Upper Bala, and 21 in the Silurian. But, as the following list shows, some of these are species with a great vertical range, and therefore ought to be left out of the argument. After their removal we find that there are 8 or 9 characteristically Middle Bala species, 3 or 4 Upper Bala species, and 3 Silurian species. A mistake against which we must guard ourselves is to lay too little stress on the occurrence of some species belonging to the fauna of a bed which is poor in organic remains, or which has been insufficiently worked out from a palæontological point of view. We may, I think, safely consider that the Middle Bala and most of the Silurian have had their organic contents investigated very fully,

<sup>1</sup> 'List of the Fossil Faunas of Sweden. I.—Cambrian and Lower Silurian.' Stockholm, 1888.

but with respect to the Upper Bala we cannot say the same, for the fossils so far collected are both few in numbers and poorly preserved, and the fauna requires much more working out. Thus we must attach more importance to the occurrence of a few typical Upper Bala forms than their mere number alone would seem to justify.

LIST OF KEISLEY LIMESTONE FOSSILS OCCURRING IN OTHER  
BRITISH BEDS.

	Lower Bala.	Middle Bala.	Upper Bala.	Silurian.
<i>Cheirurus bimucronatus</i> Murch. ....	...	*	*	*
" <i>clavifrons</i> (? Dalm.) .....	...	*	*	*
<i>Sphærexochus mirus</i> , Beyr. ....	*	*	*	*
<i>Calymene Blumenbachi</i> , Brong. ....	...	*	*	*
<i>Illænus Bowmani</i> , Salt. ....	*	*		
<i>Staurocephalus Murchisoni</i> , Barr. ....	...	...	*	*
<i>Phillipsinella parabola</i> , Barr. ....	...	...	*	*
<i>Remopleurides longicostatus</i> , Portl. ....	...	...	*	*
<i>Lichas laxatus</i> , M'Coy .....	...	*	*	
" <i>hibernicus</i> , Portl. ....	*			
<i>Primitia M'Coyi</i> , Salt. ....	*			
<i>Orthis calligramma</i> , Dalm. ....	*	*	*	*
" <i>Actonia</i> , Sow. ....	*	*	*	*
" <i>alternata</i> , Sow. ....	?	*	*	*
" <i>biforata</i> , Schloth. ....	...	*	*	*
" <i>biloba</i> , L. ....	...	*	...	*
" <i>elegantula</i> , Dalm. ....	*	*	*	*
" <i>flabellulum</i> , Sow. ....	...	*	?	*
" <i>testudinaria</i> , Dalm. ....	*	*	*	*
" <i>vespertilio</i> , Sow. ....	?	*	*	*
<i>Strophomena antiquata</i> , Sow. ....	...	*	...	*
" <i>corrugatella</i> , Dav. ....	...	*	...	*
<i>Triplecia insularis</i> , Eichw. ....	...	*	...	*
<i>Hyattella Portlockiana</i> , Dav. ....	*			
<i>Streptis monilifera</i> , M'Coy .....	...	...	...	*
<i>Rafinesquina expansa</i> , Sow. ....	*	*	...	*
"  ? <i>deltoides</i> .....	?	*		
<i>Leptæna rhomboidalis</i> , Wilck. ....	*	*	*	*
<i>Christiania tenuicincta</i> , M'Coy .....	...	*	*	*
<i>Plectambonites transversalis</i> , Dalm. .	...	*	...	*
" <i>quinquecostata</i> , M'Coy .....	...	*	*	*
<i>Camerella</i> ? <i>Thomsoni</i> , Dav. ....	*			
<i>Atrypa marginalis</i> , Dalm. ....	...	...	...	*
? <i>Ptilodictya costellata</i> , M'Coy .....	...	*		
<i>Holopea concinna</i> , M'Coy .....	...	*		
" <i>striatella</i> , Sow. ....	...	*		
? <i>Pterinea subfalcata</i> , Onr. (var. at Keisley) .....	...	...	...	*
<i>Sphæronites pyriformis</i> , Forbes .....	...	...	*	
<i>Prasopora Grayæ</i> , Nich. & Eth. ....	*			
<i>Halysites catenularia</i> , L. ....	*	*	*	*
<i>Stenopora fibrosa</i> , Goldf. ....	*	*		
? <i>Nebulipora lens</i> , M'Coy .....	...	*		
<i>Streptelasma europæum</i> , F. Röm. ...	*			

It is clear that the bed contains a fauna with Middle and Upper Bala rather than Lower Bala affinities; and the occurrence of the species *Staurocephalus Murchisoni*, *Phillipsinella parabola*, *Remopleurides longicostatus*, and *Sphaeronites pyriformis*, which do not range down below the Upper Bala, points to the inclusion of the bed in the Upper Bala. The presence of some Silurian species might incline us to assign to the Keisley Limestone a somewhat high position in the Upper Bala; but on comparing the lists of the fossils from the *Staurocephalus*-zone and the Ashgill Shales in England and Wales with the list from the Keisley bed, it is at once apparent that the relationship is much closer with the former than with the latter.

Thus, in the *Staurocephalus*-zone, we find the following Keisley species present:—

<i>Remopleurides longicostatus.</i>	<i>Christiania tenuicincta.</i>
<i>Illænus Bowmani.</i>	<i>Orthis calligramma.</i>
<i>Lichas laxatus.</i>	" <i>elegantula.</i>
<i>Phillipsinella parabola.</i>	" <i>testudinaria.</i>
<i>Cheirurus bimucronatus.</i>	<i>Leptæna rhomboidalis.</i>
" <i>juvenis</i> (= <i>clavifrons</i> , ? Dalm.)	<i>Plectambonites quinquecostata.</i>
<i>Staurocephalus Murchisoni.</i>	<i>Halysites catenularia.</i>
<i>Sphaeræochus mirus.</i>	<i>Stenopora fibrosa.</i>

In the Ashgill Shales and Redhill Beds, on the other hand, only the following Keisley species are present:—

<i>Calymene Blumenbachi.</i>	<i>Orthis elegantula.</i>
<i>Cheirurus clavifrons.</i>	" <i>testudinaria.</i>
<i>Orthis Actoniæ.</i>	" <i>vespertilio.</i>
" <i>alternata.</i>	<i>Leptæna rhomboidalis.</i>
" <i>biforata.</i>	<i>Christiania tenuicincta.</i>
" <i>calligramma.</i>	<i>Holopea concinna.</i>

The argillaceous instead of calcareous nature of the sediment, and the different conditions of deposition, undoubtedly have much to do with the different facies of the Ashgill Shale fauna. There are, however, certain marked deficiencies in the Keisley Limestone fauna when we compare it with any part of the Upper Bala. Thus the genus *Trinucleus* is completely wanting, though *Tr. seticornis* is a characteristic trilobite of the whole Upper Bala throughout England and Wales. The two typically Ashgill Shale brachiopods, namely, *Orthis protensa* and *Strophomena siluriana*, are also conspicuous by their absence. The genus *Phacops* is completely absent from Keisley, so far as is known, though this genus is very rich in species and individuals throughout the Middle and Upper Bala elsewhere.

The affinities of the Keisley Limestone fauna with that of the Slade Beds and Hirnant Limestone are too remote to necessitate entering into the question here.

Full weight must be given to the large number of peculiar species found in the Keisley Limestone. Thus, of its well-determined species, omitting all those about which there is any doubt, 11 are absolutely peculiar to it, and 14 others are nowhere else found in the United Kingdom except in the Kildare Limestone.

The possession of so many peculiar forms stamps the fauna with a distinct individuality and strongly differentiates it from all other British beds.

Summing up, therefore, the palæontological evidence with reference to its stratigraphical position, we find: (1) that the fauna has a thoroughly Ordovician facies; (2) that it possesses a large number of peculiar species; (3) that while possessing a considerable number of Middle Bala species, yet the presence of certain forms known elsewhere only from or only commencing in the Upper Bala Beds points to a closer relationship to the latter than to the Middle Bala; (4) that the affinity of the fauna is much closer with that of the *Staurocephalus*-zone than with that of the overlying Ashgill Shales; (5) that the presence of so many peculiar forms, as well as the absence of certain typical species of the *Staurocephalus*-zone, precludes us from considering the Keisley Limestone and *Staurocephalus*-zone to be on exactly the same horizon, while the presence of a number of Middle Bala forms inclines us to put the Keisley Limestone slightly below rather than above the *Staurocephalus*-zone.

Thus it is at the bottom of the Upper Bala that on the strength of the palæontological evidence I would put the Keisley Limestone. Mr. Marr has arrived at nearly the same conclusion,<sup>1</sup> for he says that its fauna distinctly belongs to a lower horizon than the Ashgill Shales, and he would place it immediately below the *Staurocephalus*-Limestone as the uppermost bed of the Applethwaite Beds of the Sleddale Group of the Coniston Limestone Series, that is, at the top of the Middle Bala.

Sedgwick and Salter<sup>2</sup> assigned the fossils from this bed to the Middle Bala group.

#### IRISH AND CONTINENTAL EQUIVALENTS.

Throughout the preceding description of the fauna of the Keisley Limestone frequent reference has been made to the Chair of Kildare Limestone, the *Leptæna*-Limestone of Dalecarlia, and the Borkholm and Lyckholm zones, which constitute Schmidt's Stage F of the East Baltic provinces of Russia, and many of the Keisley species have been mentioned as occurring in one or more of these beds. A brief summary of the common species will bring out the close relationship of these beds clearly. Unfortunately, only in the case of the Kildare and *Leptæna* Limestones has the fauna been to any extent adequately worked out, and even in these two cases there is room for a further scrutiny. The lists of fossils from the Borkholm and Lyckholm beds are very meagre. Schmidt,<sup>3</sup> however, states that the Swedish *Leptæna*-Limestone of the Osmundsberg in Dalarna which he visited seems perfectly identical with the white Bork-

<sup>1</sup> Geol. Mag. 1892, pp. 97 & 445.

<sup>2</sup> Cat. Cambr. & Sil. Foss. Woodw. Mus. (1873) p. 54, etc.

<sup>3</sup> Quart. Journ. Geol. Soc. vol. xxxviii. (1882) p. 514; [quoted by Linnarsson], Zeitschr. d. Deutsch. geol. Gesellsch. vol. xxv. (1873) pp. 696-697.

holm Limestone, and he regards them as formed at the same time in the same ocean. To support this view he quotes a list of identical fossils from the same bed, amongst which we notice several species which are not found on higher or lower horizons in those districts. It is on this occurrence of peculiar species of very limited vertical range that we must depend for the correlation of beds in distant lands, as is notoriously exemplified by the graptolites and Ammonoidea.

The homotaxial equivalence of the Keisley Limestone with that of Kildare is practically proved by the occurrence in both of the following species (List I.), which are unknown from any other beds in the British Isles. The presence also of the many common species (enumerated in List II.) in these two limestones strongly supports this conclusion.

## LIST I.

<i>Cyphoniscus socialis.</i>	<i>Homalonotus punctillosus.</i>
<i>Cyphaspis (Törnquistia) Nicholsoni.</i>	<i>Illænus fallax.</i>
<i>Cheirurus cancrurus.</i>	? „ <i>Ræmeri.</i>
„ <i>keisleyensis.</i>	? „ <i>cæcus.</i>
„ ( <i>Pseudosphærexochus</i> ) <i>con-</i>	<i>Harpes Wegelini.</i>
„ <i>formis.</i>	<i>Cythere Wrightiana.</i>
? „ ( „ ) <i>subquadratus.</i>	<i>Atrypa expansa.</i>
<i>Sphærexochus latirugatus.</i>	<i>Fenestella assimilis.</i>
? <i>Sphærocoryphe granulata.</i>	<i>Loxonema striatissimum.</i>
<i>Lichas bulbiceps.</i>	<i>Cyclonema rupestre.</i>
? „ <i>bifurcatus.</i>	„ <i>sulciferum.</i>
<i>Tiresias inculptus.</i>	

## LIST II.

<i>Cheirurus bimucronatus.</i>	<i>Rafinesquina expansa.</i>
? „ <i>clavifrons?</i>	<i>Strophomena corrugatella.</i>
<i>Sphærexochus mirus.</i>	„ <i>antiquata.</i>
<i>Staurocephalus Murchisoni.</i>	<i>Leptæna rhomboidalis.</i>
<i>Lichas laxatus.</i>	<i>Plectambonites quinquecostata.</i>
„ <i>hibernicus.</i>	? „ <i>transversalis.</i>
<i>Illænus Bowmani.</i>	<i>Christiania tenuicincta.</i>
<i>Remopleurides longicostatus.</i>	<i>Streptis monilifera.</i>
<i>Primitia M'Coys.</i>	<i>Triplecia insularis.</i>
<i>Atrypa marginalis.</i>	<i>Hyattella Portlockiana.</i>
<i>Orthis Actoniae.</i>	? <i>Ptilodictya recta.</i>
? „ <i>alternata.</i>	? <i>Euomphalus subsulcatus.</i>
„ <i>biforata.</i>	<i>Holopea concinna.</i>
„ <i>calligramma.</i>	<i>Conularia, sp.</i>
„ <i>flabellulum.</i>	<i>Sphæronites pyriformis.</i>
? „ <i>testudinaria.</i>	<i>Favosites alveolaris.</i>
„ <i>vespertilio.</i>	<i>Stenopora fibrosa.</i>
<i>Rafinesquina deltoidea, var.</i>	<i>Halysites catenularia.</i>

Turning now to the *Leptæna*-Limestone of Dalecarlia we see that the following species, peculiar to that rock in Sweden, occur at Keisley. Those marked with an asterisk are doubtful at Keisley.

<i>Cheirurus glaber.</i>	<i>Euomphalus obtusangulus.</i>
<i>Lichas conformis (var. at Keisley).</i>	<i>Eunema carinatum.</i>
* <i>Harpes costatus.</i>	* <i>Orthis conferta.</i>
„ <i>Wegelini.</i>	<i>Dayia pentagonalis.</i>
<i>Homalonotus punctillosus.</i>	<i>Atrypa expansa</i>
* <i>Euomphalus nitidulus.</i>	

In addition to the foregoing the following Keisley species occur in the *Leptaena*-Limestone:—

<i>Cheirurus (Pseudosphærexochus) conformis.</i>	<i>Orthis biloba.</i>
<i>Sphærexochus mirus.</i>	" <i>calligramma.</i>
* <i>Sphærocoryphe granulata.</i>	<i>Strophomena corrugatella.</i>
<i>Lichas affinis.</i>	<i>Leptaena rhomboidalis.</i>
" <i>laxatus.</i>	? <i>Rafinesquina deltoidea, var. undata.</i>
<i>Illænus fallax.</i>	<i>Plectambonites Schmidt.</i>
" <i>Rœmeri.</i>	? " <i>quinquecostata.</i>
<i>Orthis Actoniæ.</i>	<i>Hyattella Portlockiana.</i>
" <i>biforata.</i>	* <i>Heliolites dubia.</i>
	<i>Halysites catenularia.</i>

The allied but not identical species need not again be mentioned. The evidence already adduced is sufficient to show the homotaxial equivalence of the beds.

With regard to the Russian beds Schmidt, as above mentioned, has insisted that the *Leptaena*-Limestone is on the same horizon as his Borkholm zone. It is confirmatory of my conclusions as to the homotaxial equivalence of these beds that several Kildare fossils which do not occur elsewhere in the British Isles are identical with species from these Russian beds; as, for example, *Lichas lævis* (Eichw.) and *L. margaritifer* (Nieszk.).

The difficulty as to the stratigraphical position of the *Leptaena*-Limestone, indeed, enters into the above correlation. The divergence of opinion on this point is well known. Briefly, one party, represented by Törnquist, places the *Leptaena*-Limestone above the *Retiolites*-Shales; the other party, to which Schmalensee, F. Römer, and Marr belong, put it immediately above the *Trinucleus*-Beds and below the *Rastrites*-Shales. I am not in a position to criticize these two views, nor is this the occasion to do so, but I may point out that Schmidt has indisputably established the stratigraphical position and relations of the Borkholm zone in a region in which the succession of the beds is not confused or indistinct from deformation or dislocation of the strata; that he has proved it to be at the top of the Ordovician System, and its fauna to be essentially identical with that of the *Leptaena*-Limestone.

Törnquist<sup>1</sup> has given the reasons for his view of the case in a number of valuable papers. Marr<sup>2</sup> at first went with him, but in 1885<sup>3</sup> rejected that view, although he expressed the opinion that the *Leptaena*-Limestone contained 'a mixture of faunas of several of the Haverfordwest beds, viz. the Lower Llandovery, the *Trinucleus seticornis*-beds, and perhaps even of the Robeston Wathen Limestone.'

<sup>1</sup> 'Om Lagerfölj. i. Dal. undersil. Bildning.,' K. Vetensk. Akad. Förhandl. 1867; 'Geol. Iakt. o. d. Kambr. o. Silur. Lagf. i. Siljans.' Öfv. K. Vetensk. Akad. Förhandl. 1871, no. 1; 'Om Siljans. Pal. Format.' *ibid.* 1874, no. 4, p. 3; 'Berättelse, etc.' *ibid.* 1879, no. 2; Geol. Fören. i Stockholm Förhandl. no. 90, vol. vii. (1884) pt. 6, p. 304; *ibid.* vol. viii. (1886); *ibid.* vol. xiv. (1892), nos. 141, 147, etc.

<sup>2</sup> Quart. Journ. Geol. Soc. vol. xxxviii. (1882) p. 313.

<sup>3</sup> *Ibid.* vol. xli. (1885) p. 489.

Schmalensee<sup>1</sup> has expressed the view that the *Leptæna*-Limestone corresponds with the horny Klingkalk immediately above the *Trinucleus*-Shales, and Marr<sup>2</sup> likewise says that the Keisley Limestone may be represented by a white horny limestone seen in the stream at the Upper Bridge, Skelgill Brook, containing large *Orthocera* and occurring immediately below the *Staurocephalus*-Limestone. Nathorst<sup>3</sup> illustrates this view of the occurrence of the *Leptæna*-Limestone by a diagram showing the local swelling-out of a thin band of limestone into a thick reef-like mass. Ferd. Römer,<sup>4</sup> on palæontological grounds, adopts the view that the *Leptæna*-Limestone is at the upper limit of the Lower Silurian [= Ordovician]; and Holm<sup>5</sup> and Andersson,<sup>6</sup> more recently, do the same.

It may be noticed here that several of the species limited in Sweden to the *Leptæna*-Limestone, in England to the Keisley Limestone, and in Ireland to the Chair of Kildare Limestone occur in the East Baltic provinces, not only in the Borkholm Limestone, which Schmidt<sup>7</sup> correlates exactly with the *Leptæna*-Limestone, but also in the underlying Lyckholm zone. Thus *Pseudosphærexochus conformis*, *Cheirurus* cf. *glaber*, *Cybele brevicauda*,<sup>8</sup> *Harpes Wegelini*, *Lichas dalecarlicus*, *Bronteus laticauda*, and *Heliolites dubia* are recorded among others by Schmidt<sup>9</sup> from the Lyckholm zone, but in Sweden for the first and only time from the *Leptæna*-Limestone. Schmidt<sup>10</sup> indeed says that the Lyckholm and Borkholm zones are so closely allied in their faunas that they cannot be separated at present as distinct stages. Yet, on the other hand, though he considers his Stage F to represent 'the British Caradoc Sandstone and the Coniston and Craighead Limestones,' it is remarkable that so many of its typical species do not occur in Britain till the Keisley Limestone, which we have been led to place at the base of the Upper Bala—e. g. *Pseudosphærexochus conformis*, *Cheirurus* cf. *glaber*, *Illænus Rœmeri*, *I. cæcus*, *Harpes Wegelini*, *Plectambonites Schmidtii*, *Cyclonema rupestre*, *Pleurotomaria notabilis*. It is also noticeable that several Keisley Limestone species are very closely allied to forms not occurring in lower beds in Britain, but in lower beds in Scandinavia. Of these the following are examples:—*Cheirurus keisleyensis*, which is allied to *Ch. subulatus* of the *Trinucleus*-Schists, and *Cyphaspis Nicholsoni*, which so much resembles *Trilobites trira diatus* of the same beds.

<sup>1</sup> 'Om Leptænak. Plats i Silur. Lag.' Geol. Fören. i Stockh. Förhandl. no. 89, vol. vii. (1884), pt. 5, p. 280; *ibid.* no. 146, vol. xiv. (1892), pt. 6, p. 497.

<sup>2</sup> Geol. Mag. 1892, p. 97.

<sup>3</sup> 'Någr. o. o. Slipsandst. i. Dal.' Geol. Fören. i Stockh. Förhandl. no. 93, vol. vii. (1884) pt. 9, p. 559.

<sup>4</sup> 'Lethæa Erratica,' Palæont. Abhandl. Berlin, vol. ii. (1885) pt. v. p. 72.

<sup>5</sup> Sveriges Geol. Undersökn. ser. c, no. 115, pp. 14, 15, Stockholm, 1890.

<sup>6</sup> Öfvers. K. Sv. Vet. Akad. Förhandl. 50 Årg. p. 571, Stockholm.

<sup>7</sup> Quart. Journ. Geol. Soc. vol. xxxviii. (1882) p. 514.

<sup>8</sup> This species is stated by Schmidt to occur also in his Stage E.

<sup>9</sup> 'Rev. ostbalt. silur. Trilob.,' pt. i. Mém. Acad. Imp. des Sci. St. Pétersbourg, ser. 7, vol. xxx. (1881) no. 1.

<sup>10</sup> Quart. Journ. Geol. Soc. vol. xxxviii. (1882) p. 514.

*Sphaerocoryphe granulata*, *Illænus Roëmeri*, and *Plectambonites Schmidtii* occur in the *Trinucleus*-Schists of Sweden as well as in the *Leptæna*-Limestone, but are known only from the Keisley Limestone in Britain. *Illænus fallax*, found only at Keisley and Kildare in the United Kingdom, occurs as low down as the *Chasmops*-Limestone in Sweden.

These facts appear to indicate that the species developed at an earlier period in Eastern Europe, and thence migrated in a westerly direction. Marr<sup>1</sup> has pointed to similar evidence in the case of the Cystidean and *Orthoceras*-Limestones of Sweden and Russia.

#### MODE OF OCCURRENCE AND CHARACTERS OF THE KEISLEY LIMESTONE.

The Keisley Limestone occurs as an isolated mass of limestone on the western side of the southern end of the Cross Fell inlier. The earliest mention of it is in a paper by Buckland<sup>2</sup> in 1807. Recently its relations have been described in brief by Marr & Nicholson.<sup>3</sup> The narrow elongated area which it occupies is bounded on all sides by faults, and in no neighbouring locality is a limestone with similar characters, thickness, and fossils known to exist. Consequently, its exact stratigraphical relations and horizon have been a matter of much dispute. The lithological characters of the rock are by no means simple or uniform. The mass in fact appears to consist of several more or less well-marked types, or perhaps beds, of limestone with thin subsidiary shaly layers.

Thus, lithologically, we may distinguish the following more or less distinct varieties of the limestone: (1) a pale pink, fine-grained, compact, homogeneous limestone with comparatively few organic remains and no crinoid-stems; (2) a dark grey, bituminous, compact or crystalline limestone, likewise poor in fossils and devoid of crinoids; (3) a very coarsely crystalline, white or reddish-stained limestone full of the characteristic fossils and many crinoid-stems. The crystallization of the matrix in this case has extended to these included organic fragments, as described by Prof. Nicholson<sup>4</sup>; (4) a dark greyish compact limestone, not coarsely crystalline, crowded with *Orthoceras*, but containing few other genera of fossils; (5) a pale greyish crystalline limestone with many fossils. Other transitional varieties occur. Some layers of the limestone are full of *Illæni*, and a dozen or more head-shields and pygidia may be seen on a slab a foot or so square.

These varieties of texture and organic contents do not occur with

<sup>1</sup> Quart. Journ. Geol. Soc. vol. xxxvi. (1880) p. 279; vol. xxxviii. (1882) p. 313.

<sup>2</sup> Trans. Geol. Soc. ser. 1, vol. iv. pt. i. (1816) p. 105, pl. v., section, no. 3. In this paper the limestone is apparently considered to be of Carboniferous age.

<sup>3</sup> Quart. Journ. Geol. Soc. vol. xlvii. (1891) p. 507.

<sup>4</sup> Nicholson & Lydekker, 'Manual of Palæontology,' 3rd ed. (1889) vol. i. p. 20, figs. 5a, 5b.

much regularity or allow themselves to be traced far laterally, but the greatest development of the dark bituminous, poorly fossiliferous variety is found in the large quarry on the hillside, which is still worked. This quarry lies at the foot of the hill, and shows a southerly to south-easterly dip of these beds. On the higher slopes the grey, pink, or coarsely crystalline varieties are met with, but whether they lie above or below the bituminous variety is doubtful.

The red-staining of some parts of the limestone is undoubtedly due to a comparatively recent oxidation of the contained iron, or possibly to the infiltration of chalybeate waters.

The patchy manner in which some of the varieties of limestone occur, even in the same hand-specimen, seems to point to original slight differences in the deposit or to segregation at local centres while the calcareous mud was soft. This 'patchiness' is especially noticeable in the case of the fine-grained pink variety of the limestone.

Some of the minute structural features are due to the dynamic agencies which have affected the rock.

#### EVIDENCE OF DISTURBANCE.

Direct evidence of considerable mechanical disturbance of the limestone is afforded by the twisted wisps of shales included in the mass, as Marr & Nicholson have remarked (*loc. cit.*). In the old disused quarry, south of the one now worked, there may be seen a section of a partially overturned fold, and of what appears to be a thrust-plane, with considerable shattering and crushing of the rock along the gliding-surface.

Marr & Nicholson believe that the limestone has been thickened by the thrusting-up together of the calcareous portions and squeezing-out of the shaly layers by the action of a force acting from the south-west, and they mention that inversion of some of the beds appears indicated by the occurrence of *Illeni* with their convex surfaces downward. We must in fact regard the so-called Keisley Limestone as a series of thin limestone-bands separated by thinner shaly layers, which have been folded, crushed together, and forced over each other so as to present a spurious thickness.

#### STRATIGRAPHICAL CONSIDERATIONS.

Since we are led to regard the thickness of the Keisley Limestone as largely due to mechanical deformation and not entirely to original deposition, and the obscurity of its relations as due to its isolation by faults, we might not unnaturally think that it was a block of the neighbouring strata squeezed up and displaced. This view, however, is seen to be utterly untenable when we ascertain the unique facies of the fauna and its dissimilarity to that of any other British beds (see *infra*). There is, however, an idea, which at first sight appears probable, that the Keisley Limestone is the sole remnant of what was once a widespread formation, which

has suffered enormous denudation, leading to its complete removal except in this one spot. Since everyone must concede, even from the above evidence of the fossils, that the fauna has an Ordovician facies, we look down the list of Ordovician rocks of the district to see at what horizon it can be inserted. But there is no gap in the series or trace of such a widespread denudation, at any rate until we come to the top of the system, and at this point a difficulty arises, for the authorities on this district are divided in their opinions.

Marr & Nicholson<sup>1</sup> do not mention any break between the Ordovician and Silurian, but have traced the whole series in unbroken succession from the rhyolite and ashes below the *Corona*-beds up into the Brathay Flags, which are of Wenlock Shale age.

The first-named author<sup>2</sup> moreover states that he has not detected any traces of the supposed denudation at the close of Ordovician times in this area, and certainly if it really exists, the evidence of it has not yet been published. In the Lake District, however, there is a physical break between the Ashgill Shales and the overlying series, which is marked in various localities by the well-known conglomerate with *Meristella* (?) *crassa*. The great irregularity in the thickness of the Ashgill Shales in that district is to be attributed either to an overlap of the overlying strata or to an unconformity, and several facts seem more in favour of the latter.<sup>3</sup>

Mr. Goodchild<sup>4</sup> is the main upholder of the denudation-theory in the Cross Fell area, and he disputes the continuity of deposition from Ordovician into Silurian times. Roughly dividing the Bala rocks of the Cross Fell inlier into a lower 'calcareous shale' series and an upper 'mainly calcareous' series graduating into each other, he says:—'The limestone of Keisley belongs, I believe, to a higher part of this calcareous series than has been left by pre-Silurian denudation elsewhere in the area under notice.'

If, however, we can show that the palæontological affinities of the bed are not with the Ashgill Shales, but with beds below them, we shall be forced on these grounds alone to reject the theory that the limestone is the remnant of a bed at the very top of the Ordovician System, unless, indeed, we betake ourselves to Barrande's theory of colonies. Mr. Goodchild (*loc. cit.*) admits that the patch of limestone is faulted-in all round, so that its relations to other beds cannot be directly observed, but only inferred.

In a case, therefore, such as this, the determination of the exact horizon must be made entirely from the evidence of the fossils and the affinities of the fauna.

<sup>1</sup> Quart. Journ. Geol. Soc. vol. xlvii. (1891) p. 500, and Geol. Mag. 1892, p. 97.

<sup>2</sup> Geol. Mag. 1892, p. 445.

<sup>3</sup> Marr, Quart. Journ. Geol. Soc. vol. xxxiv. (1878) p. 871; T. M<sup>c</sup>K. Hughes, Geol. Mag. 1867, p. 354; Aveline, Geol. Mag. 1872, p. 441, and *ibid.* 1876, p. 282.

<sup>4</sup> Geol. Mag. 1892, p. 295.

CONDITIONS OF DEPOSITION AND ORIGIN OF THE FAUNA  
OF THE KEISLEY LIMESTONE.

The isolation of the patch of limestone at Keisley has been fully emphasized, but, as already mentioned, Marr<sup>1</sup> is inclined to think that it is merely a very local development, under peculiar and very restricted conditions, of a thin limestone underlying the *Staurocephalus*-Limestone. A white horny limestone in Skelgill, and a similar limestone in Swindale Beck may be, in his opinion, the attenuated and lithologically-different representatives of the Keisley mass. He adduces cases in other districts with beds of various ages in which 'reefs' or lenticular masses of crystalline limestone occur on the same horizon as these horny limestones and in close connexion with them. Such is the case with some Devonian limestones near Torquay, with the Konieprus Limestone (Ff2) in Bohemia, with the *Leptaena*-Limestone and Klingkalk of Dalecarlia (according to Nathorst<sup>2</sup>), with the 'knoll-reefs' described by Tiddeman,<sup>3</sup> of Carboniferous age, south of the Craven fault in West Yorkshire, and with some Devonian limestones of the Ardennes. In all these instances the district and rocks in which they occur have suffered great disturbance.

With regard to the Keisley Limestone, I am inclined to think that we may best explain the fact that it is not palæontologically represented elsewhere in the British Isles, except at Kildare, by supposing that a wave of migration started from the Baltic towards the close of Middle Bala times; that it travelled in a westerly direction over Scandinavia, the North of England, and into Ireland, but only in isolated spots—such as are now found in Dalecarlia, Keisley, and Kildare—did the fauna which it bore (namely, the fauna of Stage F of Western Russia) find the conditions suitable for its settlement. In the intervening areas it was unable to exist, at any rate in its entirety. Many of the species of the fauna of the seas which it invaded continued to flourish alongside of it, and contributed their remains to the formation of the limestone-patches. On the surrounding portions of the sea-floor, thin horny limestone accumulated in some parts, and in others shales, etc., but without the peculiar fauna. After an existence of brief duration in these isolated outposts, far removed from its original home, most of the fauna died out, mainly owing to the cessation of favourable conditions, but partly owing to the immigration of the new fauna of the *Staurocephalus*-zone. It left but few descendants behind it.

The facts in favour of the view that the existence of this fauna was largely conditional on the physical and biological environment are: (1) the presence of numerous specifically-identical forms, although the localities are so widely separated one from another; (2) the absolute limitation of many of these forms to these patches of limestone; (3) the occurrence of blind species of *Illænus* with

<sup>1</sup> Geol. Mag. 1892, p. 97.

<sup>2</sup> Geol. Fören. i Stockholm Förhandl. no. 93, vol. vii. (1884) p. 559.

<sup>3</sup> Rep. Internat. Geol. Congr. 1888, pp. 319-322.

common structural peculiarities; (4) the similar lithological character of the patches.

The evidence in favour of the brief duration of the fauna consists in (1) the comparatively slight change in the peculiar facies of the fauna, despite the considerable distance apart of the several localities; (2) the small development of local species or varieties; (3) the little impression that it has left on subsequent faunas.

So far, therefore, as our present knowledge goes, we may look upon this 'Stage F' fauna as presenting an example of discontinuous distribution. The period during which the area of distribution was continuous lasted only during the time necessary for the migration, and it was therefore so transient as to leave scarcely a trace behind in the intervening tracts between the few spots where the fauna was able to take root. These spots now alone indicate the size of the area over which the wave of migration spread.

The fact that the limestone in each of these 'outposts' or 'stations' has suffered so much mechanical disturbance may, perhaps, be in the main attributable to its reef-like nature and mode of occurrence, as a local thickening of an elsewhere thin band of rock. But I do not wish to generalize, or to imply that this suggested explanation applies to those examples of 'reefs' among Devonian and Carboniferous rocks which Mr. Marr has quoted (*loc. cit.*). Each case must be decided independently and on its own merits.

#### SUMMARY AND CONCLUSION.

As the result of the above detailed inquiry into the characters of the fauna of the Keisley Limestone and the relations of the rock, it appears to me that the following facts are established:—

- (1) The fauna has a thoroughly Ordovician facies.
- (2) It is closely comparable with that from the Chair of Kildare Limestone and that of the *Leptæna*-Limestone of Dalecarlia, and less closely with that of Stage F of the East Baltic provinces.
- (3) Its palæontological features point to its stratigraphical position being at the base of the Upper Bala.
- (4) It must be regarded as the locally-thickened development of a bed which is elsewhere in Great Britain very thin or entirely absent, or represented by beds of entirely different lithological characters containing a different fauna.
- (5) The fauna has certain unique characters which mark it off from all other known assemblages of fossils in Great Britain.

*Note.*—Recently I have been informed by Mr. R. Clark, of the Geological Survey of Ireland, that the limestones of Toormakeady, Co. Mayo, Courtown, Co. Wexford, and Caherconree, Co. Kerry, are lithologically and palæontologically (so far as the fossils are known) identical with the Kildare Limestone. At present,

I have been unable, from lack of time, to confirm personally the accuracy of this statement, which I find also appears in the Geological Survey Memoirs dealing with those districts, but I intend to take the earliest opportunity of visiting these localities. The scanty lists of fossils from them which have appeared in the Explanations of Sheets 160, 161, etc. (1863), p. 12 (Caherconree); sheets 148, 149 (1887), pp. 21-24 (Courtown); sheets 73, 74, etc. (1876), pp. 28, 31, and 33; and sheets 93, 94, etc. (1878), p. 114 (Toormakeady), certainly contain several of the Kildare species, and the specimens of the rocks which I have seen bear a remarkable resemblance to the Keisley and Kildare Limestones. If it be subsequently established by more minute investigation that these patches of limestone at Toormakeady, Courtown, and Caherconree are of the same age as that at Keisley, none of the conclusions arrived at in this paper will have to be rejected, but these three localities will have to be quoted as additional 'outposts' of this peculiar fauna.

## EXPLANATION OF PLATE VI.

- Fig. 1. *Orthis* (*Hebertella*?) *keisleyensis*, sp. n. Pedicle-valve.  $\times 3$ .  
 1 a. Outline of side view of pedicle-valve.  $\times 3$ .  
 1 b. Natural size.  
 2. *Atrypina similis*, sp. n. Pedicle-valve.  $\times 3$ .  
 2 a. Brachial-valve (young individual).  $\times 3$ .  
 2 b. Natural size.  
 3. *Atrypina similis*, sp. n. Brachial valve.  $\times 3$ .  
 3 a. Natural size.  
 4. *Syntrophia affinis*, sp. n. Pedicle-valve.  $\times 3$ .  
 4 a. Natural size.  
 5. *Dayia pentagonalis*, sp. n. Brachial valve.  $\times 3$ .  
 5 a. Pedicle-valve.  $\times 3$ .  
 5 b. Anterior margin of valves.  $\times 3$ .  
 5 c. Natural size.  
 6. *Loxonema striatissimum* (Salter MS.). Natural size.  
 7. *Platyceras verisimile*, sp. n.  $\times 2$ .  
 7 a. Side view.  $\times 2$ .  
 7 b. Natural size.  
 8. *Murchisonia*, sp.  $\times 3$ .  
 8 a. Natural size.  
 9. *Anodontopsis*, sp.  $\times 3$ .  
 9 a. Natural size.

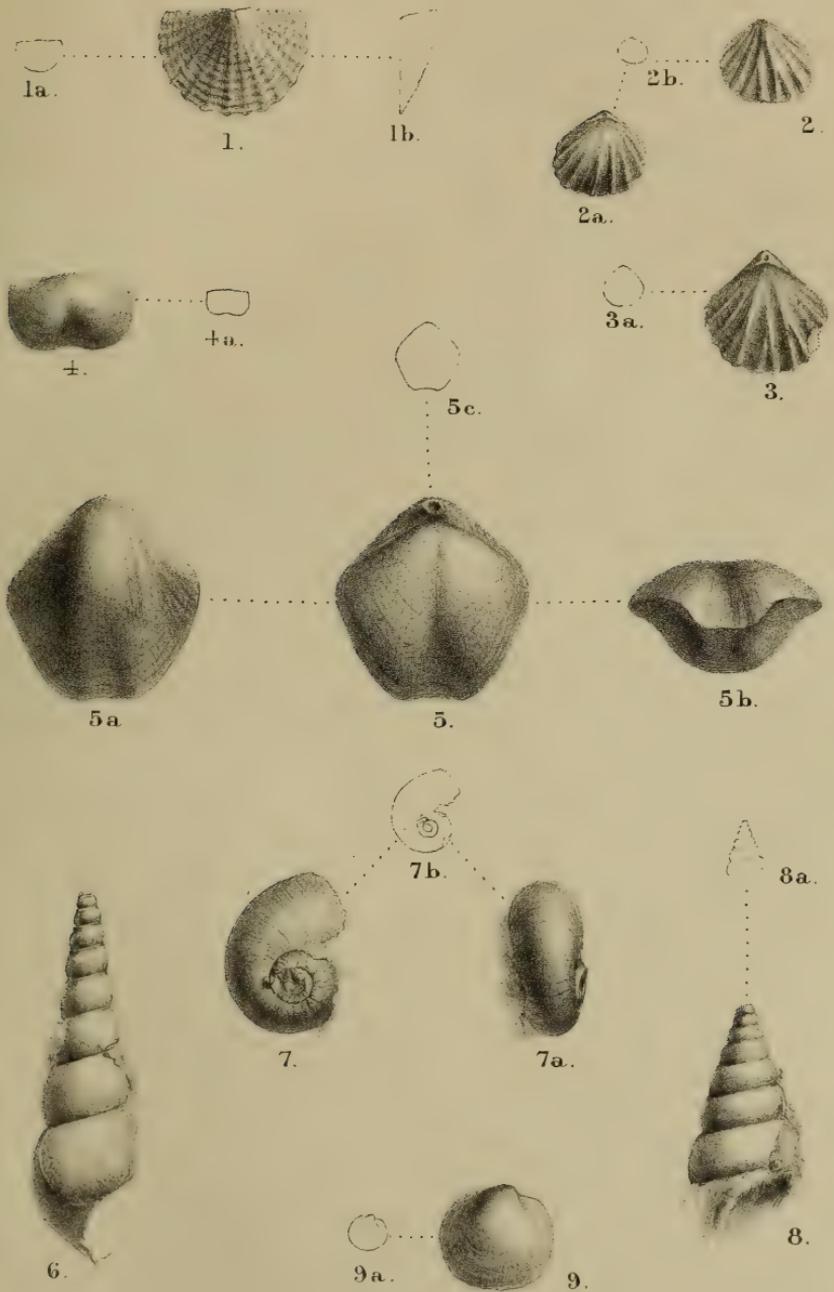
## DISCUSSION.

MR. MARR could not, at the late period of the evening at which the paper concluded, say much upon the points where he agreed with the Author, so would speak at once regarding matters on which he disagreed. He doubted whether the limestones of Keisley were all upon one horizon, though there certainly was a very definite fauna intermediate between that of the Applethwaite Limestone and that of the *Staurocephalus*-Limestone; whether that fauna was referable to Middle or Upper Bala depended upon the line taken between these two groups—which had been originally separated one from another by Sedgwick on stratigraphical grounds, though he (the

speaker) had attempted to define the base of the Upper Bala in Britain upon palæontological grounds. The Author was mistaken in saying that the speaker considered the Keisley Limestone a local development; what he did think was that its peculiar features at Keisley were due to subsequent earth-movement. Finally, he disputed the statement that *Trinuclæus seticornis* was a characteristic Upper Bala fossil. The type (in Sweden) came from Middle Bala beds; it was very common in Middle Bala beds in Britain, and, so far as the speaker's experience went, rare in Upper Bala beds.

Dr. G. J. HINDE enquired of the Author whether he had compared the fauna of the Keisley Limestone with that of the Hudson River formation of Eastern North America, and more particularly with that shown on the Island of Anticosti. Judging from the specimens exhibited, it seemed to the speaker that there were several species common to these widely-separated areas.

The AUTHOR, in replying to Mr. Marr, who objected to the use of percentages in determining the relations of faunas, held that percentages were merely a concise way of stating ascertained facts, and were only misleading when the special conditions and modifying circumstances of each case were left out of account. Mr. Marr also denied that *Trinuclæus seticornis* was specially characteristic of Upper Bala beds, though some years ago he had called the Upper Bala beds of the Haverfordwest area after that fossil. From the examination of a very large number of so-called examples of this species from the Middle Bala, the Author could positively state that the great majority of them were quite distinct from the common form which bears this name in Upper Bala beds. He had had no opportunity of comparing the Keisley Limestone fauna with that of the Hudson River Group.





6. *Another POSSIBLE CAUSE of the GLACIAL EPOCH.* By Prof. EDWARD HULL, M.A., LL.D., F.R.S., F.G.S. (Read December 2nd, 1896.)

[Abstract.]

IN the introductory portion of the paper the Author gives an account of the submarine topography of the area east of North America, and summarizes Dr. J. W. Spencer's work upon a submerged Antillean continent; he then deals with the effects which would be produced upon the Gulf Stream by the uprising of this continent in the Glacial Period, and maintains that, as the current could not pass into the Gulf of Mexico (being debarred by a coast of high continental land), it would flow directly northwards into the North Atlantic, and thereby be deprived of about  $10^{\circ}$  (Fahr.) of heat: the effects of which may be practically illustrated by supposing the isothermal line of  $32^{\circ}$  to take the place of that of  $42^{\circ}$  in the northern hemisphere. He argues that the increased snowfall which would thus be caused over certain areas would tend to intensify the cold through all the adjoining tracts.

To the effects produced in this way must be added those due to the elevation of the land of Eastern North America and to an elevation of North-western Europe, which is supposed to have occurred at the end of Pliocene times. These elevations would intensify the glaciation caused by the difference of direction taken by the Gulf Stream.

#### DISCUSSION.

The Rev. EDWIN HILL, while welcoming the paper, refrained from discussing Prof. Spencer's views or the influence on climate of the Gulf Stream. There remained the real point of the paper—a suggestion that Prof. Spencer's views involved a deviation of the Stream—a new suggestion. He wished to know the grounds for the estimated reduction of temperature, and would be glad to have a comparison between the Gulf Stream in such conditions and the present North Pacific current; also a discussion of the effects on the winds which cause currents. It must be remembered, moreover, that a deviation in the Stream might throw more of it onto our coasts. A good review of the question would be valuable.

Dr. BLANFORD agreed with the previous speaker in feeling doubtful whether a change in the configuration of the American coast would prevent a warm current from still impinging upon the shores of North-western Europe. He also called attention to the circumstance that evidence of Pleistocene glaciation was not confined to the neighbourhood of the Atlantic, but had been clearly shown to exist in other parts of the world—for instance, the Himalayas and New Zealand. The speaker expressed his opinion that the main cause of the Glacial Epoch was still unknown.

The AUTHOR, in reply to Mr. Hill, stated that he could not dis-

sociate his argument from the conclusions of Prof. Spencer; and as regards these conclusions, they had not been challenged by any American geologists with whom he had been able to confer, nor by Mr. Jukes-Browne, who had reviewed Prof. Spencer's memoirs in the pages of the 'Geological Magazine.'

Replying to Dr. Blanford with reference to his remarks on the Pleistocene extension of the Himalayan glaciers, of which he (the Author) had been fully aware, it seemed to him that any great refrigeration of the climate over Western and Northern Europe would extend its influence even into the heart of Asia. At the same time the objection was not very easy to meet, except by supposing an elevation of this region to a greater extent than at present.<sup>1</sup>

<sup>1</sup> [The Author has since dealt with this point in the 'Geological Magazine' for January 1897, p. 48.]

7. NOTE on VOLCANIC BOMBS in the SCHALSTEINS of NASSAU. By Prof. E. KAYSER, Ph.D., For. Corr. G.S. (Communicated by the Secretary. Read December 16th, 1896.)

THE origin of the schalsteins of Nassau, the Harz, and other districts has remained hitherto an unsolved enigma for geologists. This, however, is not surprising, considering the very variable nature of the rocks. Generally of greyish-green colour, with highly-developed slaty cleavage, and with a large admixture of calcareous and chloritic matter, the schalsteins are sometimes earthy, sometimes coarse-grained to conglomeratic and brecciated—and in this latter case they contain frequently fragments of foreign rocks of extremely diverse derivation, such as diabase, porphyry, limestone, slate, etc. The schalsteins are, moreover, sometimes fossiliferous and distinctly bedded, and sometimes unfossiliferous, with as little evidence of stratification as an eruptive rock.

Some geologists consider the schalsteins as originating from a mixture of disintegrated diabases and ordinary argillaceous mud; others see in them a product of metamorphic processes; while most observers look upon them as volcanic tuffs, but greatly changed in consequence of their great age. That this last opinion is the only correct one seems clearly proved by the bombs which I have discovered.

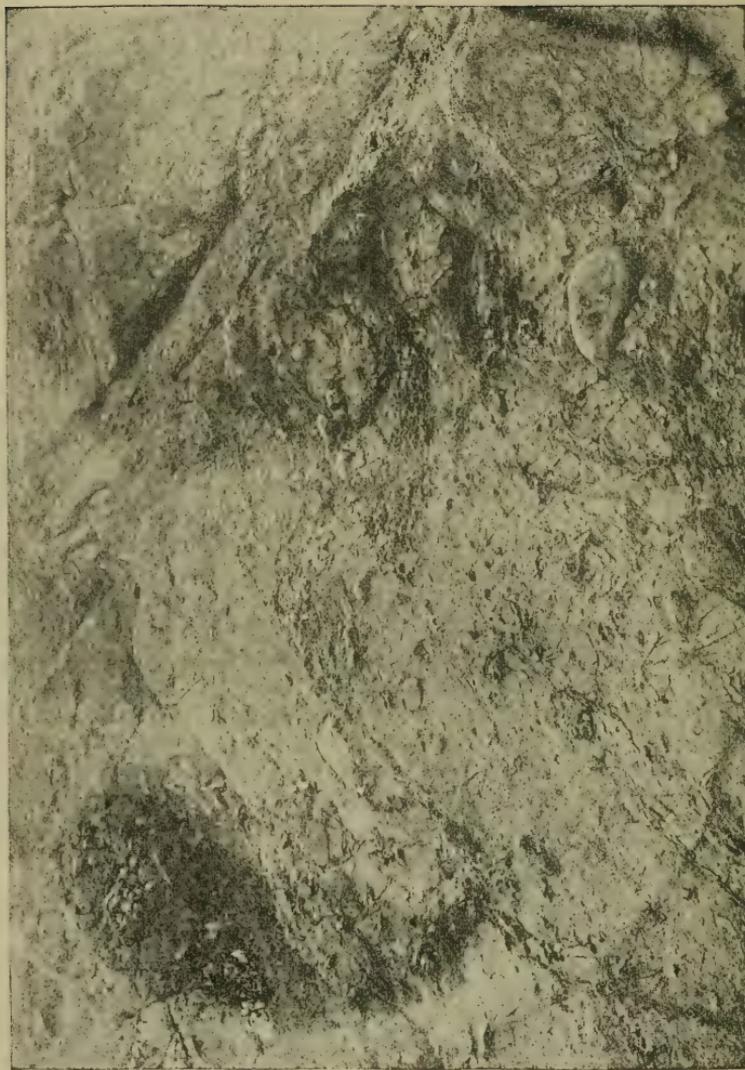
These bombs are found in great numbers in two localities in the neighbourhood of Oberscheld, near Dillenburg: firstly in the vicinity of the village of Bicken (well known to the palæontologist on account of the occurrence there of Hercynian and Upper Devonian fossils), in a fine, earthy schalstein, very well stratified; and secondly, close to Oberscheld, in a slaty rock, less clearly stratified.

In the first locality the rock forms a small hill, projecting from the surrounding Culm Measures and constituting geologically an anticlinal fold; in the second locality it is only separated from the superjacent Culm Measures by a moderately thick layer of diabase. The above-mentioned schalsteins must, therefore, belong to the uppermost horizon of the Upper Devonian.

The bombs are generally rounded, sometimes, however, angular; varying in size from that of a walnut to that of a man's fist, but sometimes as big as a man's head. They consist of a kernel of coarse-grained rock resembling gabbro, with a comparatively thin rind of 'mandelstein.' The kernel is composed, according to the researches of my colleague, Prof. M. Bauer, of a crystalline aggregate of calcite, mica, chlorite, and other minerals, and represents fragments of limestone altered by contact-metamorphism. The rind is 1 to 2 centim. thick, generally finely porous, but contains occasionally very large bubble-cavities, filled with calcite or zeolites.

The Oberscheld bombs are therefore very similar to the well-known bombs of olivine, mica, hornblende, etc., encrusted with a rind of lava, found in the tuffs of the Eifel, Auvergne, and other volcanic districts.

Portion of quarry-face in schalstein (diabase-tuff), showing the embedded volcanic bombs,  
at Rumpelsberg, near Oberschedl. (From a photograph.)



[Scale : about  $\frac{1}{20}$  linear.]

Together with the contorted diabasic lavas, also found in recent years in the Dillenburg area, and doubtless representing the superficial part of old lava-streams, these bombs undoubtedly prove that volcanic action in that far-off Palæozoic time was similar in all essential points to volcanic action in our own days. The bombs further demonstrate the explosive character of this volcanic action. Near Oberscheld and Bicken volcanoes must have arisen in Devonian times, from whose craters vast quantities of earthy or ashy materials, and innumerable fragments of the rocks, existing deep down below the surface and forced up by the escaping steam, etc., have been ejected. Thus did many fragments come into contact with the molten lava ascending through the same funnel, and were coated with a crust of lava, the above-mentioned mandelstein-rind.

Although, in the course of countless ages, every trace of the outward form of these old volcanoes has been destroyed, yet the bombs here preserved, which were ejected from them, demonstrate clearly the existence of the craters and show that their activity was in every respect similar to that of recent volcanoes.

8. *On the AFFINITIES of the ECHINOTHURIDÆ; and on PEDINOTHURIA and HELIKODIADEMA, two NEW GENERA of ECHINOIDEA.* By J. W. GREGORY, D.Sc., F.G.S., F.Z.S., Assistant in the Geological Department, British Museum. (Read December 2nd, 1896.)

## [PLATE VII.]

THE genus *Echinothuria* was founded by S. P. Woodward<sup>1</sup> in 1863 to include two Chalk fossils in the British Museum (Nat. Hist.). The specimen first discovered was found at Rochester, and it was regarded as a fossil cirripede until Darwin refused to accept it as a member of that class. Ed. Forbes then proposed to describe it as an holothurian, but finally declined this responsibility. It was not till the second specimen was found at Charlton by the Rev. J. N. Glass that the two fossils were recognized as probably fragments of an abnormal echinid. S. P. Woodward discussed the possibility of the fossils being holothurians or allied to Palæozoic echinids, such as *Protoechinus*; but he rejected both ideas, and cautiously described the specimens as belonging to a new genus of echinoderm, of which the affinities 'are still matter for conjecture.' He remarked that 'the disciples of von Baer may regard it as a "generalized form" of echinoderm'; but he shows that he realized one strong objection to this view, by pointing out the fact of the fossil 'coming, however, rather late in the geological day.'

The importance of the genus *Echinothuria* was not fully appreciated until 1873. In that year Sir Wyville Thomson<sup>2</sup> published an account of some recent echinids with flexible tests: for one series of these he proposed the name *Calveria*, but this has since made way for that of *Asthenosoma*, which had been given by Grube<sup>3</sup> in 1868. Thomson recognized the affinity of the deep-sea species with the Chalk fossil, and included both, with a third genus *Phormosoma*, in a new family—Echinothuridæ.

The possible affinity of these flexible echinids with the Palæozoic genera at once aroused the interest of palæontologists. Prof. J. Young,<sup>4</sup> in 1873, and Mr. R. Etheridge, Jun., in 1874, promptly called attention to the resemblances between them. The latter author welcomed the new genera as throwing light on the relationship between Palæozoic and recent Echini, and as serving 'to unite

<sup>1</sup> 'On *Echinothuria floriss*, a New and Anomalous Echinoderm from the Chalk of Kent,' *Geologist*, vol. vi. (1863) pp. 327-330, & pl. xviii.

<sup>2</sup> 'The Depths of the Sea,' 1873, pp. 155-159; 'On the Echinoidea of the Porcupine Deep-Sea Dredging Expedition,' *Phil. Trans. Roy. Soc.* vol. clxiv. (1874) pp. 730-737.

<sup>3</sup> '*Asthenosoma varium*, n. sp.,' *Jahresber. Schles. Gesellsch. Breslau*, vol. xlv. (1868) pp. 42-44.

<sup>4</sup> 'On a Carboniferous Genus of Echinoderms with Overlapping Plates,' *Geol. Mag.* 1873, pp. 301-303.

the echini of the present seas with certain of those genera which existed during Palæozoic times.'<sup>1</sup>

The view of the close affinity of the Echinothuridæ with the Palæozoic 'Perischoechinidæ' was not allowed to pass unchallenged. It was denied by the late W. Keeping,<sup>2</sup> from a study of the fossil forms, and by Prof. F. J. Bell<sup>3</sup> in his classification of the recent families. Bell, however, still regarded the gap between the Echinothuridæ and other ectobranchiate echinids as very marked. He included the family in his Ectobranchiata, which he divided into two series: one of these, the Neoproctous, included all regular echinids except the Cidaridæ and Saleniidæ; it was subdivided into two subseries, the 'polylepid,' including only the Echinothuridæ, and the 'decalepid,' containing all the rest.

Prof. A. Agassiz, about the same time, also clearly recognized the affinity of the Echinothuridæ with the typical families of living ectobranchiate echinids. He even remarked<sup>4</sup> that 'it is difficult to separate this group of echinids as a distinct family from the Diadematidæ.' But he counteracted this advanced view and gave great encouragement to the older hypothesis by the remark 'that the Palæchinidæ are far more closely allied to the recent echinids than is usually supposed, and that we have in the recent Echinothuridæ structural features combining the characteristics of the normal Desmosticha and of the Palæchinidæ.'<sup>5</sup>

This view received its most definite exposition in an important memoir by the cousins P. & F. Sarasin,<sup>6</sup> published in 1888. These authors, impressed by many remarkable features in the anatomy of a new species of *Asthenosoma* (*A. urens*), claimed that the Echinothuridæ are the most primitive of living Echinoidea, and established the origin of this class from an holothuroid ancestor. They laid especial stress on the great size of the 'Stewart's organs,' on the presence of a series of powerful radial muscles, and on the absence of the supposed calycinal system of plates. Bell,<sup>7</sup> however, showed in 1889 that both the 'Stewart's organs' and radial muscles are absent or rudimentary in the genus *Phormosoma*, and that these organs therefore do not possess the importance attached to them by the Sarasins.

<sup>1</sup> 'On the Relationship existing between the Echinothuridæ, Wyv. Thoms., and the Perischoechinidæ, M'Coy,' Quart. Journ. Geol. Soc. vol. xxx. (1874) pp. 307-315, & pl. xxiv.

<sup>2</sup> 'Notes on the Palæozoic Echini,' *ibid.* vol. xxxii. (1876) p. 40.

<sup>3</sup> 'Observations on the Characters of the Echinoidea, pt. iv.: The Echinometridæ; their Affinities and Systematic Position,' Proc. Zool. Soc. 1881, p. 417.

<sup>4</sup> 'Report on the Echinoidea,' *Challenger* Exped., Zool. vol. iii. (1881) p. 71.

<sup>5</sup> *Ibid.* p. 81.

<sup>6</sup> 'Ueber die Anatomie der Echinothuriden u. die Phylogenie der Echinodermen,' *Ergebn. naturw. Forsch. auf Ceylon*, vol. i. (1888) pp. 83-151.

<sup>7</sup> 'Report of a Deep-Sea Trawling Cruise off the S.W. Coast of Ireland under the direction of Rev. W. Spotswood Green. Echinodermata,' by F. J. Bell, *Ann. Mag. Nat. Hist.* ser. 6, vol. iv. (1889) pp. 436-438.

Duncan, who carefully considered the Sarasins' arguments during the preparation of his 'Revision of the Genera and Great Groups of the Echinoidea,' did not accept their conclusions. He pointed out the differences between the Palæozoic echinids and the Echinothuridæ, and concluded that 'it appears more reasonable to place the Echinothuridæ near the Diadematidæ, granting some atavism, than to station them at the end of the Palæchinoidea.'<sup>1</sup> Like Bell, however, he separated them from the rest of his order, the Diadematoida (which included all Neozoic regular echinids except the Cidaridæ), as a special suborder, the Streptosomata.

Hence there have been, and still are, two opposite theories as to the affinities of the Echinothuridæ. According to one school, the characters of this family are primitive and ancestral; according to the other, they are degenerate and highly specialized. As it is impossible to progress with the phylogenetic classification of the echinids until it be known whether the Echinothuridæ are a root or whether they are a branch near the summit, I may be excused for again calling attention to this question.

As we have already seen, it has been remarked by A. Agassiz, Bell, and Duncan—to whom Neumayr<sup>2</sup> may be added—that, in spite of the resemblances between the Echinothuridæ and the flexible Palæozoic echinids, this family is most closely allied to the Diadematidæ. It was natural first to compare *Asthenosoma* with *Astropyga*. But, as Wyville Thomson remarked in 1874, although 'some characters would seem to indicate a tendency to a passage from the Diadematidæ to the Echinothuridæ, through such forms as *Astropyga*, the resemblances are for the most part superficial, and very important anatomical characters maintain, according to our present knowledge, a broad line of distinction between the families.'<sup>3</sup> *Astropyga* is now recognized as a thin-tested member of the family Pedinidæ, with no special resemblances to any of the Echinothuridæ.

In most previous attempts to determine the origin of this family, the living echinothurids have been taken as the starting-point. The ancestry of the family is inferred from the characters of the latest and most specialized, instead of from those of the earliest and most primitive members. The best clue as to the origin of the Echinothuridæ is obtained from *Pelanechinus*, a Corallian genus founded by W. Keeping,<sup>4</sup> and ably described by T. T. Groom.<sup>5</sup> His account leaves no doubt that *Pelanechinus* is an echinothurid, of which family it is the oldest known form.

<sup>1</sup> 'A Revision of the Genera and Great Groups of the Echinoidea,' Journ. Linn. Soc., Zool. vol. xxiii. (1891) pp. 39-40.

<sup>2</sup> 'Die Stämme des Thierreiches,' vol. i. (1889) p. 377.

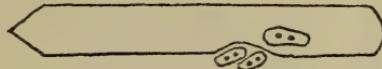
<sup>3</sup> Phil. Trans. Roy. Soc. vol. clxiv. (1874) p. 732.

<sup>4</sup> 'On *Pelanechinus*, a New Genus of Sea-Urchins from the Coral Rag,' Quart. Journ. Geol. Soc. vol. xxxiv. (1878) pp. 924-930.

<sup>5</sup> 'On some New Features in *Pelanechinus corallinus*,' *ibid.* vol. xliii. (1887) pp. 703-714 & pl. xxviii.

*The Characters of the Ambulacra in the Echinothuridæ.*—Since Duncan's classical paper on the 'Structure of the Ambulacra of some Fossil Genera and Species of Regular Echinoidea,'<sup>1</sup> it has been universally admitted that the characters of the ambulacral plates offer the best guidance in the classification of that section of the class. These plates in *Asthenosoma* and *Phormosoma* are very different from those of any other living echinid. It will be advisable therefore, in the first place, to endeavour to trace their gradual development. In the living echinothurids the ambulacral plates are all free; two-thirds of the pore-pairs occur in small plates ('klasma-plates') lying along the horizontal sutures between the remaining plates (fig. 1). Both characters remind us of the ambulacral plates of some Palæozoic echinids, which are multiserial, simple, and free. But in the living echinothurids every third plate is a large primary; and in spite of the apparent irregularity of the plates, they may be recognized as occurring in triplets. This

Fig. 1.—*Ambulacral plates of Phormosoma Uranus.* (After A. Agassiz.)



is quite different from anything met with among the Palæozoic echinids, and they agree fundamentally with the typical Diadematoidea. If the Echinothuridæ are to be regarded as descendants from the Palæozoic echinids, then compound ambulacral plates have been twice independently developed from the simple primary plates of the latter and of the Cidaridæ. This is not impossible, for heterogenetic homœomorphy unquestionably occurs sometimes. It is highly probable that echinids with 'arbacioid' ambulacral plates have developed from forms with simple ambulacral plates, through stages represented by the genera *Salenia* and *Acrosalenia*; while those with 'diademoid' ambulacral plates have developed through forms such as *Eodiadema* and *Archæodiadema*. It is conceivable that there may have been a third line along which the Echinothuridæ have developed; but there is no evidence of any such development, and we ought not to assume this origin in face of actual evidence for one which is inherently far more probable.

It will be remembered that the typical 'diademoid' ambulacral plates consist of three primary plates fused into one (fig. 9, p. 121). The middle primary is usually the largest. The gradual growth of this central plate may be traced until the adoral and aboral plates are cut off from the vertical suture-line, and thus become demi-plates (fig. 6*d*, p. 118). By a further progress in the same direction, the demi-plates are reduced to the condition of 'klasma-plates,'<sup>2</sup> detached

<sup>1</sup> Quart. Journ. Geol. Soc. vol. xli. (1885) pp. 419-452.

<sup>2</sup> A name suggested for the small, eye-shaped plates, which are cut off from contact with either the vertical suture running down the centre of the ambulacral area, or that between the ambulacrum and interambulacrum. They represent a stage of reduction further than that of demi-plates. From κλάσμα, a fraction.

from both of the vertical sutures, and lying only on the horizontal sutures (see fig. 1), as in *Phormosoma Uranus*. Now in *Pelanechinus* the ambital ambulacral plates (fig. 2) each consist of three primary ambulacral plates and three demi-plates and three klasma-plates, or nine constituents in all. This arrangement is apparently so complex that Mr. Groom suggests that it is to be regarded as a new type of ambulacral plate.<sup>1</sup> But the plates near the end of an ambulacrum consist of triplets, each composed of a central large primary with a demi-plate (or klasma-plate) above and below it (fig. 3). This is the arrangement of a typical 'diademoid' plate. If we follow along an ambulacrum of a *Pelanechinus*, we find a gradual passage from the simple diademoid triplets to the large compound plates of the ambitus. These plates may, therefore, be regarded as formed by the fusion of three diademoid plates.

In the living Echinothuridæ the ambulacral triplets are usually described as formed of a large aboral primary and two small demi-plates in the adoral suture of the primary (fig. 1, p. 115). This view obscures the diademoid structure of the plates. If we examine the ambital plates the usual view appears the natural one. But if we examine the ambulacral plates near the apex, we find that they are composed of a central primary between an adoral and an aboral primary, as, for example, in *Phormosoma bursarium* (fig. 4), and near the peristome the same arrangement recurs (fig. 5); that is to say, the plates are typically diademoid, and agree in arrangement with the equivalent plates of *Pelanechinus*. From these upper plates we may follow the series downward, seeing the gradual increase of the central plate, and the reduction of the demi-plates until they occur as small klasma-plates in the horizontal suture. The development of the plates shows, therefore, that the ambulacral plates

Fig. 2.—Ambital ambulacral plate of *Pelanechinus*. (After Groom.)

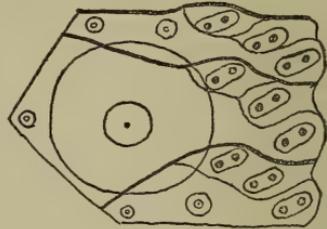


Fig. 3.—Peristomal ambulacral plates of *Pelanechinus*, showing division into triplets of the diademoid type.

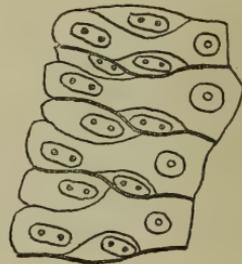
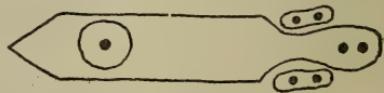


Fig. 4.—Ambulacral plates of *Phormosoma bursarium* near the apex. (After A. Agassiz.)



<sup>1</sup> Quart. Journ. Geol. Soc. vol. xliii, (1887) p. 707. The author, however, there regards the triplets as of the echinoid, and not of the diademoid type.

ought to be described as composed of a central primary between aboral and adoral demi-plates; and of the pair of pore-pairs below each primary, one belongs to the same triplet as the plate above, and the other to that of the plate below. The limits of the triplets in *Pelanechinus* are shown in fig. 5.

*Pelanechinus* and the living echinothurids, therefore, begin with plates of identically the same arrangement. In *Pelanechinus* three of the triplets fuse into a compound plate; while in *Asthenosoma* and *Phormosoma*, on the other hand, the triplets are broken up—owing to reduction in the calcification of the test.

It appears, therefore, possible to explain the peculiar arrangement of the ambulacral plates of living echinothurids as due: 1st, to the fusion of three diademoid triplets; 2nd, to their dissociation *pari passu* with the reduction of

the calcareous matter in the test, as the plates become thinner and the test flexible. If this view be correct, then the flexibility of the Echinothuridæ is a secondary character, and was not due to inheritance from a flexible, Palæozoic ancestor.

The structure of the ambulacral plates seems conclusively to prove that the Echinothuridæ are members of the order Diademoida. The question arises whether the members of this family have descended from a diademoid ancestor, or whether the rest of that order have descended from an echinothurid.

That the former alternative is the true one is rendered probable by several reasons:—1stly, the Echinothuridæ are younger than many of the Diademoida, for this order begins in the Lower Lias, while the family does not appear until the Corallian; 2ndly, the oldest form of echinothurid is more nearly allied to the nearest diademid than are the later, and apparently more primitive, members of the family. To accept the other alternative would make diademids found in the Lower Lias, and even some older forms occurring in the Trias, descendants from genera not known to occur earlier than the Corallian.

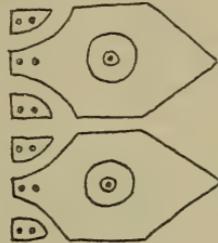
Let us therefore next enquire whether there be any member of the Diademoida, of Corallian or pre-Corallian age, from which *Pelanechinus* could have been derived.

Neumayr<sup>1</sup> has already suggested that the evolution of the family was through 'a series from *Hemipedina* by *Pelanechinus* to the Echinothuridæ.' It is true that the only species of *Pelanechinus* was originally described as an *Hemipedina*<sup>2</sup>; and the two genera

<sup>1</sup> 'Ueber *Palæchinus*, *Typhlechinus*, und die Echinothuriden,' Neues Jahrb. 1890, vol. i. p. 85.

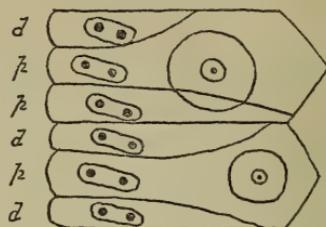
<sup>2</sup> *H. corallina*, Wright, 'Monogr. Brit. Foss. Ech. Ool.,' p. 163, pl. xii. fig. 1.

Fig. 5.—Ambulacral plates of *Phormosoma luculentum* near the peristome. (After A. Agassiz.)



agree in having perforate, non-crenulate tubercles, and low, broad interambulacral plates, each with a row of tubercles. But the genera differ widely by the structure of the ambulacral plates. In *Hemipedina* the compound ambulacral plates are always formed of three primaries, and the pore-pairs are a simple vertical series. But in *Pelanechinus* the pore-pairs are triserial. We have therefore to look for its ancestor among the triserial Pedinidæ, and not among the uniserial Diadematiidæ to which *Hemipedina* belongs.

Fig. 6.—Ambulacral plates of *Pedina*. (After Duncan.)



Before following this clue, however, we must remember that Duncan adopted a course which, if agreed upon, would prevent the derivation of the Echinothuridæ from such specialized Diademoida as the Pedinidæ. Duncan divided the order Diademoida into two suborders—the Streptosomata, including the Echinothuridæ, and the Stereosomata, including the rest of the order. He defined the Streptosomata as follows<sup>1</sup>:—‘Test more or less flexible, with external and internal branchiæ. Ambulacral plates alone continued beyond the peristome to the stoma.’ But all these characters also occur among the other suborder, the Stereosomata. In the pedinid *Astropyga* and the diademid *Helikodiadema* (see *infra*, p. 121) the test is more or less flexible. Both external and internal branchiæ are as well developed in *Diadema* as they are in *Phormosoma*.<sup>2</sup> In those of the Stereosomata which have plates on the peristomal membrane, these are always ambulacral.

Hence Duncan’s diagnosis is useless, and there is no evidence to show that the Echinothuridæ diverged from the main diademoid stem at a very early period. We may search therefore among the triserial members of that order for a suitable ancestor for the echinothurids. Of all the Pedinidæ, *Pedina* is most like *Pelanechinus*. The interambulacral plates have the same tuberculation, for in both genera they are multiserial, perforate, and non-crenulate.

The ambulacral plates of *Pedina* show a series of stages between simple diademoid plates and those of *Pelanechinus*. The ambital plates of *Pedina* usually consist of three primaries, of very unequal size. In some cases the middle primary increases so much in size that it crowds out the other two constituents and reduces them to demi-plates (fig. 6). These demi-plates may even lose any connexion with the vertical suture between the ambulacral and interambulacral areas; they are thus reduced to the position of klasma-plates on the horizontal sutures between the primaries. Plates in this

<sup>1</sup> Journ. Linn. Soc., Zool. vol. xxiii. (1890) p. 25.

<sup>2</sup> F. J. Bell, Ann. Mag. Nat. Hist. ser. 6, vol. iv. (1889) p. 437.

condition are not common in *Pedina*; but they do occur, and they are identical in arrangement with the ambulacral plates near the apex of *Pelanechinus* and *Phormosoma*.

Thus *Pedina* suggests the point at which the echinothurid branch diverged from the main diademoid stem. The gap between *Pelanechinus* and the nearest member of the rest of the order Diademoida is bridged by a new echinid from the German Jura, which I have accordingly named *Pedinothuria*. Its test being small and rigid, it appears to be nearer to the Pedinidæ than to the Echinothuridæ.

#### PEDINOTHURIA, gen. nov.

*Diagnosis*.—Pedinidæ with the test small, rigid, and turban-shaped.

Apical system large, its diameter about half that of the test. The arrangement of the plates is unknown.

Ambulacra.—Near the apex the plates are simple primaries. At the ambitus the pore-pairs are biserial, owing to the reduction of alternate primaries to demi-plates. Below the ambitus the pore-pairs are triserial, owing to the presence of a second demi-plate on the horizontal suture between two primaries.

Near the peristome the plates are not compound; they are all demi-plates, and occur in three series. Those of the median series are the largest, and they may bear a miliary granule.

There are no primary tubercles on the ambulacra; but two rows of small, regular granules run down each ambulacrum. Near the peristome they are small, and limited to the primary plate on which they occur.

Interambulacra.—The plates are unituberculate. Upon each there is a prominent, primary tubercle, which is perforate and crenulate. About seven in each vertical series. The mamelons are perforated. Near the peristome the ambulacra are broader than the interambulacra.

Peristome small; branchial slits very deep.

*Distribution*.—Jurassic, Germany.

#### PEDINOTHURIA CIDADROIDES, sp. nov. (Pl. VII. figs. 1-3.)

*Diagnosis*.—Test circular, depressed. Oral surface very flat; aboral half slightly tumid.

Apical system slightly more than half the width of the test in diameter.

Interambulacra.—Seven plates in each vertical series. Scrobicular areas confluent. Miliary granules scarce.

Ambulacra.—Structure as in generic diagnosis. The change from the uniserial to the biserial arrangement of the pore-pairs occurs at the 12th or 13th plate from the apex.

*Dimensions*.—Diameter, 12 millim.; height, 5 millim.; diameter of apical area, 7 millim.; diameter of peristome, 4 millim.; width of ambulacrum at ambitus,  $2\frac{1}{2}$  millim.; width of interambulacrum

at ambitus, 5 millim.; width of interambulacral plates in each series, 7 millim.

*Distribution*.—Weisser Jura, Germany. Type, B. M., no. 34,724.

*Affinities*.—This specimen was sent to the Museum labelled *Diplocidaris*. Its deep branchial slits and compound ambulacral plates show that it cannot belong to the order Cidarida. There can be no doubt that it is a member of the order Diademoida, for the genus is regular and ectobranchiate. It is distinguished from the suborder Calycinæ (including the Saleniidæ and Acrosaleniidæ), in the absence of knowledge of the structure of the apical system, by the complexity of the ambulacral plates. From the suborders Arbacina and Echinina it differs in having the ambulacral plates diademoid, instead of on the arbacid or echinoid type. The genus falls easily into the suborder Diademina, owing to the character of the ambulacral plates. In this suborder there are six families; of which the Orthopsidæ have simple ambulacral plates; the Diadematidæ and the Diplopedinidæ respectively have regularly uniserial and biserial pore-pairs; the Cyphosomatidæ have the pore-pairs in high curved arcs. This leaves only the two families of the Pedinidæ and Echinothuridæ, with both of which the genus agrees in some respects. Thus the ambulacral plates may consist of a central primary and two demi-plates, one or both of which may be further reduced to klasma-plates. The plates just below the ambitus of *Pedinothuria* agree exactly with those of *Asthenosoma*, except that they are thicker and solidly united to their fellows. They are more of the echinothurid type than of that of *Pedina*. Nevertheless, owing to the rigidity of the test, and the unituberculate, cidaroid character of the interambulacral plates, it appears advisable to include the genus in the family Pedinidæ.

The exact horizon whence the fossil came is unfortunately unknown. It is simply labelled 'Weisser Jura, Germany.' The test has apparently been washed in weak acid, and thus it may not be safe to guess its horizon from its appearance. But, as far as I can judge, it probably came from either Western Bavaria or Württemberg, and from the horizon  $\gamma$  of the Weisser Jura. In that case it would be older than the earliest echinothurid, which lived in the succeeding stage of the Weisser Jura  $\epsilon$ .

As the main difference between *Pedinothuria* and *Pelanechinus* is that the latter had a somewhat flexible test, it is advisable to consider the value of this character. The evidence of *Astropyga* and of the deep-sea spatangids, such as *Calymne* and *Cystechinus*, shows that flexibility is not limited to a single family, and may be independently acquired; it is probably due to changes of environment leading to diminished calcification of the test. We must therefore be prepared to meet with imbricating-plates in any group of echinids.

In various Mesozoic rocks there occur isolated plates, with truncated margins, which, if imbrication and flexibility were limited to the Echinothuridæ, would have to be referred to that

family. S. P. Woodward called attention to these plates in his original description of *Echinothuria*. Spines had previously been figured by Forbes, first as belonging to *Micraster*<sup>1</sup> and then to *Cidaris*.<sup>2</sup> S. P. Woodward<sup>3</sup> and Wright<sup>4</sup> showed a truer appreciation of their characters by assigning them to *Diadema*. At this time, however, the echinid was known only from isolated plates. In Wright's 'Monograph of the Cretaceous Echinoidea' a better

Fig. 7.—Ambulacral plates of *Helikodiadema* at summit of ambulacrum.



Fig. 9.—Ambulacral plates of *Helikodiadema* adjoining peristome.

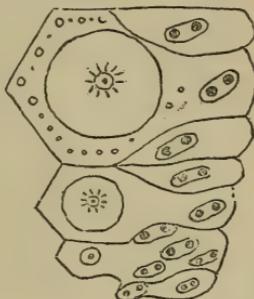


Fig. 8.—Ambulacral plate of *Helikodiadema*.

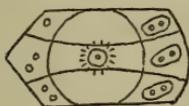


Fig. 10.—Genital plate of *Helikodiadema*.



specimen was figured, with the plates in their relative positions:<sup>5</sup> it was named *Pseudodiadema fragile*. The structure of the ambulacral plates was not shown; but the accompanying figure (7) of a specimen in the British Museum (B. M. 46,781) shows that the plates are diademoid.

The echinid is most nearly allied to *Pseudodiadema*, but the differences between it and that genus seem well worthy of generic distinction. I therefore describe it as follows:—

*HELIKODIADEMA*,<sup>6</sup> gen. nov. (Figs. 7–10.)

*Diagnosis*.—Diademata with a large, flexible test, composed of thin, loosely-fitting plates. Peristome and periproct large. Perignathic processes slender.

<sup>1</sup> E. Forbes, in Dixon's 'Geol. Suss.,' Expl. of pl., p. x, pl. xxv. fig. 28.

<sup>2</sup> *Id.*, Dec. Geol. Surv. no. iii. pl. x. fig. 15.

<sup>3</sup> S. P. Woodward, *ibid.* no. v. pl. ii. p. 11.

<sup>4</sup> Wright, 'Monogr. Cret. Ech.' pl. xiv. fig. 2.

<sup>5</sup> *Ibid.* pl. lxxx.

<sup>6</sup> From *ἐλικος*, twisting.

Apical system apparently a single circle of ten plates. Genital plates pentagonal and large.

Ambulacra.—The plates near the apex are primaries. At the ambitus they are of three fused primaries. Near the peristome they are crowded, and demi-plates are numerous.

Tubercles perforate and crenulate.

Spines annulated, fluted, hollow.

*Distribution*.—Chalk, England.

*Type Species*.—*Helikodiadema fragile* (Wilts.), of which the synonymy is as follows:—

*Cidaris*, sp., Forbes, 1850, in Dixon, 'Geol. Suss.,' Expl. of pl., p. x, pl. xxv. fig. 28.

*Micraster*, sp., Forbes, 1850, Dec. Geol. Surv. no. iii. pl. x. fig. 15.

*Diadema*, sp., S. P. Woodward, 1856, Dec. Geol. Surv. no. v. pl. ii. p. 11; Wright, 1868, 'Mon. Cret. Ech.' pl. xiv. fig. 2; S. P. Woodward, 1878, in Dixon, 'Geol. Suss.' 2nd edit. p. 372, pl. xxv. [28] fig. 28.

*Pseudodiadema fragile*, Wiltshire, 1882, in Wright, *op. cit.* pl. lxxx.

#### SUMMARY OF CONCLUSIONS.

1. That the family Echinothuridæ is a member of the order Diademoida, and is derived from the Pedinidæ.

2. That the oldest member of the family is the genus *Pelanechinus*, and that the extreme flexibility and loose articulation of the plates of the living genera *Asthenosoma* and *Phormosoma* are due to diminished calcification of the plates.

3. That the apparently primitive features of the Echinothuridæ are secondarily acquired and are not primæval. The recent genera are therefore extremely specialized, instead of being primitive forms.

4. A new genus *Pedinothuria* is a connecting-link between the Pedinidæ and the Echinothuridæ.

5. A new genus *Helikodiadema*, which has a flexible test, is a modified form of *Pseudodiadema*; it has probably arisen from the adoption of deep-sea life having resulted in diminished calcification of the test.

[For Explanation of Plate VII., see p. 134.]

9. On ECHINOCYSTIS and PALÆODISCUS—two SILURIAN GENERA of ECHINOIDEA. By J. W. GREGORY, D.Sc., F.G.S., F.Z.S., Assistant in the Geological Department, British Museum. (Read December 2nd, 1896.)

## [PLATE VII.]

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## I. INTRODUCTION.

THE persistence with which the Crinoidea, Echinoidea, and Stelleroidea have maintained their essential characters, from their first appearance until the present time, has been often remarked and has received very different explanations. Thus, Prof. Poulton<sup>1</sup> [3, pp. 507-509], in his recent address to the Zoological Section of the British Association, deduces from the fact the vast duration of that part of the pre-Cambrian era during which the earth was inhabited. When the palæontological record begins in the Cambrian period, the phylum Echinoderma was already in existence. It was represented by the crinids, cystids, and stellerids, which were joined in the Ordovician by echinids. But, in spite of their early appearance, the oldest known members of the surviving classes may be assigned to their respective divisions as readily as if they were perfectly-preserved recent specimens. That the different classes of echinoderms have descended from a common ancestor is now unquestioned; but the search for missing links between those that still exist has not been attended with any success. The two recent classifications of the Echinoderma by Bell [1] and Hæckel [3, p. 164] unite the Stelleroidea and Echinoidea into one section. But the oldest known members of these two classes resemble one another less than do some of their later representatives; and we do not yet know a single intermediate form between them. Similarly, *Tiarechinus*, which of all Echinoidea most resembles the Crinoidea, came far too late to give any evidence as to the ancestry of either class. The only fossil echinids which give much help in linking their class with any of the others are the Silurian *Echinocystis* and *Palæodiscus*, of which the structure is imperfectly known.

I prepared some notes on both genera in 1888, which the late

<sup>1</sup> The numerals in thick type throughout this paper refer to the bibliographical list on p. 134.

Melchior Neumayr kindly urged me to publish then. The hope, however, of obtaining access to better specimens has delayed me from doing so until now.

## II. HISTORY OF THE GENERA.

*Palæodiscus* was the first established of the two genera. It was founded by J. W. Salter in 1857 [9, p. 332, pl. ix. fig. 6] on a fossil from the Ludlow Flags of Leintwardine. He described it as a new starfish, a view which seemed to be established by the flattened, pentagonal form of the fossil and its radiating lanceolate ambulacra, which were apparently limited to one side of the body.

*Echinocystis* (or *Echinocystites*) was founded by Wyville Thomson in 1861 [11] for some fossils from the same horizon as *Palæodiscus*. He recognized that they were echinids with affinities to the cystids, and placed *Palæodiscus* as a flat member of the same family. In this course, however, he has not been widely supported. Wright [14, p. 35], who next referred to *Palæodiscus* in 1863, accepted it as an asterid, and Zittel, in 1879 [15, p. 453], did the same, placing it in his suborder Encrinasteriæ. Neumayr, in 1881, republished Wright's figure, and concluded [7, p. 156], 'trotzdem tauchte kein Bedenken gegen die Seesternnatur dieser Formen auf.'

Nevertheless, Duncan, in 1889, after examining specimens, not only regarded *Palæodiscus* as an echinid, but he made it a synonym of the genus *Echinocystis* [2, p. 20]. The latter genus had, meanwhile, been made by von Zittel [15, p. 480] the type of a new order of Echinoidea named Cystocidaroida, while Steinmann and Döderlein [10, p. 180] used it as the basis of an order of Cystoidea which they named Cystechinoidea. Finally, Jackson retains it among the Echinoidea [4, p. 242].

*Palæodiscus* is therefore regarded as an echinid or an asterid, and *Echinocystis* as an echinid or a cystid. As there are good specimens of both genera in the British Museum, I propose to describe them—in order to attempt the determination of the class or classes to which they belong. The specimens all come from the Lower Ludlow Flags of Leintwardine; those of *Echinocystis* are casts, which yield good impressions in wax of the original animals.

## III. THE STRUCTURE OF ECHINOCYSTIS.

The specimens representing this genus in the British Museum are mostly crushed on to a plane, passing through the ambitus. Sir Wyville Thomson, however, figured specimens which had been flattened along a plane passing vertically upward through the mouth, and these show the general form of the animal. Steinmann's diagrammatic restoration is based on these figures. The remaining points in the anatomy are illustrated by different specimens in the British Museum; thus the structure of the ambulacra and the shape and position of the madreporite are shown in No. 40,158, and the character of the jaws in Nos. E 1256 and 40,156.

The following account of the animal has been compiled from the

Museum specimens, supplemented by Thomson's figures for the shape of the test:—

*Description.*—Form spheroidal, either prolate or oblate. The test is thin and flexible. The peristome is central on the lower surface. The anus is protected by a group of large plates; it is not opposite the mouth, but opens in the posterior interambulacrum.

Ambulacra regular in width, tapering gradually to the apex. Each ambulacrum consists of four series of plates. The plates are small, simple demi-plates. The pore-pairs are biserial (fig. 1).

Interambulacra of numerous irregular, angular plates. In the widest parts of the interambulacra they are about ten in width, decreasing in number above and below. The plates vary from triangular to hexagonal. Most of the interambulacral plates bear small granules, which support short, sharp, movable spines. Small miliary granules also occur.

Madreporite large, circular or polygonal; granular in appearance, being perhaps perforated by many fine pores. It is situated in the posterior interambulacrum, a short distance from the meeting-point of the five ambulacra.

Apical plates absent.

Jaws large and powerful. The masticatory apparatus is described by Thomson as 'a five-sided pyramid . . . . composed of pairs of strong, hollow, wedge-shaped jaws.' The apparatus consists of five pyramids, which in general character resemble those of the *Cidaridæ*, although there does not appear to have been either rotula or brace. The symphysis between the two half-pyramids is long, and the epiphyses are short. Seen from the back (fig. 2), a deep triangular depression appears to occupy most of the surface of each half. At the free angle of each half-pyramid there are three depressions, separated by branches from the marginal ridge; these depressions and ridges were probably used for muscular attachments. The distal apex of the pyramid is very sharp (fig. 3): according to Thomson there were strong spines situated at this point, a statement which I have been unable to verify.

*Distribution.*—Leintwardine Flags, Lower Ludlow, near Leintwardine, Shropshire. There are two species—*E. uva* and *E. pomum*, but the former may be only a young stage of the latter.

Fig. 1.—*Ambulacral plates of Echinocystis.*

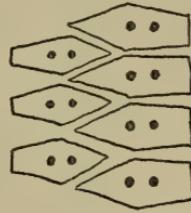


Fig. 2.—*Pyramid from masticatory apparatus of Echinocystis, seen from behind.*



Fig. 3.—*Distal end of pyramid of Echinocystis from the side.*



## IV. THE AFFINITIES OF ECHINOCYSTIS.

*Echinocystis* has been assigned to both the classes Echinoidea and Cystoidea, and there can be little doubt that it belongs to one of them. In order to determine in which of the two it is to be placed, we must first consider the essential differences between them. We are at once confronted with the difficulty that the diagnoses of the class Cystoidea are very unsatisfactory, and it is easier to condemn than to improve them. Bell, in 1891, when discussing the inter-relations of the classes of Echinoderma, recoiled from the task of drawing up a diagnosis of the Cystoidea, and hoped [1, p. 215] that 'perhaps a palæontologist will oblige.' Since that date two palæontologists have 'obliged,' and we must first enquire whether *Echinocystis* is necessarily included by them among the cystids.

Von Zittel [16, p. 148], in 1895, defined the Cystoidea as follows:—'Extinct, short-stalked, more rarely unstalked Pelmatozoa, with more or less irregularly-arranged calycinal plates, with the arms feebly developed, and sometimes quite absent. The calycinal plates are frequently perforated by fine canals.'

There is nothing in this diagnosis except the word Pelmatozoa to exclude *Echinocystis*; for it is an extinct, unstalked form, with irregularly-arranged plates, without arms, and having some of the plates perforated by fine canals. But *Lepidesthes* and *Melonites* both possess the same series of characters, for in these two genera the plates protecting the body are less regular than in *Caryocrinus* or *Porocrinus*. We have therefore to refer back to von Zittel's diagnosis of Pelmatozoa to see if this will exclude forms like *Tiarachinus* and yet admit *Echinocystis*.

The diagnosis of the Pelmatozoa [16, p. 113] is as follows;—'Echinoderma which are fixed by a jointed stem or directly by the aboral (dorsal) side of the body, either throughout life or in youth. A bag-shaped, calyx-shaped, or spherical capsule of calcareous plates encloses the body-cavity. On the upper (oral or ventral) side are the mouth and anus, as well as ambulacral vessels leading to the mouth. At the distal ends of the ambulacral furrows of the tegmen there usually arise jointed arms, or the ambulacral furrows continue over the sides of the cup, and are bordered on both sides by pinnules. The lower (dorsal, aboral) side is encompassed by one or two circles of basal plates, which either rest on the stem or surround a centro-dorsal plate.' The positive characters in this definition are:—(1) fixation at one period of life; (2) a capsule of calcareous plates; (3) the occurrence of mouth, anus, and ambulacra on the upper surface; (4) the presence of arms or pinnules; (5) the double circlet of calycinal plates.

This combination of characters does not, however, give any test by which we can at once say whether a certain fossil is a cystid or an echinid. There are exceptions in regard to each character. Thus we now know both pelmatozoic and apelmatozoic cystids and crinoids, including forms which not only have no stalk, but no trace of an aboral attachment. Prof. Bell remarks [1, p. 210],

‘I suppose no morphologist will be bold enough to say whether *Marsupites* or the irregular Blastoids are primarily or secondarily free forms.’ To affirm that *Marsupites* had a fixed stage is to push the analogy with *Antedon* to extreme and improbable limits. *Antedon* retains in the adult definite traces of its early attachment; its central plate is called a centro-dorsal, that is, it is regarded as the modified top stem-joint. But the corresponding plate in *Marsupites* is called a dorso-central, that is, it is regarded as the central basal plate; therefore, *ex hypothesi*, *Marsupites* cannot have had a stem, and its dorso-central shows no scar left from attachment by that plate.

In *Uintacrinus* the improbability of the members having passed through a fixed stage is still greater, for the genus was probably pelagic, and pelagic animals usually have free-swimming larvæ, even when those of their littoral or abyssal representatives are fixed.

The second statement in the diagnosis of Pelmatozoa, namely, that the body is enclosed in a capsule of calcareous plates, is useless, for it is as true of echinids as of crinids.

The third point in the definition has too many exceptions on both sides to be valid. The mouth and anus are both oral in many echinids, whereas the anus is not on the oral side in some cystids, such as *Anomalocystis*. There are no ambulacral furrows in some cystids, such as *Aristocystis*, while they occur in some echinids, and are there on the same side as the mouth and anus, as, for example, in *Scutella*.

The fourth character quoted is the presence of arms or pinnule-bearing extensions of the ambulacra in Pelmatozoa; but this would probably exclude genera such as *Aristocystis* from this division of the echinoderms.

The last structure relied on is the occurrence of calycinal plates; but if we accept the theory of the homology of the central, aboral plates of echinids and stellerids with the plates of the calyx of crinids, then these plates are better represented in some echinids (such as *Tiarechinus*) and stellerids (such as *Ophiopyrgus*) than in some cystids.

There is therefore no single character in von Zittel’s definitions, of either Cystoidea or Pelmatozoa, which can serve as a certain test as to whether a fossil is to be included among them. As of the five characters of the Pelmatozoa *Echinocystis* probably lacked the first; as the second is equally typical of echinids and of cystids; and as *Echinocystis* certainly had not the third, fourth, or fifth, then this genus cannot be included among the Pelmatozoa as defined by von Zittel. According to him [16, p. 174] the Echinoidea are characterized by (1) a spherical, discoid, or oval body; (2) a body-cavity enclosed by solid plates bearing movable spines; (3) a ventral mouth; (4) an anus situated in the disc, or between this and the mouth; and (5) five ambulacra bordered by pore-series. As *Echinocystis* has all these characters, it appears that von Zittel was quite justified in restoring the genus to the Echinoidea.

A later diagnosis of the Cystoidea has been recently issued by

Häckel. He divides the Echinoderma into three 'cladoms'; the first or Monorchonia includes the Cystoidea; the last or Pentorchonia includes the Echinoidea. The Monorchonia includes those with 'one pair of gonads and an unpaired dorsal genital duct; the ovoid gland, genital sinus, and genital stolons are altogether absent' [3, p. 164]. In the Pentorchonia, on the other hand, 'the gonads are pentamerous; there are five interradial dorsal genital stolons; there is an ovoid body with periproctal genital sinus; the mouth is ventral. They are free, creeping on the ventral surface.'

The characters used in these diagnoses are all points of visceral anatomy, except one which is a habit, and they cannot be easily determined for the fossil forms. But, so far as they can be ascertained, they are not invariable. The gonads are not actually pentamerous in many echinids; in most spatangids there are four; in *Galerites* and some species of *Holactypus* there are also four; in *Tripylus* there are but three.

It may be replied that in such echinids the ancestors had five gonads, and the number has been reduced by secondary changes, which need not be considered in the main diagnosis. But if a diagnosis is to be regarded as a summary of the essential characters of the class to which it refers, then a character which may be lost by secondary changes ought not to enter into it; if the character can be readily lost it is not essential. If the possession of five gonads is an essential character of the Echinoidea, then an animal with only three or four gonads is not an echinid.

This character is not only useless as a test-distinction between echinids and cystids, but it certainly could not be used to separate *Echinocystis* and *Palæodiscus* from the Echinoidea; for the pentamerous symmetry in these is so well marked, and the interambulacral areas are so capacious, that there was probably a gonad in each interambulacrum. We are therefore driven back to Häckel's fuller diagnosis of the Cystoidea on p. 72 of the same monograph. This may be translated as follows:—'Echinoderma, with the essential forms of the body bilateral-radial; with a radial anthodium [*i. e.* ambulacral rosette], which is composed of several (2-5 or more) ambulacra. Theca uniaxial or radial; it is rarely free at the aboral pole of the principal axis, but mostly directly sessile or fastened or fixed by a stem. The tegument has rarely a flexible scaly armour, generally a rigid plate-armour, which is composed of very numerous polygonal small plates, irregularly arranged; some of the latter are frequently fused to form larger plates. The mouth is always central at the oral pole of the primary axis; it is radially an oblique cleft, often circular, mostly with radial incisions and three to five lips. The anus is always excentric, on the ventral side, with valvular pyramid. Between mouth and anus there is usually a gonopore ("third aperture"), rarely also a hydropore ("fourth aperture"). The skeletal appendages are mostly developed in the form of pinnules, more rarely as a peristomal circle of radial "brachioles," or as a girdle of thecal arms.'

This diagnosis includes ten characters:—(1) the bilateral-radial

symmetry; (2) a radial anthodium; (3) theca uniaxial or radial; (4) usually fixed aborally, but sometimes free; (5) a scaly or plated test; (6) a central mouth; (7) an excentric anus on the aboral side; (8) a valvular pyramid; (9) gonopore and hydropore, when present, situated between mouth and anus; (10) the presence of pinnules, arms, or brachioles. This diagnosis clearly separates the cystids from the crinids and from the members of Hæckel's new class, the Amphoralia; but it does not give any very satisfactory grounds for separation from the echinids. The Echinoidea agree with the Cystoidea in characters Nos. 1, 2, 3, and 5; some echinids agree with some cystids in Nos. 4, 6, 7, and 8<sup>1</sup>; 9 and 10 are not present in all cystids, for there is no more reason to regard *Aristocystis* as having pinnules, arms, or armlets than some Palæozoic echinids. Thus the diagnosis does not yield a single constant, invariable distinction between the Cystoidea and the Echinoidea.

In order, therefore, to refer *Echinocystis* to its class, we have to rely on the sum of its characters. It agrees with both cystids and echinids in the possession of characters 1, 2, 3, 5, 6, 7, and 8. In the remaining characters, 4, 9, and 10, it agrees with typical echinids, but differs from typical cystids. Hence it seems more reasonable to follow von Zittel and assign the genus to the Echinoidea than, with Neumayr and Steinmann, to regard it as a cystid. The absence of calycinal plates or of any aboral attachment; the presence of a jaw-apparatus and of articulatory spines; the development of an exoskeleton, which is spherical in shape, and consists of closely-fitting plates; the occurrence of biserial ambulacral pore-pairs; and, finally, the ventral aspect of the mouth, are all characters in which *Echinocystis* agrees with the Echinoidea.

#### V. THE STRUCTURE OF PALÆODISCUS.

Form.—Discoid, possibly subpentagonal. Test thin and probably flexible. Mouth central on lower surface. Anus aboral, central.

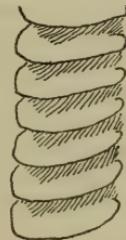
Ambulacra broad on the oral surface, but gradually diminishing in width on the aboral surface. In flattened specimens they are somewhat petaloid (a character, however, greatly exaggerated in Wright's figure).

On the oral surface the ambulacral plates are simple, thin, and bar-shaped (fig. 4).

On the aboral surface each ambulacrum consists of two alternate series of simple, thin, bar-shaped plates. There are no pores through the plates, but the podia must have been extruded through the sutures between them.

On the aboral surface the ambulacra are narrower (see, for example, E 1482); and, according to Wyville Thomson, there is a series of single pores on each side.

Fig. 4.—Ambulacral plates of Palæodiscus.



<sup>1</sup> A valvular pyramid occurs in *Palæostoma*.

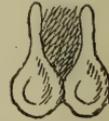
Interambulacra of angular, irregular, scale-like plates in many series; at the ambitus there are ten in width in each inter-radius.

The interambulacral plates bear numerous short spines.

Apical plates unknown, probably absent. The periproctal area is large. Madreporite unknown.

**Jaws.**—According to Salter's figure [9, pl. ix. fig. 6*b*], the oral armament apparently consists of an oral ring of the ambulacral type, that is, the ambulacral constituents form the prominent projections. Specimens in the British Museum, however (such as 40,307), show that the masticatory apparatus is very different from that of stellerids. It consists (Pl. VII. fig. 5*b*) of five pairs of irregularly triangular plates; those of each pair are joined together proximally, but are free at the distal (*i. e.* the oral) ends, where they are separated by a deep cleft. The distal ends are expanded (fig. 5). According to Salter, some spines are situated at the apex of each half-pyramid.

Fig. 5.—Pair of half-pyramids of *Palæodiscus*.



## VI. THE AFFINITIES OF PALÆODISCUS.

The previous discussion as to the affinities of *Echinocystis* has cleared the way for the consideration of those of *Palæodiscus*, which in many respects is the simpler form. It differs still more markedly from the typical echinids, but it is even less like a cystid, and the genus is usually assigned to the Stellerioidea, as by Neumayr, Zittel, and Wright.

*Palæodiscus* resembles the stellerids in two important respects. In the first place, the ambulacra appear in most specimens to be limited to the oral surface; but the case is not clear, for if Wyville Thomson's figures be correct, the genus is truly desmactinic. Secondly, the ambulacral plates are not perforated by pores, at least on the oral surface; but in the echinid *Asthenosoma* some of the podia pass out through the sutures between the plates, for their klasma-plates (see *ante*, p. 115) are reduced to spicular rings.

Fortunately, however, the fundamental difference between the Echinoidea and Stellerioidea can generally be applied: in the former the ambulacral plates cover the radial water-vascular vessel, which is within the test, whereas in the stellerids this vessel lies in a groove on the external side of the ambulacral plates. In *Palæodiscus* the ambulacral plates are flush with those of the interradii, and in all probability the radial water-vascular vessel was within the test. The general characters of the skeleton are also more echinoid than asteroid; the absence of special adambulacral plates, the occurrence of small articulating spines, the resemblance of the interradiial perisomatic plates to those of *Echinocystis*, and the character of the masticatory apparatus, are all points which ally *Palæodiscus* to the Echinoidea and separate it from the Stellerioidea.

We must, however, compare this genus with the Cystoidea, for there is a considerable agreement in some respects between it and *Agelacrinus*. *Palæodiscus* is not aborally fixed; it has no pinnules, and, in all probability, it had no calycinal plates. Of the nine characters which Hæckel assigns to the Cystoidea, *Palæodiscus* has only such as are common to the Echinoidea.

The only reason for regarding it as a cystid is based on its resemblance to *Agelacrinus*, which, however, is merely superficial. In *Agelacrinus* the anus is on the oral surface; the ambulacra are limited to part of the oral surface alone; there is no jaw-apparatus; the ambulacra are sinuous, and there is a peripheral zone of plates round the disc.

Hæckel is probably correct in regarding *Agelacrinus*<sup>1</sup> as a flattened form of *Hemicystis*, in which greater extension of the pinnule-bearing grooves is obtained by their being twisted. *Hemicystis* has no resemblance to a stellerid; and to accept this view of the origin of *Agelacrinus* means the abandonment of any fundamental affinity between it and *Palæodiscus*.

There is, however, one genus, which, if correctly described by Worthen and Miller [13, p. 335], may be a Carboniferous representative of either *Palæodiscus* or *Echinocystis*. According to the description of its authors, this remarkable form has an irregular, sac-like body; above the mouth there is a series of plates which may represent jaws. The name *Echinodiscus* was given to this fossil by Worthen and Miller, but this term having been preoccupied by Agassiz for an echinid, for which it is still in use, the name of the cystid may be changed to *Discocystis*.

#### VII. THE HOMOLOGIES OF THE MASTICATORY PYRAMIDS AND APICAL PLATES OF ECHINOIDEA.

From the considerations stated in the previous section, it seems advisable to regard *Palæodiscus* as an echinid, allied to *Echinocystis*, although not congeneric as Duncan made it. In this case it is certainly the most primitive of Echinoidea, and represents a condition when the ambulacral plates were only in part perforated by pores. The presence of a masticatory apparatus is of interest, especially as it gives us some suggestions regarding the origin of that structure. The figures published by Lovén and his accompanying remarks [5, pp. 8 & 9, pl. iii. figs. 22 & 23], show that while the teeth are interradian in development, the plates that form the half-pyramids lie above the ambulacra, and are to be regarded as ambulacral in origin. In *Echinocystis* the pyramids agree with those of *Cidaris*, at least in their fundamental characters; but in *Palæodiscus* the structure is far more primitive. Beside the oral ends of the ambulacra lie two strong plates, which are fixed together aborally, but are separated by a deep groove near the mouth.

<sup>1</sup> The type-species of *Agelacrinus* is *A. hamiltonensis*, Vanux. (Geol. Rep. New York, 1842, pp. 158, 306), not *A. vorticellatus*, Hall, as stated by Hæckel. The genus *Agelacystis* founded [Hæckel, 3, p. 114] on *A. hamiltonensis*, is therefore a synonym of *Agelacrinus*.

These plates are, in all probability, ambulacral in origin, and each plate is then homologous with the half-pyramid of *Echinocystis*. In order, therefore, to form the pyramids of *Echinocystis*, it is only necessary to assume that the two free ends of the half-pyramids of *Palæodiscus* bent inward, so that the symphysis was continued along the whole length, instead of being limited to the aboral end. At the same time, increase in the strength of the muscular attachments led to the development of ridges and depressions on the proximal end.

*Palæodiscus* therefore gives useful information as to the origin of the masticatory apparatus of the gnathostomate echinids. For, just as in the Stellerioidea the adoral ambulacral plates are modified to form the ambulacral oral projections of asterids, and the jaws (that is, the distal portion of the syngnaths) of ophiurids, so it is probable that the pyramids of the masticatory apparatus of echinids arose as a modification of the peristomal ambulacral plates. As it is, however, possible that the whole apparatus was formed around the œsophagus, and not as part of the exoskeleton, it would not be safe to definitely claim the pyramids as the homologues of the ambulacral oral projections of asterids and of the jaws of ophiurids.

The absence of calycinal plates is of great interest, as it appears fatal to the theory assigning a crinoid ancestry to the Echinoidea. The insignificance of these plates in the oldest echinids, when compared with specialized forms such as *Tiarechinus* and *Lysechinus* or larval *Strongylocentrotus*, shows that the so-called 'calycinal plates' are not primitive. MacBride [6, p. 436] has thrown doubt on the homology of these plates in asterids and crinids, and *Echinocystis* suggests similar doubts for echinids. In the early echinids these plates appear as a ring round the anus. In *Echinocystis* the anus opens at the centre of a circle of five valvular plates. This Silurian echinid is followed by others in the Devonian and Carboniferous, such as *Palæchinus* and *Perischodomus*, in which the anus likewise opens in the centre of five rather large plates. I see no reason why these five circumanal plates of *Palæchinus* are not homologous with the five circumanal plates of *Echinocystis*. Such at least is by no means so far-fetched an idea as that which makes these plates the homologues of the basal circlet of the crinoid calyx. It is therefore at least possible, and perhaps even probable, that the apical or so-called 'calycinal plates' of echinids are homologous with the anal valvular pyramid of Cystoidea, and not with the plates of the calyx.<sup>1</sup>

#### VIII. CLASSIFICATION OF THE CYSTOCIDAROIDA.

As *Echinocystis* and *Palæodiscus* are therefore accepted as two genera of Echinoidea, it may be advisable in conclusion to attempt a synopsis of the order to which they belong.

<sup>1</sup> It may be suggested that the genital pores mark out the basal circlet, and that these pores probably opened, in *Echinocystis*, round the apex, and not round the anus. But the connexion of these pores, as of the water-pore, with any plates is a purely secondary feature, and cannot be used for the determination of a primary homology.

## Order CYSTOCIDAROIDA, Zittel, 1879.

**Diagnosis.**—Echinoidea with a test composed of irregular, thin, spine-bearing plates; the mouth is central; the anus is aboral; the madreporite is large and single, and occurs in the same interambulacrum as the anus (unknown on one genus); there are no calycinal plates; the ambulacral plates are simple, and may be perforate or imperforate; there is a jaw-apparatus composed of five pyramids.

## Family 1. PALÆODISCIDÆ.

**Diagnosis.**—Cystocidaroida with a depressed pentagonal body. The ambulacral plates on the oral surface are imperforate. The anus is central.

Genus *Palæodiscus*, Salter, 1857 [9].

**Type-species.**—*P. ferox*, Salter. Leintwardine Flags, Lower Ludlow.

## Family 2. ECHINOCYSTIDÆ.

**Diagnosis.**—Cystocidaroida with a spherical body. The ambulacral plates are perforated by pores; the pore-pairs are biserial, and some demi-plates are present. The anus is excentric.

Genus *Echinocystis*, Wyv. Thomson, 1861 [11] (*non* Hall, 1867).<sup>1</sup>

**Synonym.**—*Cystocidaris*, Zittel, 1879.

**Type-species.**—*Echinocystis pomum*, Wyv. Thomson, 1861.

Von Zittel includes the genus *Spatangopsis*, founded by Torell [12, p. 11] on a species named *Sp. costata*, as a possible cystocidarid. Torell, however, describes the genus as having five sharp radial costæ; and though it is possibly an echinoderm, the narrowness of the costæ would exclude it from the Cystocidaroida, whether these radial structures are ambulacral or not.

## IX. SUMMARY OF CONCLUSIONS.

1. The structures of the Silurian genera *Palæodiscus*, Salt., and *Echinocystis*, Wyv. Th., are redescribed.
2. It is concluded that *Echinocystis* is an echinid, and not a cystid; and that *Palæodiscus* is an echinid, and not an asterid.
3. The name *Scolocystis* is given to the cystid named *Echinocystis* by Hall; and that of *Discocystis* to the form named *Echinodiscus* by Worthen and Miller.
4. In a discussion of the affinities of *Echinocystis*, the two latest

<sup>1</sup> Zittel called attention to the fact that the name *Echinocystis* has been used by Hall for cystids as well as by Thomson for echinids. By a slight oversight he omitted to notice that Thomson had priority by six years, and Zittel therefore kept the name *Echinocystis* for cystids and renamed Thomson's genus *Cystocidaris*. Although this has been more than once pointed out (*e.g.* Duncan, 2, p. 20), Hæckel retains *Echinocystis* for the cystid. To save further confusion, I propose the name *Scolocystis* for this cystid (from *σκῶλος*, a thorn). *Acanthocystis*, also accepted by Hæckel, has long been preoccupied among Protozoa by Carter. Hall's date is sometimes given as 1864; some advance copies of the Report were issued in 1865, but it was not published until 1867.

diagnoses of the Cystoidea are considered, and it is contended that they do not enable us to draw any sharp line of distinction between the Cystoidea and the Echinoidea.

5. It is shown that the masticatory apparatus of *Palæodiscus* and *Echinocystis* explain the origin of that structure in gnathostomate echinids.
6. It is suggested that *Echinocystis* renders probable the homology of the so-called 'calycinal plates' of Echinoidea with the plates of the valvular pyramid of Cystoidea, and not with the calyx-plates.

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#### EXPLANATION OF PLATE VII.

- Fig. 1. *Pedinothuria cidaroides*, sp. n., B.M. 34.724.—Figs. 1 *a*, *b*, and *c*, the test seen respectively from below, from the side, and from above.  $\times 3$  diam.
- Fig. 1 *d*. Outline. Natural size.
- Fig. 2. An interambulacrum of the same.  $\times 5$  diam.
- Fig. 3 *a*. An ambulacrum of the same.  $\times 5$  diam. Figs. 3 *b*, *c*, and *d*. Parts of an ambulacrum, showing arrangement of the plates.
- Fig. 4. *Echinocystis pomum*, Wyv. Th.—A specimen in the British Museum, from the Leintwardine Flags, showing the aboral surface, with madreporite and ambulacra. Natural size.
- Fig. 5. *Palæodiscus ferox*, Salt. A specimen in the British Museum, from the Leintwardine Flags.—Fig. 5 *a*, oral side; 5 *b*, the oral armament of the same specimen, from a wax mould. Natural size.

## DISCUSSION (ON THE TWO PRECEDING PAPERS).

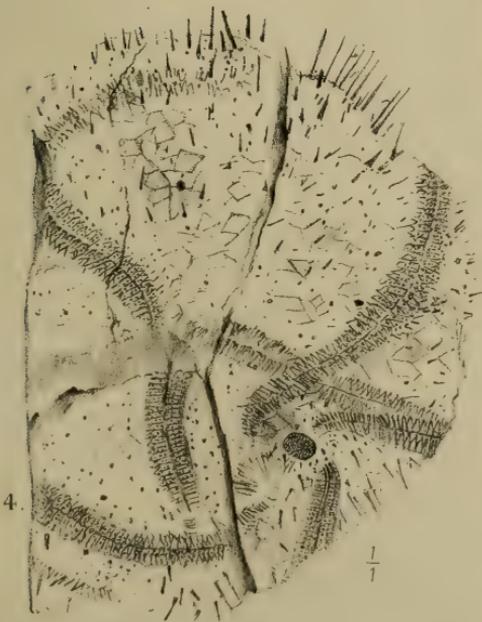
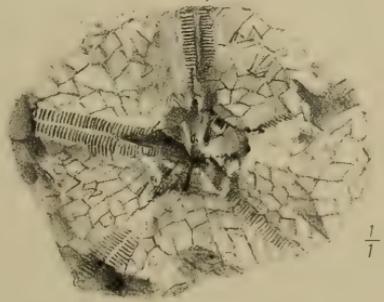
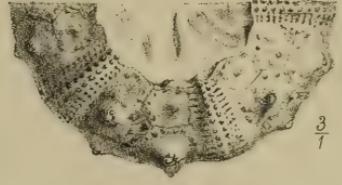
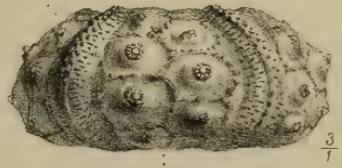
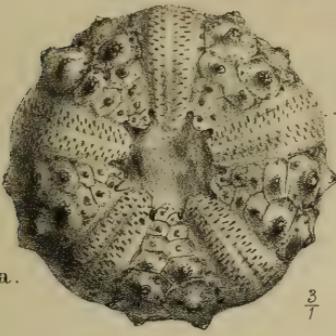
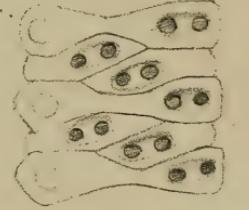
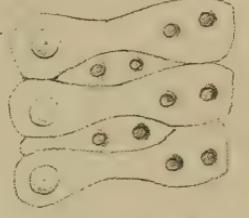
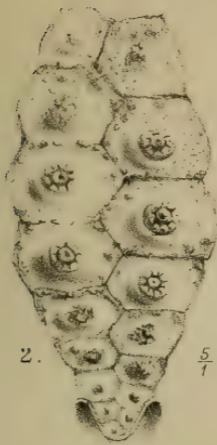
Mr. F. BATHER inclined to accept the homology of the anal pyramid of *Echinocystis* with the anal pyramid of cystids on the one hand and the proximal apical plates of echinoids on the other, and agreed that it would prove entire absence of homogeneity between the apical system of echinoids and the calyceal system of crinoids and certain cystids. It was not, however, fair to say that Lovén, Carpenter, and Sladen had derived Echinoidea from a crinoid ancestor: this theory was a fiction of its opponents—*e. g.* Semon and the Sarasins. What had been maintained was that the homologue of the calyceal system could be traced in all classes of Echinoderma, and therefore had been possessed by their common ancestor. But the rejection of this theory did not imply, as Dr. Gregory had seemed to suggest, the rejection of the hypothesis that the quinquerradiate symmetry of Echinoderma was due to a fixed mode of life. In this group it could not be due to a free-swimming existence, since free-swimming forms were secondary developments; a creeping existence, again, produced antero-posterior elongation. Nor was the possession of perradial ambulacra, whether epithecal, hypothecal, or exotheal, the common heritage of the whole phylum Echinoderma from a 'Pentactæa' ancestor. The simplest cystids—Aristocystidæ—showed no trace of radial symmetry in the arrangement of plates, nor of any extensions from the circumoral water-ring, nor of ciliated grooves leading to the mouth. Whether *Echinocystis* were placed in the Cystidea or Echinoidea was a mere question of names; but while its relation to the Echinoidea was clear, its relations to the Cystidea were still veiled. *Echinocystis*, in common with other echinodermata, must have descended from simple forms like the Aristocystidæ, and the quinquerradiate extension of its water-system must have arisen during a period of fixation somewhere in the race-history. This habit of life must have acted on hypothecal extensions from the water-ring, communicating with the exterior through pores between the plates, as in *Agelacrinus* and similar fixed forms, a position retained in *Palæodiscus*; ambulacral pores had no connexion with the scattered cystid diplopores. The position of the madreporite might throw some light on the question: information as to this, or any suggestions by the Author as to the probable line of ancestry, would be of much interest.

The Rev. J. F. BLAKE referred to the diagrams drawn by the Author showing on one side a row of simple ambulacral plates, and on the other a series of primary and demi-plates, and enquired whether there was any palæontological evidence to show that, as described by the Author, the demi-plates were diminished primaries pushed aside by the growth of the others, or, in the reverse order, growing plates which were destined to become ultimately equal to the other primaries, and thus the whole structure should pass from the complex to the simple.

The PRESIDENT asked the Author whether he had had an opportunity of examining the supposed echinoid forms found some years

ago by Dr. Torell in the Cambrian rocks of Sweden, apparently the oldest at present known.

The AUTHOR replied that the *Spatangopsis* of Torell may be an echinoderm, but it is not an ally of the Cystocidaroida. In reply to Mr. Blake, he said that the development of the echinid ambulacral plates is from the simple to the complex. He had not said that Lovén, Carpenter, or Sladen had asserted the development of Echinoidea from Crinoidea, but only that their homology of the apical plates with the calyx-plates of the Pelmatozoa suggested the origin of the Echinoidea from that group of echinoderms of which the Crinoidea are the only living representatives. He had not stated it as his opinion that a pentaradiate water-vascular system was an essential character of an echinoderm, but that this view was assumed by those who argued that the pentaradiate symmetry of echinoderms was due to fixation. He agreed with Mr. Bather that this character was not essential. The madreporite of *Echinocystis* is not at the apex, but in the posterior interambulacrum.



1d.



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10. *On GLACIAL PHENOMENA of PALÆOZOIC AGE in the VARANGER FIORD.* By AUBREY STRAHAN, Esq., M.A., F.G.S. (Read January 20th, 1897.)

[PLATES VIII-X.]

AN expedition to Vadsö in the *Norse King* having been organized to observe the total eclipse of the sun in 1896, I took advantage of it for the purpose of examining as much of the Varanger Fiord as time would permit. I had two objects more especially in view: firstly, a visit to a section described by Dr. Reusch as showing a conglomerate of glacial origin intercalated in rocks of reputed Palæozoic age<sup>1</sup>; and, secondly, an examination of the raised beaches and glacial phenomena of the region. The remoteness of the fiord probably accounts for the fact that the remarkable section discovered by Dr. Reusch had remained unvisited by any other geologist, and for the rejection of his conclusions in the face of most convincing evidence.

The section in question lies about 26 miles farther up the Fiord than Vadsö, where the *Norse King* lay, and for my opportunities of visiting it I was indebted to Mr. R. R. Pirrie, who most generously allowed me the use of one of his small steamers for that purpose. I had also the advantage of the assistance of Mr. Charles Upton and Mr. E. Dickson, F.G.S., in examining the section.

The Varanger Fiord runs nearly east and west, and is about 50 miles long, with a breadth of 12 miles at Vadsö, and of 3 to 7 miles west of that town. At its western extremity it divides into a northern branch, known as the Mœsk Fiord,<sup>2</sup> and a southern branch, at the head of which lies the Lapp settlement of Karlbotn. The fiord itself has been excavated along the junction of the crystalline rocks with a sedimentary and little altered formation known as the Gaisa<sup>3</sup> system, and consequently presents a marked contrast in the scenery of its northern and southern shores. The former, occupied by the Gaisa Beds, presents a succession of desolate moorlands, rising gently to a height of 600 or 800 feet, or even 1000 feet inland; the southern shore, on the other hand, is diversified by the rugged outlines characteristic of the older rocks, and is intersected by numerous deep fiords of the usual Norwegian type.

The boundary-line between the two systems is shown on Keilhau's

<sup>1</sup> Norges geologiske Undersøgelse: 'Det nordlige Norges Geologi,' 1891, pp. 26-34. See also Aarvog for 1891, p. 78.

<sup>2</sup> It may be worth noting here that good quarters are obtainable at Nyborg, on the northern shores of the Mœsk Fiord, and that an excellent road leads thence to Vadsö (30 miles) in the one direction and to the Tana River (9 miles) in the other.

<sup>3</sup> The term 'Gaisa,' in Finnish, is equivalent to 'Fjeldtop' in Norse, which, literally translated, is 'mountain-top.'



map of Norway (1844), and on Dr. Dahll's map,<sup>1</sup> to strike the shore of the fiord in the peninsula known as Kvalnes, and to run thence to Karlbotn, and so westward to the Tana River near Polmag. I found a good exposure of the junction a short distance north-east of Karlbotn, in the direction of Bigganjargga. On the foreshore the granitic rocks rise into view for a few yards in the form of a low boss, upon, and closely adherent to, which lay a few inches of hard sandy material. Immediately upon this came well-bedded grits, consisting of disintegrated granitic débris redistributed as a sediment, which passed up into sandstones of the usual Gaisa type. On one side of the boss a small hollow, due to a pre-Gaisa joint or small fault in the granitic rocks, had been filled up with a coarse conglomerate before being overspread by the Gaisa sediments. The conglomerate consisted of partially-rounded blocks of granitic rocks ranging up to 6 inches in diameter. The surface of the boss, like all the other rock-exposures of the neighbourhood, was strongly glaciated, but neither in this nor in any other respect was there evidence of contemporaneous ice-action. The section proved conclusively, however, that the crystalline rocks had been metamorphosed and subjected to vast denudation before the Gaisa epoch commenced, the relations of the two systems rather forcibly bringing to my mind those of the Carboniferous strata to highly-altered rocks as seen in parts of our own country. Viewed from the hillside above, the boundary-line between the two was clearly marked out in its westward course towards the Tana River by the same scenic features as those which distinguish the two sides of the Varanger Fiord.

These basement-beds of the Gaisa system pass up, in a few feet, into well-bedded quartz-grits, often containing quartz-pebbles, and interstratified with red shales. Strata of this character form the promontory which separates the two arms of the Varanger Fiord, the grits giving rise to frequent little scarps separated by swampy hollows, in which disintegrated shale is occasionally visible. They dip at a gentle angle northward, and in proceeding in that direction, and presumably therefore ascending in the series, we noticed less conglomerate, but more shale and sandstone, frequently of a red or purplish tinge. The fine section in the precipitous ravine of the Mæskelv, 2 miles east of Nyborg, shows upwards of 100 feet of alternations of grey grits and red or mottled shales, in beds of 1 to 2 feet in thickness. The strata here have been thrown into sharp folds running E.N.E., a somewhat unusual feature in this neighbourhood, for the Gaisa Beds, wherever else I saw them, showed but little disturbance.<sup>2</sup>

At Vadsö a low cliff, extending for some distance westward,

<sup>1</sup> 'Geologisk Kart over det nordlige Norge, udarbejdet efter Foranstaltning af den Kongelige Norske Regjerings Departement for det Indre,' Kristiania, 1866-1879. I am indebted to Mr. W. H. Hudleston for the interesting fact that the position of the boundary was correctly fixed by Keilhau more than 50 years ago.

<sup>2</sup> The section is figured in Reusch's 'Geology of Northern Norway' 1891, p. 35.

consists of irregularly-bedded sandstones with grey and purplish shales. The sandstones occur in the most irregular manner and wedge in so suddenly as almost to resemble included masses; they contain also fragments of shale more or less rolled, and in this and other respects indicate that deposition alternated with erosion under the influence of variable currents. The rather bolder cliff on the southern side of Vadsö Island presents crags of grey quartz-grit separated by upwards of 20 feet of fine red sandstone, current-bedded in thin laminae. I saw also on the hillsides boulders which I believe to have been derived from the Gaisa rocks, in which fragments of dolomite were abundant.

In all these respects the Gaisa Beds present only such features as are common to rocks of the type of the Wealden, Trias, Coal Measures, or Old Red Sandstone, and give no hint of the action of ice. But on visiting the section near Bigganjargga,<sup>1</sup> referred to by Dr. Reusch, I found a deposit of which I have seen no counterpart in any of those formations. The cliff there rises from the shore in a succession of rock-ledges, the strata being nearly horizontal and free from surface-deposits. In the lowest ledge, just above high-tide mark, a lenticular mass of darker rock intercalated between the ledges of sandstone at once arrests the attention, even as seen from the deck of a steamer (Pl. VIII). The mass wedges in abruptly, and at a distance of about 4 yards from the point of its first appearance attains a thickness of 8 feet. Thence it runs for about 70 yards at the foot of the cliff, until the gentle dip carries it beneath the sea, the thickness nowhere exceeding about 10 feet. Its base is remarkably straight, for a reason given hereafter; but its upper surface undulates as the thickness of the mass varies, and on these undulations the overlying sandstones have been tranquilly deposited in such a way as to level-up the irregularities, some of the beds thinning away against the sloping sides of the mass (Pl. IX), while others overtop it and extend continuously across it.

Having been deposited on a sloping surface, these strata vary in thickness and are slightly inclined, but in the overlying sediments all such irregularities of deposition gradually disappear, and a few feet up in the cliff the bedding runs evenly and uninterruptedly over the site of the buried lenticle. For an inch or two at their base the sandstones in contact with the buried mass contain material washed up from its surface.

The mass itself is a boulder-rock quite unlike any of the Gaisa sandstones or conglomerates which I saw elsewhere. It is referred to by Dr. Reusch as a conglomerate, but from the fact of its being neither stratified nor waterworn I prefer to avoid the use of that term. It may be described as a dark-bluish or ashy-grey friable rock, composed of a heterogeneous mixture of grit, sand, and clay

<sup>1</sup> The section is exposed about 2 miles north-east of the two or three Lapp huts known by that name, and about a mile west of the Island of Suolo shown on the map (p. 138).



*CYCADEOIDEA GIGANTEA*, sp. nov.



Fig. 1.

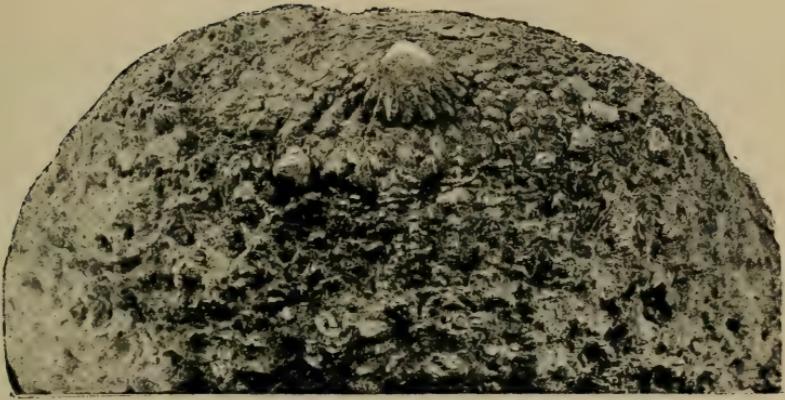
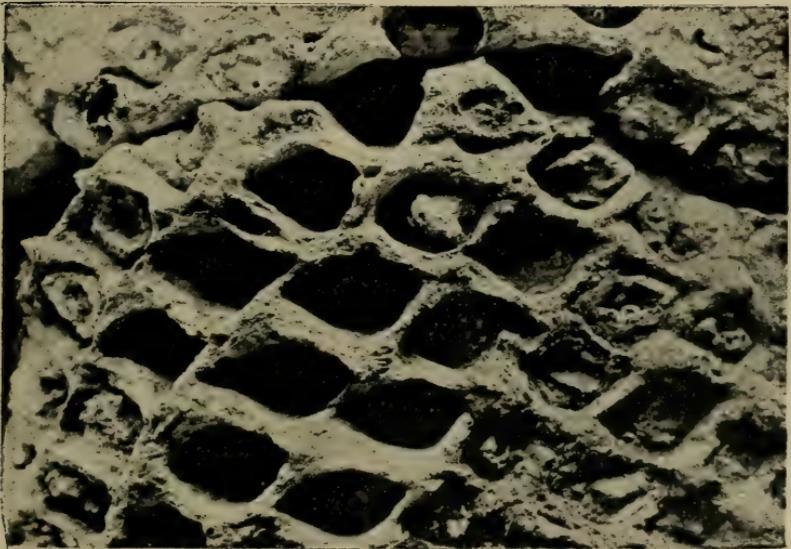
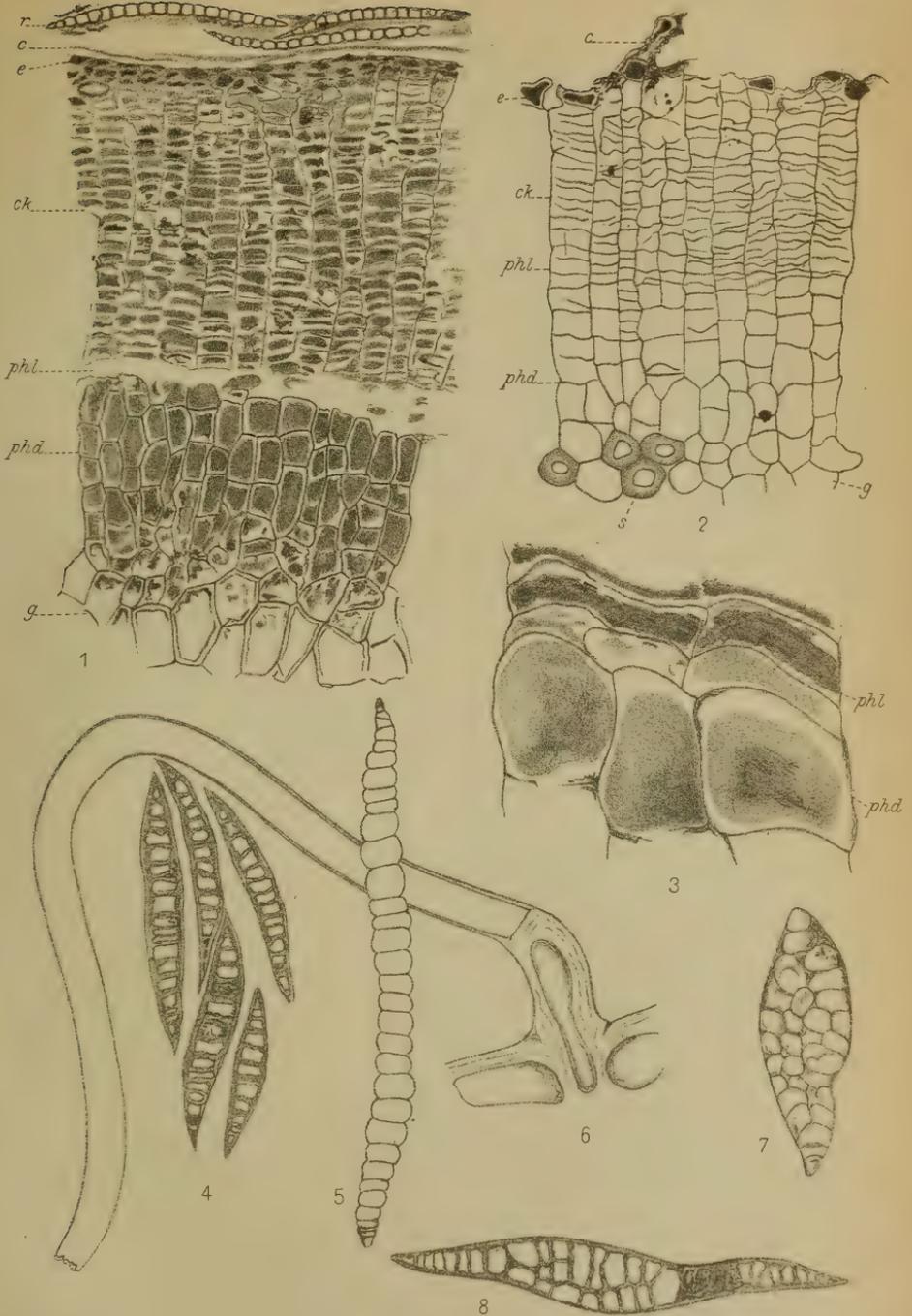


Fig. 2.



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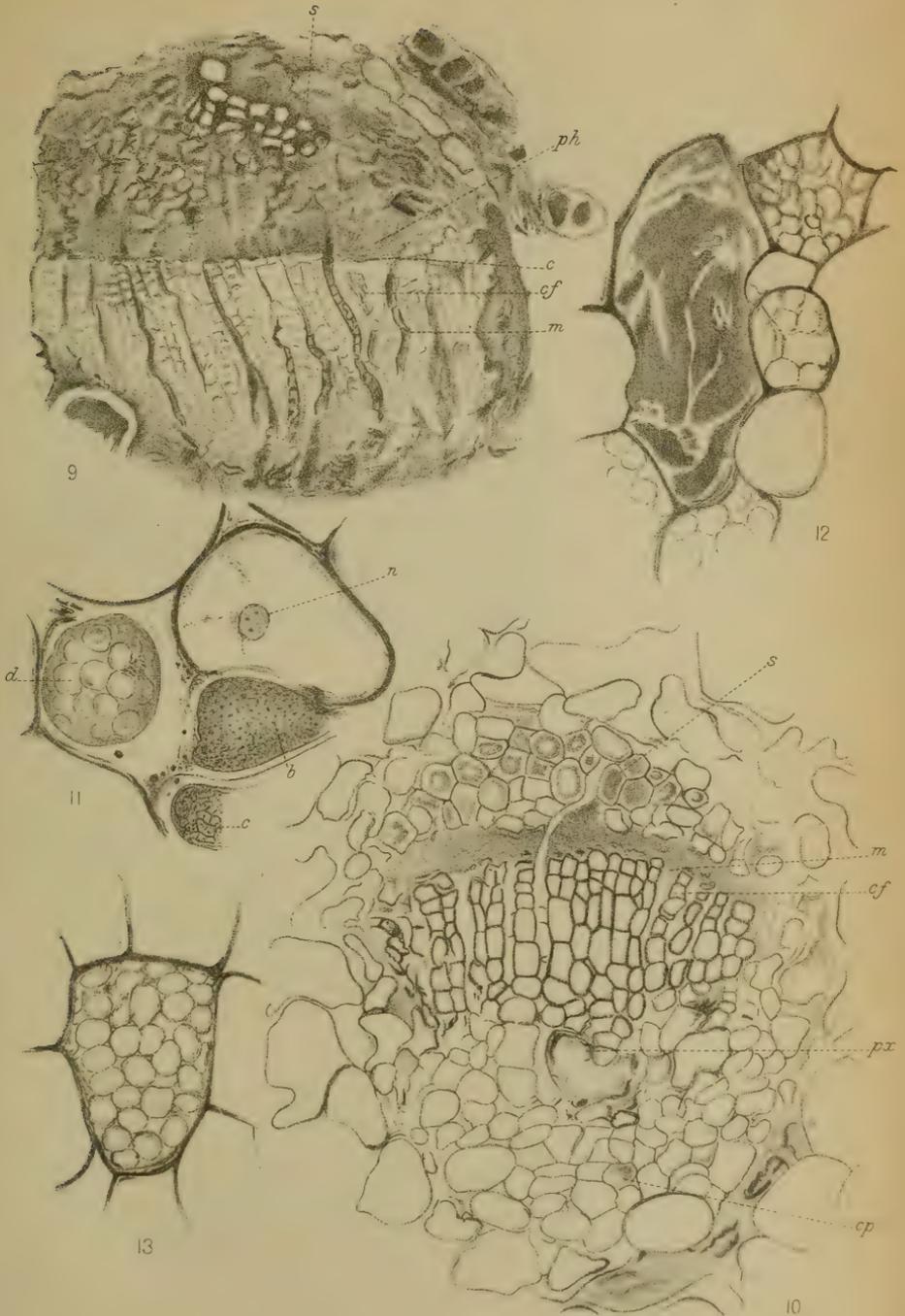


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CYCADEOIDEA, MACROZAMIA, ETC.



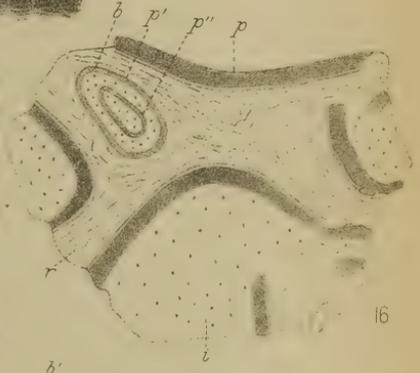
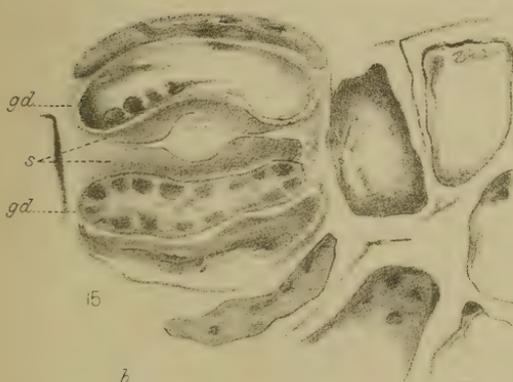
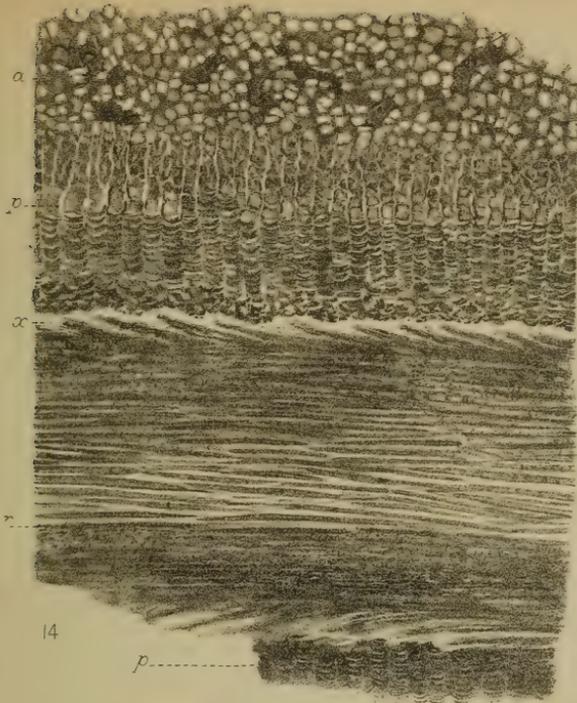


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CYCADEOIDEA AND BENNETTITES.





A.C.Seward del

Edwin Wilson, Cambridge.

CYCADEOIDEA.



of all degrees of coarseness, and containing boulders ranging up to 2 feet in length scattered through it. Though quite unstratified, it shows here and there a slight schistose<sup>1</sup> structure. The included boulders, which are of all shapes and lie at all angles, consist principally of red and grey granites, and of quartz-grits resembling those of the Gaisa formation. I did not succeed in finding any striated blocks, but the fact that the matrix has been hardened and adheres closely to the boulders prevented me from examining more than two or three in the limited time at my disposal. From a similar boulder-rock at Mortensnes, however, which I unfortunately missed seeing, Dr. Reusch describes and figures well-glaciated blocks of dolomite.<sup>2</sup>

Before quitting this part of the subject I would point out that the form of the intercalated mass of boulder-rock, as well as the fact that fragments of it occur in the base of the overlying strata, indicate that it underwent denudation before it was buried. Not improbably it extended considerably farther west than the present limit, as indeed is suggested by the extension of the striated pavement in that direction. It is easy to conceive that the whole mass might have been washed away, excepting only the larger boulders, in which case the glacial episode would have been recorded only by the presence of large erratic blocks embedded in Gaisa quartzites. Some of the erratic-bearing beds in other parts of the world, subsequently alluded to, possibly originated in this way.

The boulder-rock rests on a regularly-bedded sandstone of the usual type, and has been weathered back so as to expose several square yards of the remarkably even surface of that rock. The platform thus exposed is not only smoothed, but conspicuously and characteristically striated (Pl. X). The scratches can be followed in some cases for 2 or 3 yards, not only up to the foot of the little cliff of boulder-rock, but under it, a fact of which I made certain by wedging out some masses of that material, and exposing a fresh portion of the platform. This striated pavement is visible for a short distance beyond the point where the boulder-rock thins out, as already mentioned. Three sets of striæ can be detected, the strongest running N. 30° W., a second, less marked, ranging N. 70° W., while a few occur with the direction N. 10° W. Though strongly scored, as well as smoothed, the sandstone does not seem to have suffered much erosion, for the boulder-rock rests upon the same bed throughout the section. The sandstone is traversed by a few irregular joints,

<sup>1</sup> [By the word 'schistose' reference is made merely to an obscure fissile structure developed here and there in the rock, in consequence of which it splits more readily along certain curving, nearly horizontal planes than in other directions. The microscope shows, as I am informed by Mr. Teall, that the rock is quite uncrushed, and has not been subjected to such movements as would have taken place if the striated surface had been part of a thrust-plane.—Jan. 29th, 1897.]

<sup>2</sup> 'Geology of Northern Norway,' 1891, pp. 30 *et seqq.* It is worth noting that stones in a conglomerate have been known to acquire scratches by subsequent movements in the rock, whether by squeezing in a gritty matrix or by grinding against one another. Dr. Reusch's figures, which are reproduced from photographs, in no way recall such markings, but represent boulders with the shape and striation characteristic of ice-action.

the lines due to which, however, on the striated platform bear no resemblance to glacial groovings. The striæ have, beyond question, been cut into that surface independently of any structure possessed by the rock, and are in all respects characteristic glacial markings.

From the character of the markings it is necessary to suppose that the sand of which the quartzite consists must have become consolidated before the ice advanced over it, although it must apparently have been newly formed at that time. I suggest, however, that it may not have been literally the latest deposit, but that it may have been buried, more or less consolidated, and only brought into contact with the ice by the removal of all overlying sediment that had not become compacted.

The evidence detailed above seems to leave no room for doubt that we have here an intercalation of a true glacial till<sup>1</sup> in the Gaisa formation, for it provides an answer to every alternative theory. Three possible explanations of the section had suggested themselves to me before my visit to the spot:—

- (1) That the striæ had been made during the Glacial Epoch or subsequently.
- (2) That the till had been forced in between the ledges of sandstone during that epoch.
- (3) That the till was not a glacially-formed deposit, but a crush-conglomerate or a fault-breccia, and that the striated surface beneath it was the floor of a thrust-plane.

The first of these is disposed of by the fact that the striæ unquestionably pass beneath the till.

The second is negatived by the fact that the till existed before the sandstones above it were deposited, for the obstruction offered by it to the even distribution of the sand, until it was finally buried, is perfectly clear.

The third, which had seemed the most probable, is equally untenable. A crush-conglomerate or a fault-breccia is made up of the fragments of the strata which it traverses; the till, on the contrary, consists largely of boulders and débris of granitic rocks, which can nowhere form part of the Gaisa formation. Nor does the striated floor present any of the features of a fault or thrust-plane, for the markings are confined to the one surface, and do not occur along more than one plane, as happens with slickenside, nor is there any indication of shattering in the rocks either in a direction parallel to the grooved surface or in any other. That such a fault or thrust-plane should exist here is highly improbable, for there is no sign in the neighbourhood of such disturbance as the theory demands. Lastly, the relation of the till to the sandstones above it is alone sufficient to disprove the hypothesis.

<sup>1</sup> The name 'till' is used here, not as indicating the presence of clay, but as descriptive of a material formed by the mixing together by glacial action of the débris of rocks of any composition.

Under these circumstances I accept without hesitation Dr. Reusch's conclusion that the phenomena are due to glacial action, and that they were produced contemporaneously in the Gaisa formation.

The determination of the age of the Gaisa rocks now became an object of importance, and a diligent search for fossils was made by myself and other members of the expedition, but unfortunately without result. Up to the present no fossils have been recorded from these rocks, and in their absence we have to fall back upon the stratigraphical relations of the system to other groups in the north of Norway. Of these I had no opportunity of judging, and therefore abstract all that is at present known on the subject from the publications of the Norwegian geologists. According to Dr. Dahll, the Gaisa rests unconformably upon an older system known as the Raipas, which also is later than the metamorphism of the crystalline rocks, and, like the Gaisa, unfossiliferous. The Raipas is regarded by Dr. Dahll as representing Devonian, and the Gaisa as being either Trias, Dyas, or Carboniferous.<sup>1</sup> Dr. Reusch, on the other hand, throws doubts on the supposed unconformity between the Raipas and Gaisa, and compares the whole sedimentary group with the Sparagmite formation of Southern Norway.<sup>2</sup> This formation, which is described as consisting largely of felspathic sandstones and quartzites, also rests upon a denuded surface of highly-metamorphosed rocks, and is overlain by strata containing the *Olenellus*-fauna, a fact which proves that it is of Cambrian or earlier age. Dr. Nathorst expresses an opinion that Dr. Reusch's view that the Gaisa is of the same age as the Sparagmite is more probable than that of Dr. Dahll.<sup>3</sup> So far, therefore, as our information goes at present, the Gaisa Beds may be of about the same age as the basal Cambrian quartzite, or they may be even as old as the Torridon Sandstone.

In general lithological characters the Gaisa Beds belong to the type of the great continental formations; the scarps of quartz-grit with intervening red sandstones or red shales reproduce the appearance and scenery of much of both the Torridon Sandstone and the Old Red Sandstone, while the irregularly-bedded sandstones and shales of the cliff near Vadsö so strongly recalled parts of the Coal Measures that I was in constant expectation of finding plant-remains.<sup>4</sup> The red sandstones could no less appropriately be matched by parts of the Bunter. They all belong, in fact, to the type prevailing in those formations which have been the first to be deposited at the close of a great continental epoch. Among the characteristics common to such formations may be mentioned, firstly, that they rest upon a deeply-denuded surface of much older rocks; secondly, that they originated in a copious supply of more or less raw detritus—that is, of detritus which had neither been completely decomposed nor ground down to the last stage of fineness, and which may even

<sup>1</sup> 'Geology of Northern Norway,' 1891, p. 197.

<sup>2</sup> *Ibid.* p. 199.

<sup>3</sup> 'Geology of Sweden,' by A. G. Nathorst, 1894, p. 153.

<sup>4</sup> It is interesting to note here that upwards of 230 feet of productive Coal Measures intervene between two erratic-bearing series in New South Wales.

at times be traced to its source among the older rocks; thirdly, that deposition was not only unequal but alternated with erosion, leading to fragments of one bed being included as pebbles in another; fourthly, that they rarely contain marine organisms, or such strata as usually compose marine formations, while on the other hand drifted plant-remains are not uncommon; fifthly, that such limestones as occur consist, when unaltered, of amorphous carbonate of lime and not of organic remains; while, lastly, there is common to all a tendency to a red colour. All these characteristics may be taken as indicating the proximity of large land-areas, and it is in rocks of this type, if anywhere, that evidence of the existence of land-ice might be expected to be preserved.

We are here reminded that ice-action was called in so long ago as 1855 by Ramsay<sup>1</sup> to account for certain characters in the Old Red Sandstone and the Permian, and though the evidence on which he relied has since been proved by Mr. Wickham King to have been insufficient, the idea has been revived of late years by Mr. Oldham. More recently Dr. Hicks found evidence of glacial action in the Cambrian rocks of Wales, not only in the presence of large boulders, but in the enormous thickness of beds devoid of marine life,<sup>2</sup> and points out that 'at no time since, unless in the Glacial period, does there seem to have been so much land in the higher latitudes, and it is, therefore, reasonable to suppose that in the earlier stages at least of the epoch the climate was one of great cold' (*op. cit.* p. 252). It is especially noteworthy that the Gaisa Beds appear to be approximately of the same age as the rocks referred to by Dr. Hicks.

In the formations in other parts of the world in which glacial phenomena occur we find a repetition of the same general characteristics. Most of those described consist of sandstones, mudstones, and conglomerates of great thickness, and showing, in the interspersal of great erratics, evidence of the prolonged action of ice, though in some cases striated pavements and deposits of the type of Boulder Clay have also been observed. They, therefore, differ from the Gaisa Beds, which at present are known to contain only an occasional glacial episode, during which there seems to have been a sudden and possibly brief invasion of the water by land-ice, though the sediments above and below contain no erratics or any other hint of glacial action. But both to the Gaisa and the other formations there seems to be common a general absence of marine organisms or of strata of open-sea origin. They rarely contain any fossils save plant-remains, and in this and other respects approximate to the same type as the great continental formations alluded to above.

Evidence of glacial action in such formations has been discovered in Australia by Selwyn,<sup>3</sup> in Tasmania, in India by Dr. Blanford, in

<sup>1</sup> Quart. Journ. Geol. Soc. vol. xi. (1855) p. 185. See also R. D. Oldham, *ibid.* vol. l. (1894) p. 463.

<sup>2</sup> Geol. Mag. 1876, p. 157; *ibid.* 1880, p. 488.

<sup>3</sup> The latest account of these glacial beds, together with references to the previous literature, will be found in a paper by Prof. Edgeworth David, Quart. Journ. Geol. Soc. vol. lii. (1896) p. 289.

South Africa by Dr. Sutherland, and in South America, and though their exact age has generally been in doubt, in consequence of their poverty in fossils, many of them have been assigned to a late Carboniferous period with considerable certainty. Others are described as being of Permo-Carboniferous age, an expression which, so far as Western Europe is concerned, is extremely indefinite; while in yet a few cases their unconformable relations to strata bearing Carboniferous fossils suggest an early Mesozoic age.<sup>1</sup> But the fact that several of the glacially-formed rocks in these tropical and subtropical regions belong to approximately the same date seems extremely suggestive of a temporary but general change of climate towards the close of the Carboniferous epoch, as supposed by Feistmantel.<sup>2</sup> It will be noted, however, that the only example hitherto recorded from Northern Europe or Asia belongs, if Dr. Reusch's correlation proves to be correct, to a vastly earlier period.

The section which I have described lies in latitude 70° 8', and its situation so far north may be taken into consideration in attempting to account for the glacial episode. At the same time geographical situation does not explain all the evidences of past climates that we possess, for not only do the Australian, Indian, and African glacial deposits lie in what are now tropical and subtropical regions, but rich fossil floras and faunas have been obtained in younger formations far north of the Varanger Fiord. Nor can the phenomena be explained by supposing the existence of snow-covered mountain-ranges, for glaciers, however large they might be, would not reach the sea-level and distribute boulders in marine formations in or near the tropics. The Gaisa Beds, so far as I saw them, do not suggest the immediate neighbourhood of a mountain-region, for such conglomerates as they contain are neither coarse nor plentiful. The facts tend rather to indicate a temporary deterioration of climate both in this and the other instances recorded, but how far the Gaisa episode was universal (so far as the northern part of the globe is concerned) it must be left to future investigations to determine.

#### POSTSCRIPT.

[In consequence of the importance of the point raised in the discussion by Sir Archibald Geikie, thin sections of the boulder-rock and underlying quartzite have been cut, for the purpose of ascertaining the cause of their hardness. The sections show that the grains of sand which form a large proportion of the matrix of the boulder-rock, as well as those composing the quartzite, have been enlarged by the deposition of secondary silica in optical continuity with the original grains. The induration of the two rocks was therefore due to the same cause, and presumably took place at the

<sup>1</sup> Thus the Dwyka Conglomerate and associated Karoo Beds of South Africa, as I am informed by Mr. Gibson, rest quite unconformably upon the Zwarte-bergen Quartzite, in which Mr. Sawyer has obtained Carboniferous fossils, *Trans. Fed. Inst. Min. Eng.* vol. ix. p. 365.

<sup>2</sup> *Mem. Geol. Surv. N.S.W.* (1890), *Pal.*, No. 3, p. 181.

same time. It follows that the quartzite was not hardened by the deposition of the silica until after the deposition of the boulder-rock. For this observation I am indebted to Mr. G. Barrow.

One of the slices referred to traverses the junction of the boulder-rock and quartzite, and shows that the grains composing the quartzite project into the overlying boulder-bed and have not been cut or broken through; such as were removed in the process of glaciation were torn away bodily and incorporated in the boulder-rock. On the other hand, when the quartzite in its present condition of induration is broken, many of the grains seem to be broken across—owing to the firmness with which they are held in the matrix. This observation, which is due to Mr. Teall, proves that the quartzite is harder now than at the time of its glaciation. In one of my specimens, moreover, a small chip of a granitic rock lies embedded in the surface of the quartzite, as though it had been forced in before that rock was hard.

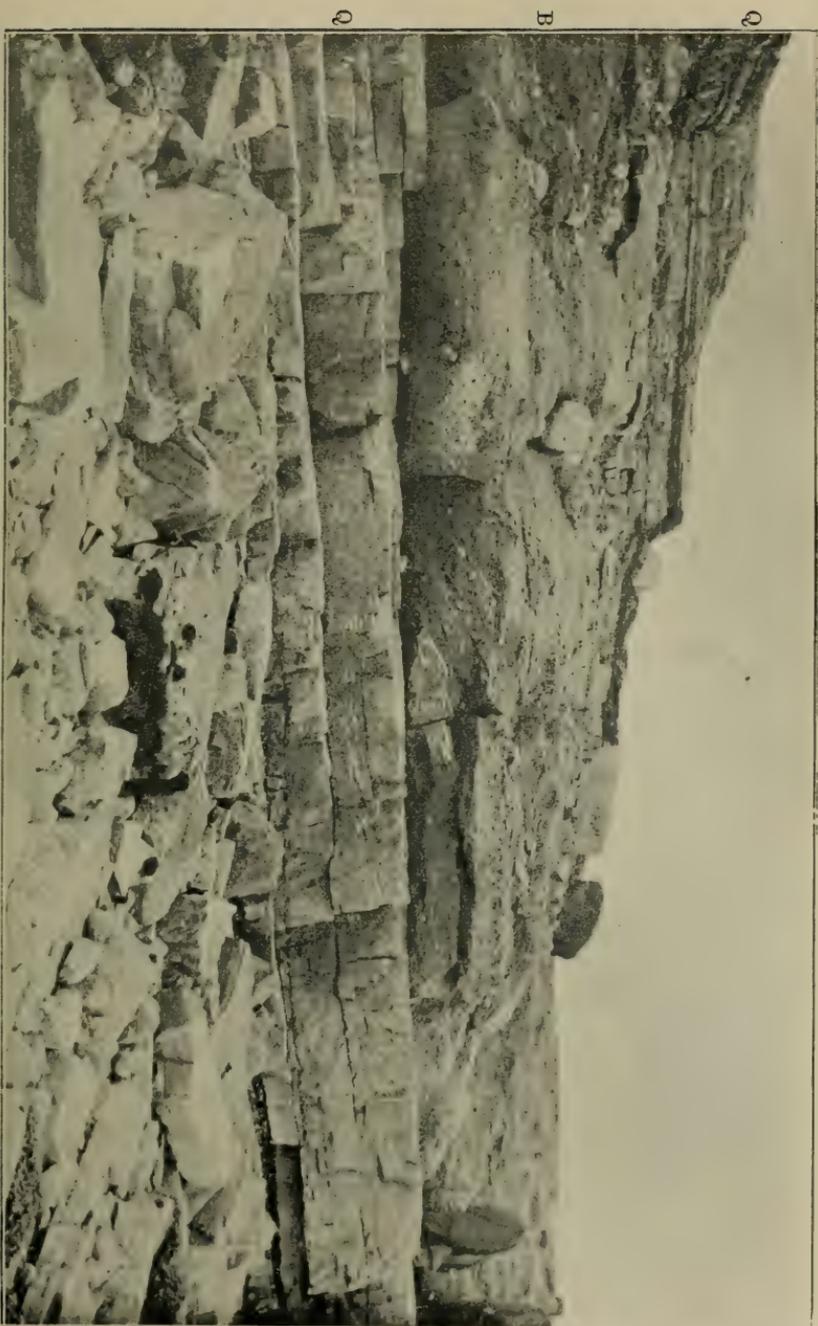
It seems that even an incoherent sand is capable of retaining glacial groovings, for I am informed by Mr. Clement Reid that the base of a boulder-clay resting on soft sand on the Norfolk coast showed ridges which were obviously casts of furrows in the surface of the sand below. A suggestive observation has been made also in Alaska by Mr. Harry Fielding Reid,<sup>1</sup> who states that 'the alpine end of the Charpentier Glacier rests on gravels. In the hundred feet or more between the glacier and Hugh Miller Inlet the gravels are streaked with uniform, straight, parallel grooves, a foot or two apart, which looked as if they had been ploughed out.' A further suggestion, made by Mr. Belinfante, that the sand may have been frozen when the ice passed over it, is deserving of consideration.—January 29th, 1897.]

<sup>1</sup> Sixteenth Annual Report U. S. Geol. Surv. (1894-95) p. 452.

#### PLATES VIII-X.

Views of cliff near Bigganjargga, showing the contemporaneous Boulder Clay interbedded with the Quartz-grits.

[For the Discussion, see p. 153.]

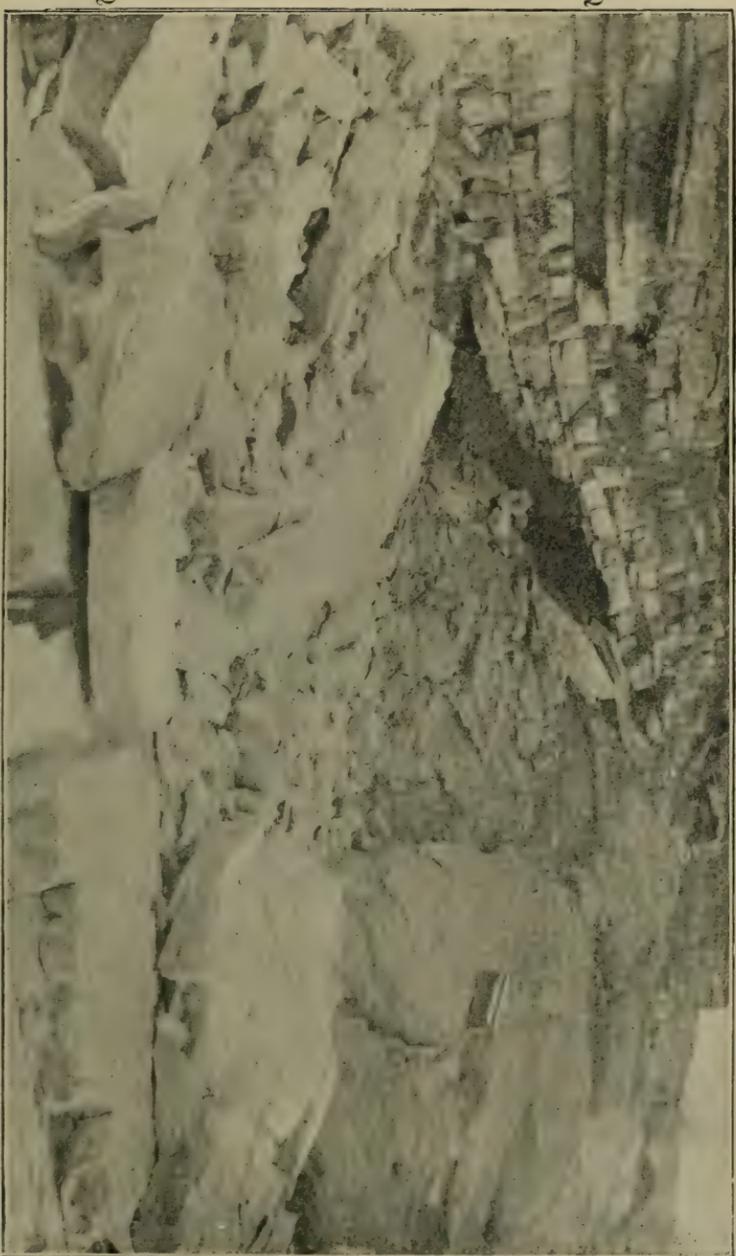


NEAR BIGGANJARGGA, LOOKING EAST.

CONTEMPORANEOUS BOULDER CLAY BETWEEN QUARTZ-GRITS (GAISA BEDS).

[Q = Quartz-grits; B = Boulder-rock.]





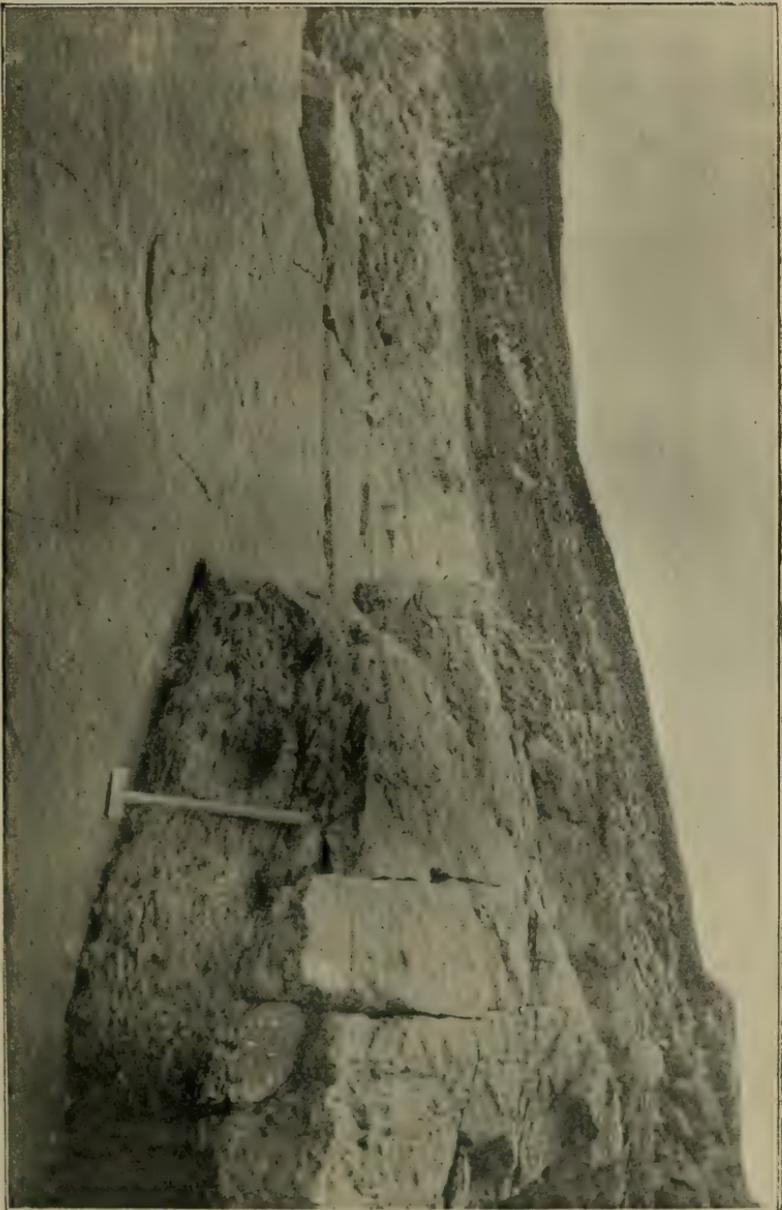
NEAR BIGGANJARGGA, LOOKING EAST.

QUARTZ-GRITS (Gaisa Beds) BEDDED ON AND AGAINST CONTEMPORANEOUS BOULDER CLAY.

The camera-case lies upon Boulder-rock in place.

[Q = Quartz-grits ; B = Boulder-rock.]





Q

B

NEAR BIGGANJARGGA, LOOKING WEST.

CONTEMPORANEOUS BOULDER CLAY, RESTING ON A GLACIATED SURFACE OF QUARTZ-GRIT, AND OVERLAIN BY QUARTZ-GRIT (GAISSA BEDS).

[Q = Quartz-grits; B = Boulder-rock; QG = Glaciated Quartz-grits.]



11. *The RAISED BEACHES and GLACIAL DEPOSITS of the VARANGER FIORD.* By AUBREY STRAHAN, Esq., M.A., F.G.S. (Read January 20th, 1897.)

THE raised beaches of the Varanger Fiord have frequently been noticed.<sup>1</sup> Though readily recognized all round Northern Norway, they are particularly well developed on the less precipitous coasts formed by the Gaisa rocks. In the immediate neighbourhood of Vadsö, the long slopes leading up to the moorlands of the interior can be seen from the sea to be diversified by a succession of terraces, too numerous to count, and lying one above the other up to a height of nearly 300 feet above the present shore. On closer examination these terraces are found to consist of shingle and sand, piled up here and there into characteristic beach-ridges, and enclosing behind them a number of shallow lakes or peat-bogs. Where the form of the ground permits they extend a considerable distance inland, and change the character of a large tract of country.

Though in every locality that I visited some of the intermediate beaches were more pronounced than others, I was not able to trace on such banks for more than a short distance, or to show that they occurred at the same level in different parts of the fiord. They seem rather to have been due to wave-action having been more energetic first in one place, then in another, as the form of the coast varied with the change of level. On the other hand, the upper limit of the series of beaches could be traced without difficulty, and, so far as I saw, contoured the hills around the fiord more or less continuously. The following aneroid-measurements were taken by Mr. W. Andrews, F.G.S., on the hillside 1 mile north-west of Vadsö:—

	Feet.
Trigonometrical Station.....	590
Highest raised beach .....	285
Numerous raised beaches, the more prominent occurring at.....	{ 240 232 227 140
A conspicuous shingle-bank north of Vadsö Church.....	92
Sea-level.....	0

The height of the Trigonometrical Station is given in the Norwegian Government Map as 184 metres, whence it would appear that the aneroid-readings should be increased by about 4 per cent. This would give 296 feet as the level of the highest beach at Vadsö, which is not far off Dr. Reusch's measurement of 93 metres. It is worth noting that when the land stood at that level the sea must have extended across the low ground separating

<sup>1</sup> [The earliest observations that I am aware of were made by B. M. Keilhau in 1837, *Nyt Mag. for Naturvidensk.* p. 244, and 'Gæa Norvegica,' Christiania, 1850.]

the Varanger Fiord from the Tana Valley, and thus communicated with the Tana Fiord so as to isolate a large tract of Norwegian Lapland. From Karlbotn I could see the terraces extending far in the direction of the Tana, but was unable to follow them for want of time. It must be noted, however, that the level of the highest beach between Nyborg and Karlbotn was only 235 feet, according to an aneroid-measurement by Mr. Dickson—that is, 61 feet lower than at Vadsö.<sup>1</sup>

The form of a raised beach is best seen at the highest level. It is usually that of a level terrace of shingle resting against the rock-slope, but not unfrequently, where the slope is gentle, the shingle has been piled up in a ridge, so as to dam back the land-water in a series of bogs and lakes, as already mentioned. The terrace or ridge often runs for a mile or two continuously, but sooner or later ends off against a rocky shoulder of the hill; in more than one such case, and notably  $1\frac{1}{2}$  mile east of Vadsö, the beach starting as a mere line of pebbles on the western side of such an obstruction increased in size eastward until it piled itself as a conspicuous bank against the next shoulder, thus pointing to the prevalent wind and wave-action having been from the west.

While traversing one of these rocky tracts on the hillside, it was easy to follow the level of the beach, even in the absence of the shingly terrace, for the rocks below that level were conspicuously distinguished by their rounded outlines and by abundant pot-holes, while those above it present the usual angular and splintered appearance due to weathering. By following the level thus marked out, I was led to more than one little isolated patch of shingle-beach, occupying what had obviously been a small shingly bay in the old shore-line. Good examples both of wave-worn rocks and of these detached patches of shingle occur on a hillside north-east of Vadsö.<sup>2</sup>

Another noticeable point was the abundance of large erratics lying on the old beaches. Though not absent above the highest beach, they occurred in greater abundance on and below that level. Among these were some of a conglomerate containing fragments of dolomite, which I believe had been derived from the Gaisa Beds, though I did not find the rock *in situ*; boulders of igneous and metamorphic rocks were common also, and had probably been brought from the ground near the head of the fiord. I infer from the presence of these erratics that floating ice was at work during the formation of the beaches, though at the present day the Varanger Fiord never freezes in its wider parts, and even in the tributary

<sup>1</sup> [My opportunities were too limited to enable me to enter into the question of differential uplift. That the level of the highest beach varies is well known, and some of the earliest observations on the subject were made by Bravais in the Altenfiord—'Sur les Lignes d'ancien Niveau de la Mer dans le Finmark' (extrait des 'Voyages en Scandinavie, en Laponie et au Spitzberg de la Corvette *La Recherche*,' Paris, 1848). Chambers made further notes on the variations of level in 1850, 'Tracings of the North of Europe,' pp. 199 *et seqq.*]

<sup>2</sup> The limit of waterworn rocks is equally well marked at Makur, according to Dr. Reusch, 'Geology of Northern Norway,' p. 91 & fig.

fiords and shallower parts not to a sufficient extent for the transport of large blocks.

The numerous ravines which are being cut by streams through the raised beaches show nothing but sand and shingle roughly stratified; but the surface of the beach, and more especially the top and landward side, is generally overspread by angular fragments. This is partly due to the splitting of the pebbles by frost, but more to the interruption of the process of shingle-making by the rising of the land. A beach formed on a subsiding shore is rolled over and over upon itself, and every part of it in turn is brought under the action of the waves. On a rising coast, on the other hand, the angular land-débris which forms the raw material, though it may be piled up in a characteristic beach-ridge, escapes being turned over and over, if the land by reason of its movement is gaining upon the sea. Marine organisms have been recorded by Col. Feilden and others in the beaches at about 50 feet above the sea in this neighbourhood,<sup>1</sup> but I could find neither shells nor bones at the higher levels, all presumably having perished in so porous a matrix.

We attempted more than once to count the beaches, but always unsuccessfully. The difficulty arose from the multitude of small subsidiary terraces like tide-marks. Here and there, and notably north of Karlbotn, we walked over what had obviously been a gravelly spit jutting out into the fiord. On the shelving surface of such spits these small terraces occurred in great numbers, spacing themselves out in a series of nearly concentric arcs on the shoal, but merging one into the other on either side of it. If it could be proved that each terrace marks the lapse of one year, the rate of elevation of the land could be determined at once. The calculation would probably show a rate of 1 or 2 inches a year, but I had no means of determining the exact gradient. On the other hand, these subordinate terraces may be merely storm-beaches, as suggested by Dr. Reusch, though it must be noted that they are remarkably equal and regularly spaced to have originated in such a manner.

The deposits of sand and shingle referred to above occur where the fiord is broad and open, but a different type sets in towards the head. Within a mile of Nyborg the Varanger Fiord terminates in a low marshy tract. No large river enters it, and there is little current beyond what is due to the slight rise and fall of the tide. The deposit now forming between tide-marks is a blue mud, over which are scattered many loose stones, none of large size. On searching for the raised beaches, I found a similar blue mud, also containing stones, and irregularly mixed with sand and shingle. Near Karlbotn also, where the fiord is of the same character, part of the raised beach-material consisted of blue clay, which, however, gave place to sand and shingle at the village. The appearance of the clay with its included stones, many of which, moreover, showed

<sup>1</sup> Quart. Journ. Geol. Soc. vol. lii. (1896) p. 724.

glacial striæ, led me at first sight to believe it to be a till, an opinion which I had occasion to change.

At Bödö there occurs a somewhat similar deposit. It forms a terrace about 70 to 80 feet high, on which the town is built, and consists of a bluish sandy clay, with many included stones and shells of *Leda (Yoldia) arctica* in the position of life; it rests on a rock-surface which is conspicuously moutonnée, but from which the striæ have been obliterated. Upon it, at a height of 70 to 80 feet above the sea, there lies a shell-marl containing, among others, the following shells<sup>1</sup>:—

<i>Mya truncata</i> , very abundant, with the valves united.		<i>Littorina obtusata</i> .
<i>Purpura lapillus</i> .		<i>Hydrobia ulvæ</i> (?).
<i>Trochus</i> .		<i>Lacuna crassior</i> .
<i>Littorina littorea</i> .		Broken nullipore and rolled echinoderm-spines.

At Tromsö I noticed a similar blue clay, and resting upon it, at a height of about 10 feet above the sea, a shell-marl from 1 to 3 feet thick, in which the following occurred:—

<i>Pecten islandicus</i> .		<i>Astarte compressa</i> .
<i>Mytilus edulis</i> .		<i>Tellina calcarea</i> .
<i>Mya truncata</i> .		<i>Littorina littorea</i> .
<i>Saxicava rugosa</i> .		<i>Tectura</i> .
<i>Cardium edule</i> .		<i>Balanus porcatus</i> .
<i>Astarte borealis</i> .		And much nullipore.
— <i>sulcata</i> .		

On the mainland opposite Tromsö the clay is worked for brick-making, and is described by Colonel Feilden as 'a homogeneous mass of blue clay with boulders and stones interspersed throughout. There is not a trace of bedding throughout the mass . . . the clay contains ice-scratched stones, and mollusca are abundant throughout the bed; examples of *Cyprina islandica* and *Pecten islandicus*, partially retaining their colour, are common, likewise stones to which the bases of a *Balanus* are attached.'<sup>2</sup> In all these cases mud is the material forming the bottom of the fiord.

My reasons for not applying the term 'till' to this deposit are briefly as follows:—Till, or the almost synonymous term Boulder Clay, which is used for this clay by Col. Feilden, always contains grit and sand, and generally in larger proportions than appear at first sight. When the proportion of clay is high, it is always because argillaceous formations have formed the source of supply, but even then it is a heterogeneous mixture of materials of all degrees of coarseness, bearing internal evidence of having been churned up, but not sorted under water. The fiord-clay, on the other hand, is a homogeneous clay or fine silty sand, such as could hardly have been accumulated except by the sorting action of water. It contains delicate mollusca, nearly all in a perfect condition, with the valves united; while, lastly, it is not such a material

<sup>1</sup> These and the other shells were identified for me by Mr. Clement Reid. The deposit was noticed so long ago as 1850 by Chambers, 'Tracings of the North of Europe,' p. 134.

<sup>2</sup> Quart. Journ. Geol. Soc. vol. lii. (1896) p. 723.

as would result from the grinding down of any rocks near which it lies. In the apparent absence of stratification it resembles such a deposit as the *Scrobicularia*-Clay of parts of the English coast, which frequently breaks more readily along vertical shrinkage-cracks than in any other directions, in consequence of its perfect homogeneity. The strongest argument in favour of the glacial origin of the blue clay lies in its containing scratched stones; but the explanation of their presence is suggested by the fact that stones are being strewn over the surface of the similar mud now forming in the bottoms of the fiords, brought there, I presume, by the ice which forms annually in the shallower waters. In connexion with this it is worth noting that such a process of distribution takes place occasionally even in this country; the mud-flats of the estuary of the Cheshire Dee have been known after hard frosts to be dotted over for some miles with erratics of slag from the Flintshire iron-works. Avoiding, on these accounts, the use of the terms Till and Boulder Clay, I adopted the name 'fiord-mud,' but the expression 'glacio-marine' used by Col. Feilden is perhaps equally suitable, so long as it does not lead to the confounding of the deposit with formations of true glacial age. In the three localities I have referred to, namely the Varanger Fiord, Bødö, and Tromsö, I consider the deposit to belong to the raised beaches, and to differ in no marked degree from the material now accumulating in the neighbouring fiords.

#### GLACIAL DEPOSITS.

To distinguish the beds of glacial age from the raised beaches was seldom easy, for not only does the fiord-mud simulate Boulder Clay, but the sand and shingle of the beaches might well pass for esker-gravel. At first I was disposed to so class these gravels, believing that their terraced outline alone was attributable to rearrangement by waves.<sup>1</sup> But after seeing some examples of Glacial Drift, above the level of the highest beach, I came to the conclusion that, though the material of the beach had often been derived from Glacial Gravels, yet it had been completely redistributed, and could no longer be regarded as part of the earlier series.

Glacial Drift was by no means so typically developed as in this country. I saw two examples, however, near Vadsö, which seemed to be characteristic. In the one case mounds and ridges, enclosing water-logged hollows, extended from the level of the highest beach along the little valley of the Thomaselv. This hummocky strip was terminated abruptly by the smooth and level terrace of the beach, and had evidently yielded much of the material of which it was composed. Many of the mounds were overspread by, and perhaps

<sup>1</sup> This is the explanation of a moraine with a perfectly level top which dams up a lake at Hammerfest. Dr. Reusch supposes the surface of the moraine to have been levelled by the waves, 'Geology of Northern Norway,' p. 101 & fig. The dam, consequently, has the composition of a moraine, but the form of a beach.

consisted of, angular sandstone-blocks, and they had assumed the form of moraines, but the valley was too small to have contained more than a diminutive glacier. A considerable quantity of talus encumbered the sides of the valley, and a winding stream had cut deeply into the hummocky débris, giving an impression of some antiquity for the mounds. The scene reminded me of many of our north country gills.

The second example referred to consisted of a conspicuous mound of sand and pebble-gravel, perched on the hillside north of Vadsö, a few feet above the level of the highest beach. The mound is slightly elongated in an east-and-west direction, and resembles a very large oval tumulus, but its size and composition disprove its artificial origin, for it contains none of the angular débris which lies round its base, but consists wholly of sand and shingle, which would have had to be carried from nearly a mile away. Though unusually isolated and conspicuous, the mound presents the same general features as those that I have seen elsewhere, and as those of many eskers in this country, which also often resemble closely great tumuli.<sup>1</sup>

With these exceptions, nearly the whole of the ground that I walked over was free from deposits of glacial age.

#### GLACIAL STRIÆ.

The shores of the Varanger Fiord are, of course, conspicuously glaciated, though less so on the Gaisa Beds of the northern side than on the crystalline rocks of the opposite coast. A finely-striated surface, however, occurs at one of the landing-stages on Vadsö Island, while the spit of land between the Nyborg and Karlbotn branches of the fiord is well glaciated all over. The striæ there range between W. 10° N. and W. 25° N., and from an inspection of a large number of 'roches moutonnées,' we were able to satisfy ourselves that the ice moved from west to east—that is, down the fiord. The distribution of the boulders supports this conclusion in so far as the spit of land approximately divides Gaisa from granitic erratics, showing that they have travelled along and not across the fiord.

The striæ appeared to be earlier than the raised beaches, for they are often obliterated under them, though the glaciated form of the rock is preserved, as in the case at Bödö referred to above. The wave-worn rocks under the highest beach at Vadsö form a stronger argument, for there the surface remains as it was left at the period of the beach, but shows no glaciation.<sup>2</sup> On the other hand, the apparent freshness of some striated surfaces under raised beaches led Col. Feilden to conclude that the glaciation went on simultaneously with the emergence of the land,<sup>3</sup> and undoubtedly

<sup>1</sup> I should mention that Mr. Upton, who accompanied me, was disposed to believe the mound to be a tumulus.

<sup>2</sup> [The observations of Chambers and many other geologists who followed him led to the same conclusion on the western coast also. There, too, large erratics lie on the top of the fiord-deposits.]

<sup>3</sup> Quart. Journ. Geol. Soc. vol. lii. (1896) p. 736.

the striæ on the shore of Vadsö Island look remarkably fresh. Their powers of survival, however, are vouched for by the fact that they are exposed to the wash of every tide and the traffic of men and boats, but have suffered no injury. Occurring as they do, moreover, at the present sea-level, they would be contemporaneous with the lowest beach—namely, that of the present day. This, in view of the fact that the upward movement of the land is still proceeding, amounts to saying that the glaciation should now be taking place. So far as the Varanger Fiord is concerned, this is not the case.

The glaciation of the fiord seemed, so far as my limited observation went, to be the work of floating ice rather than of an ice-sheet, and it was with great interest that I read, on my return, Col. Feilden's graphic description of the behaviour of drifting pack-ice in such a situation. I drew this inference from the fact that the glaciation, though so well marked along the fiord, was inconspicuous, if it existed at all, on the moorlands a few hundred feet above it. Without a far more extended experience I could not say that it was absent, but the scarps of hard sandstone which I examined near Vadsö, at a height of 400 to 600 feet above the sea, showed no signs of having been crossed by ice, while the same rock between Karlbotn and Nyborg, up to a height of about 400 feet, was smoothed and scored all over. These observations indicate that the glaciation was due either to a Varanger glacier or to ice drifting down the fiord when the land stood at a lower level. I have already mentioned that when the land stood at the level indicated by the highest raised beach there was a communication between the Varanger Fiord and the Tana Valley, and so with the Tana Fiord. The tide must then have had a free run round a large tract of Norse Lapland, and penetrated many valleys which are now high and dry. On the supposition that the striation was effected by floating ice, the fact that the striation of the rocks near Karlbotn extends nearly 140 feet above the level of the highest beach, indicates that the land stood at a still lower level during the Glacial Period than subsequently when the beaches were formed. However this may have been, there can be no doubt that, even when the land was 235 feet lower than at present, the conditions prevailing in the Varanger Fiord would not only have allowed of the formation of a considerable quantity of ice, but would have admitted of a current to move it.

#### DISCUSSION (ON THE TWO PRECEDING PAPERS).

The PRESIDENT remarked that the first paper was of unusual interest to him, for so long ago as 1876 he had argued that it seemed impossible to conceive that the thick breccias and the large boulders so abundant at the base of the Cambrian conglomerates in Wales could have accumulated, unless the pre-Cambrian land had suffered greatly from subaerial influences, including those of ice and snow. When he visited the North-western Highlands in 1878 he felt equally convinced that the breccias at the base of the

Torridon Sandstone were the result of similar causes, and in his paper in the 'Geological Magazine' for 1880, 'On Pre-Cambrian Volcanoes and Glaciers,' he gave the facts then known. He congratulated the Author on the admirable manner in which he had worked out the evidence now produced from the Varanger Fiord, and on his being able to show so conclusively that the views put forward by Dr. Reusch were substantially correct.

Sir ARCHIBALD GEIKIE congratulated the Author on having been more successful in his Arctic expedition than his companions the astronomers. Of the various possible interpretations of the phenomena described, that adopted in the paper seemed to him the most probable. At the same time it was not without its difficulties. One of the most obvious of these was presented by the striated pavement of quartzite below the boulder-bed. According to the Author's observations there appeared to be no break in the stratification, the dark boulder-bearing deposit being merely a local interruption of one continuous sequence of sedimentation. But it was clear that the striated quartzite must have been indurated, possibly even as hard as it is now, before it could receive and retain the striæ. How could this induration take place under water in a continuous series of deposits of loose siliceous sand?

The objection seemed serious, but it might not prove to be insuperable. It was conceivable that, in spite of the apparent conformability in the sections examined by the Author, there might really be a break of some magnitude represented by the boulder-bed, though in that case there would be the objection that it seems unlikely, after this prolonged interval, that sediment of precisely the same character should be laid down with perfect conformability on the previously striated bed of quartzite. If, however, no such chronological or stratigraphical break could be detected, there remained the possibility that the striated quartzite acquired its induration under water and while the immediately overlying sediments were being deposited.

A number of instances were now known where silica seems to have been deposited, on the whole, contemporaneously with the sediment. The Gannister seams of the Carboniferous system might be quoted, but still more remarkable was the evidence that the radiolarian cherts of the Arenig Series in the South of Scotland had become solid stone on the sea-bottom, and had been broken up by volcanic explosions into angular fragments which were found in the immediately overlying tuffs.

With regard to the age of the Gaisa Series, the speaker was inclined to adopt the view of Dr. Reusch, who compared this series with the sparagmite of Central and Southern Norway. He himself had seen the sparagmite *in situ*, and had been much struck with its general resemblance, both in scenery and in lithology, with the Torridonian rocks of N.W. Scotland. It was, like those rocks, older than the Cambrian system. An interesting parallel might be drawn between the Sutherland sections and those of Norway. The Lewisian Gneiss was found to pass in rounded domes and hummocks beneath the Torridon Sandstone. These forms so exactly resembled

those of ice-worn surfaces that, although no striation of the gneiss had been observed, they at once suggested the influence of glaciation. Again, the composition, disorder, and lenticular character of the coarse conglomerates sometimes met with at the base of the Torridonian Series might perhaps find their counterparts in the Gaisa rocks.

Dr. J. W. GREGORY thought that the Society was to be congratulated on this paper, and on the opportunity of seeing the Author's admirable photographs of the rocks. The previous failure to discover traces of glacial action in high northern latitudes in pre-Pleistocene times gave wide interest to Reusch's paper; and the corroboration of his views was of great value. The speaker thought the deposits of special interest, as similar conglomerates occupying identically the same stratigraphical position occur all round the Polar basin, and in places where their age can be proved. In Spitzbergen the occurrence of the conglomerates was discovered last summer, and they are there pre-Devonian. Mr. Garwood, during his ascent of Hornsund Tind, found fossils in the same series. In North-eastern Greenland the conglomerates, associated with the same red rocks, quartzites, etc., are known to occur, from the work of Payer and Ryder; and the beds re-appear from beneath the ice-cap on the western coast of Greenland. Farther south they occur in Labrador, as part of a series of red rocks and quartzites resting on the metamorphic rocks, and are referred to the Cambrian; the conglomerates consist of boulders, some of which are rounded, and others are angular, while A. P. Low states that they range in weight from an ounce to a ton. Farther north-west the beds occur in the North-eastern Provinces, and in the Coppermine River, and finally they re-appear on the northern coast of Siberia. The conglomerates are therefore probably part of a circumpolar belt. Palæontological evidence for their correlation is wanting, but they always occur resting on the metamorphic series, and are older than the oldest fossiliferous rocks of the area wherein they occur; indeed, it can be often proved that they are pre-Silurian. The absence of Silurian or Devonian pebbles in the Varanger Fiord conglomerates is a strong argument for their early Palæozoic age, as Silurian rocks probably once occurred a little farther north.

Mr. GEORGE BARROW wished to know exactly what the Author meant by the sentence 'the Boulder Clay has a somewhat schistose structure.'

Mr. HUDLESTON, having visited the Varanger Fiord some forty-two years ago, could to a certain extent corroborate the Author's statements as to the nature of the country and of the arenaceous quartzite system prevailing in Eastern Finmark. Beyond the region shown in his map, on the eastern side of the Tana Fiord, the Stanganes Fjeld rises rather steeply to heights probably reaching 3000 feet. This is a quartzite wilderness, almost as white as snow, having a strong external resemblance to the quartzite-mountains of the North-western Highlands; the system might thus include both Torridonian and basal Cambrian beds.

The importance of the Author's verification of Reusch's statements

was very great. The late Dr. Croll had been desirous of obtaining evidences of glaciation in the several formations anterior to the great Ice Age. His failure to do so he attributed to the circumstance that the evidences of glaciation are to be found principally on land-surfaces, and that the transformation of a land-surface into a sea-bottom would in most cases obliterate all traces of glaciation. A striated bed-rock went much farther in this direction than mere boulders and striated stones; and, as far as he (the speaker) knew, these occurrences on the Varanger Fiord were the only occurrences as yet established in the Northern Hemisphere, with some possible exceptions in the case of the Tschirs. For a grander exhibition of striated bed-rock they must look to the Southern Hemisphere: Prof. Edgeworth David had recently brought before the Society such evidence from Southern Australia, referred to the Permo-Carboniferous period.

With regard to the Author's second paper, he could testify from personal experience to the striking development of the terrace-formations, tier above tier, on the northern side of the Varanger Fiord.

Mr. H. B. WOODWARD remarked that there was plenty of schistosity in the Boulder Clay of Cromer, as described by Mr. Clement Reid.

The Rev. H. N. HUTCHINSON ventured to suggest that the difficulty raised by a previous speaker with regard to the absence of a break between the quartz-grits had not received the attention that it deserved. How could the lower grit have become sufficiently hardened to receive these supposed glacial striæ, if the series was unbroken by any unconformity? This was the difficulty, and it had not been met. He did not feel at all convinced himself, and would like to ask how many sets of striæ the Author had observed.

The AUTHOR, in reply, remarked on the interest of Dr. Hicks's speculation as to the glacial origin of certain British rocks of apparently the same age. To Sir Archibald Geikie's question regarding the relationship of the quartzites above the Boulder Clay to those below it, he was unable to give a definite answer, further than to say that he had seen no evidence of a break at that horizon. The characters of the rocks and their dip suggested a continuous series, but the point could not be settled in so brief a visit. The fact that the quartzite had been hard enough to receive and retain the striæ undoubtedly required explanation. It may, perhaps, have been buried, hardened, and subsequently laid bare by the ice, which presumably would erode all unconsolidated material until it reached the first hardened bed. In reply to Dr. Gregory, he had not stated that the glacial episode was local, but that the question of its extent must be left for further investigation. The boundary-line between the Gaisa and the crystalline rocks was not a thrust-plane, as suggested by Mr. Barrow, but, at the point he had examined, a clear unconformable superposition. To Mr. Hutchinson he replied that three sets of striæ occurred, one of which, however, was much stronger than the others. He was glad to see a tendency to accept the glacial origin of the phenomena. Though it was difficult to do full justice to it, the evidence on the ground was strong.

12. *On the PEMBROKE EARTHQUAKES of AUGUST, 1892, and NOVEMBER, 1893.* By CHARLES DAVISON, Sc.D., F.G.S., King Edward's High School, Birmingham. (Read January 6th, 1897.)

## [PLATE XI.]

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THE Essex earthquake, one of the strongest ever recorded in this country, occurred on April 22nd, 1884. Since that time the most important shocks are those which were felt, principally in Pembrokeshire and the surrounding counties, on August 18th, 1892, and November 2nd, 1893.<sup>1</sup> I propose in this paper to give a brief account of the nature and probable origin of these earthquakes, as well as of the slighter shocks which preceded and followed them. Owing to the large number of observations (nearly 2000) which I have collected, it is impossible for me to quote the authority for every statement here made, or to present the evidence in any detail. But, in offering my hearty thanks collectively to the numerous ladies and gentlemen who by their kindness have made this investigation possible, I should like to mention how greatly I am indebted to Prof. Lapworth for frequent advice and assistance; to Mr. Marr and Mr. Teall for information with regard to the geology of the epicentral district; and to Mr. T. Mann Jones, F.G.S., Mr. H. Cecil Moore, Mr. Harold J. E. Peake, Mr. O. M. Prouse, F.G.S., Mr. G. J. Symons, F.R.S., and especially to the Rev. W. M. Morris, formerly of Cresswell Quay, near Pembroke, for valued aid in collecting additional records.<sup>2</sup> My obligations to the last-named gentleman will be obvious when I state that he visited for this purpose nearly all parts of Pembrokeshire, and by his skill in cross-examining observers extracted details which could not have been obtained by any set of printed questions, however carefully framed.<sup>3</sup>

<sup>1</sup> [It should be mentioned that the above sentence was written before the occurrence of the Hereford earthquake of Dec. 17th, 1896.—March 1st, 1897.]

<sup>2</sup> My best thanks are also due to the editors of the 'Times,' the 'Standard,' the 'South Wales Daily News' (Cardiff), the 'Western Morning News' (Plymouth), and many other newspapers, for their courtesy in inserting letters from me asking for observations of the earthquakes.

<sup>3</sup> The expenses incurred in investigating the earthquakes of 1893 were defrayed by a grant which I had the honour of receiving from the Government Research Fund.



## I.—EARTHQUAKES OF AUGUST 17th–23rd, 1892.

The following is a list of the earthquakes of this series, the principal shock being denoted by a capital letter:—

a. <i>August 17th</i> : about 11.30 P.M.	g. <i>August 18th</i> : 2.50 A.M.
b. <i>August 18th</i> : 0.22 A.M.	h. " " about 4 A.M.
C. " 0.24 A.M.	i. <i>August 19th</i> : 9.30 A.M.
d. " 0.37 A.M.	k. <i>August 22nd</i> : about 11.55 A.M.
e. " about 1.5 A.M.	l. <i>August 23rd</i> : 4.30 A.M.
f. " about 1.40 A.M.	

It should be remarked that the earthquake denoted by the letter *i* depends on the evidence of one witness only. But, as it is recorded by a most careful observer, the usual rule of regarding such an earthquake as doubtful should, I think, be suspended in this case.

## (i) Preparatory Earthquakes.

a. *August 17th*: about 11.30 P.M.

Intensity, 3.—Number of records, 3; from 3 different places.

The shock was felt at Haverfordwest and Rudbaxton, 3 miles farther north. At the same time, two rumbling noises were heard at Pembroke.

b. *August 18th*: 0.22 A.M.

Number of records, 7; from 7 different places.

Two minutes before the principal shock, a distant sound, as of thunder, was heard, without any accompanying tremor. The places of observation are situated within a small area in the extreme south of the county (see map, p. 158). The longer axis of the area is directed approximately north and south, and its centre is either close to the coast (about  $1\frac{1}{2}$  mile west of Manorbier) or else beneath the sea. The land-area over which the sound was heard contains about 33 square miles. Five minutes before the great shock, Dr. Propert, at St. David's, heard a noise as of a cart passing. It is uncertain whether this observation refers to the same earth-sound as the others.

## (ii) Principal Earthquake. C: 0.24 A.M.

Intensity, 7.—Number of records, 712, from 555 different places; also 114 records from 111 different places at which, so far as known, the earthquake was not observed.

*Disturbed Area and Isoseismal Lines.*—On the map illustrating this earthquake (Pl. XI) are shown the isoseismal lines corresponding to intensities 4 and 5 of the Rossi-Forel scale. Portions of those corresponding to intensities 6 and 7 are also given, but the land-areas traversed by these lines are not great enough to allow of the remaining parts being drawn. On this account it is not possible to determine the position of the epicentre with great exactness.

So far as the land-areas are concerned the isoseismal 4 is probably nearly accurate. The path of this line across the sea is of course conjectural, but its trend just before leaving the land appears to indicate that it is correctly drawn. Assuming this to be the case, the area included within this curve is 255 miles in length from north to south, 225 miles from east to west, and contains about 44,860 square miles. This does not, however, represent the whole of the disturbed area, for the shock was plainly felt at several places beyond the limits of this isoseismal. There can be no doubt that it was felt at Tresco Abbey in the Scilly Isles, at Dorchester, and at South Littleton near Evesham, the distances of these places from the isoseismal being 14, 12, and 8 miles respectively. From the account given me by Mr. J. J. Cole, F.R.A.S., I believe that an exceedingly slight tremor observed by him at Sutton, in Surrey, must be attributed to this earthquake. The distance of Sutton from the epicentre is about 200 miles, and from the nearest point of the isoseismal 4 about 85 miles. Accounts have also been received from Ballinahinch and Milltown Malbay, in Co. Clare; but, from the great recorded intensity of these disturbances, whether they be seismic or not, I have no hesitation in rejecting the supposition of any connexion between them and the Pembroke earthquake.

While it is impossible to assign definite limits to the disturbed area, there can thus be no doubt that it must greatly have exceeded 45,000 square miles in extent. The disturbed area of the Essex earthquake of 1884 is estimated by Messrs. Meldola and White at about 50,000 square miles<sup>1</sup>; but this is the total area, not that included within isoseismal 4, which must have been very much smaller. The Pembroke earthquake, though not nearly so strong near the epicentre, must therefore have disturbed a far larger area. It seems reasonable to attribute this to the wide distribution of older and harder rocks over its disturbed area.

The isoseismal 5 bounds an area 172 miles long and 136 miles broad, and containing about 18,660 square miles. The centre of this curve is about  $2\frac{1}{2}$  miles west of Linney Head. Its longer axis is directed approximately north and south. If the earthquake were due to fault-slipping, it follows that in the neighbourhood of the epicentre the direction of the fault-line must be north and south.

The next isoseismal (intensity 6) includes the whole of Pembroke-shire and parts of the counties of Caerdigan, Caermarthen, and Glamorgan. Only the eastern portion of the curve can be drawn, the western part lying at some distance from the coast. Towards the south it probably passes to the north of Lundy Island, but it would be unsafe to presume too much on the strength of a single observation at that place. The land-area enclosed by this isoseismal contains about 1070 square miles.

<sup>1</sup> 'Report on the East Anglian Earthquake of April 22nd, 1884' (1885), p. 22.

The central isoseismal (intensity 7) is in the form of a semi-ellipse whose shorter axis is 21 miles in length, and whose longer axis is directed north and south. As only the northern half lies on land, it is somewhat doubtful whether the centre of the area lies beneath the land or the sea; but in either case it is probably not far from the coast, at a point about  $3\frac{1}{2}$  miles S.S.E. of Pembroke. The land-area included within this curve contains about 450 square miles. The form and position of this isoseismal corroborate the inference previously drawn as to the direction of the originating fault.

Owing to the incompleteness of the isoseismal 6, there is some uncertainty as to the direction in which the supposed fault fades. Comparing the isoseismals 7 and 5, however, it will be seen that on the eastern side of the epicentre they are separated by a distance of 52 miles, while on the western side the distance between them is as much as 62 miles. If the district on either side of the epicentre were fairly similar and uniform in structure, this would indicate that the fault fades to the west. The great extent of the disturbed area, and the fact that so much of it to the west is covered by sea, lessen the force of this inference so far as it depends on the relative position of the isoseismals.

On the other hand, the distance between the isoseismals 4 and 5 is much greater towards the north, north-east, and east, and at first sight this appears to lead to a contrary conclusion to that above stated. In the neighbourhood of the epicentre, the distance between two given isoseismals is greater on the side towards which the fault fades than on the opposite side. But at great distances from the origin the inclined position of the fault-plane has a less unequal effect on the intensity at equal distances on opposite sides of the fault, and the consequence is that two distant isoseismals are less separated on the side towards which the fault fades than on the other. It is clear, however, that the relative position of the isoseismals is governed to a great extent by the structure of the districts through which the earth-wave had to pass. The intensity appears to have died out less slowly on continuous land-areas than when sea-areas intervened, and thus the isoseismal 5 might have extended still farther west if there had been no sea to traverse. Thus, judging from this earthquake alone, a westerly hade of the fault is more probable than an easterly one.

As the intensity of the shock is greater on the side of the fault towards which it fades,<sup>1</sup> it follows that the fault must intersect the ground along a north-and-south line lying a short distance (perhaps 2 or 3 miles) east of the centre of the isoseismal 7. Referring to the map (p. 158), it will be seen that such a line nearly coincides with the longer axis of the curve bounding the area over which the earth-sound (*b*) was heard 2 minutes before the principal shock.

*Nature of the Shock.*—Owing to the time of its occurrence, many of the observers were roused by the first tremors or by the pre-

<sup>1</sup> Geol. Mag. 1896, pp. 78-79.

liminary sound, and thus the earlier phenomena were lost to them. But there remain a large number of careful accounts written by those who were awake at the time, and from these I select the following as generally descriptive of the shock in different parts of the disturbed area:—

Haverfordwest.—The shock began violently, gradually weakened, then became stronger than at first; it lasted about 14 seconds.

Cresselly.—Four sets of vibrations—weak, medium, strong, weak; the second and third sets separated by a few seconds, during which a tremulous motion was felt. Duration, about 20 seconds.

At several other places in Pembrokeshire (especially Cheriton, Cosheston, Manorbier, Redberth, and St. Florence), the nature of the shock closely resembled that felt at Cresselly.

From these and many other accounts it is clear that near the epicentre the shock, though continuous, contained two maxima of intensity, the second of which was stronger than the first. Farther away, the tremulous motion felt between the two maxima was imperceptible, and the shock then consisted of two detached series of vibrations separated by an interval of a few seconds of rest. The following may be mentioned as examples:—

Clynderwen (Caermarthenshire): sharp vibrations increasing in intensity for about 5 or 6 seconds, ceasing for 2 or 3 seconds, and renewed with greater violence for about 10 to 15 seconds.

Port Eynon (Glamorganshire): two series of vibrations, with an interval of about 10 seconds between them.

Cleavehouses (near Bideford): two distinct shocks, the first a tremor like that produced by a clap of thunder, the second more pronounced.

Ballywalter (near Gorey, Co. Wexford): two series of vibrations, the second more intense; an interval of about 2 seconds between them.

The double series of vibrations was observed practically all over the disturbed area, at Rhyl in the north, Tresco Abbey (in the Scilly Isles to the south), at Worcester on the east, and at Tullow (Co. Carlow) on the west. Excluding some rather doubtful cases, it was noticed by 42 observers, 30 of whom record the relative intensity of the vibrations. The second is said to have been the stronger at 22, and the first at 2, of these places, while at the remaining 6 places the two series are described as of approximately the same intensity. The two places at which the first series was regarded as the stronger are Martletwy, in Pembrokeshire, and Treorchy, in Glamorganshire; but there can be, I think, little doubt that these observations are incorrect. When we remember that most of the accounts were written after the lapse of several days or weeks, it is obvious that some allowance must be made for defects of memory. It is probable that the difference in intensity was not very great, but that all over the disturbed area the second maximum was stronger than the first. The significance of this conclusion will be considered in a later section dealing with the origin of the shock.

*Sound-Area.*—The earth-sound was heard at 334 places, at all but 5 of which the shock was also felt. So far as can be ascertained, the sound-area coincided nearly, but not quite, with the area bounded by the isoseismal 4; but the number of places near the boundary is too small to allow of its being laid down with any approach to accuracy. Towards the north, west, and south the two curves are close together; towards the east and south-east the sound-curve extends a few miles beyond the isoseismal.

At 53 places it is expressly stated that no earth-sound was heard, while the shock was distinctly felt. In some cases these places are near the boundary of the sound-area and help to determine its position; but 26 of them are in the counties of Monmouth, Somerset, Gloucester, and Hereford. It is not at all an uncommon experience to find the earth-sound unperceived by isolated observers at places well within the isoseismal 5. This can hardly be due to inattention on the part of the observers; rather, I believe, to the sounds being below their lower limit of audibility.

*Nature of the Earthquake-Sound.*—Within the isoseismal 5 the sound is generally compared to the passing of heavily-laden waggons or traction-engines, to thunder, etc. The sound varied in pitch and character. For instance, at Lamphey (near Pembroke), a murmuring sound resembling that of sea-waves at a distance was heard for 3 seconds, changing, when the shock was strongest, to a deep, short, heavy boom like thunder, and continuing after the shock for about 3 seconds with the same sound as at first.

Between the isoseismal lines 4 and 5, the slighter sounds which gave rise to these variations were imperceptible; the sound was more monotonous, being compared most frequently to the low roll of distant thunder, the moaning of the wind or of sea-waves, or to rain falling on the leaves of trees.

*Time-Relations of the Sound and Shock.*—In the following Table are given the time-relations of the beginning, epoch of maximum intensity, and end of the sound and shock. The figures show the number of places in different districts at which the beginning, etc., of the sound preceded (*p*), coincided with (*c*), or followed (*f*), the beginning, etc., of the shock:—

	Beginning.			Epoch of Maximum Intensity.			End.		
	<i>p.</i>	<i>c.</i>	<i>f.</i>	<i>p.</i>	<i>c.</i>	<i>f.</i>	<i>p.</i>	<i>c.</i>	<i>f.</i>
Pembrokeshire .....	31	30	4	9	41	3	5	8	54
Rest of Wales .....	18	2	0	2	6	0	2	2	3
Devon and Cornwall .....	19	1	2	5	6	1	3	4	7
Rest of England .....	7	0	0	1	0	0	2	1	3
Ireland .....	9	2	7	2	3	1	2	2	6
Totals .....	84	35	13	19	56	5	14	17	73

In considering this Table some allowance must be made for defective observation and errors of memory; but it is clear, as a first result, that the beginning of the sound generally preceded that of the shock, their epochs of maximum intensity coincided, and the end of the sound followed that of the shock.

The most notable exception to this rule is the large number of places in Pembrokeshire at which the beginning of the sound coincided with that of the shock. One reason for this is that the preliminary tremors were felt in that county, whereas in other districts the beginning of the sound was necessarily referred to the beginning of the principal vibrations. For vibrations which are rapid enough to be perceived as sound, the ear, with most observers, is a far more delicate seismoscope than the body. Moreover, there can be little doubt that the seismic focus was many miles in length, and, though partly under the sea, extended some distance up the county, so that the margins of the focus (from which, I believe, the sound-vibrations chiefly come) and the rest of the focus were almost equidistant from many of the places of observation. In other parts of the disturbed area, but especially in those which lie north and south of the epicentre, the beginning of the sound preceded that of the shock, because the nearest part of the focus was either the northern or southern lateral margin.

At Penzance and St. Goran, in the south of Cornwall, the sound is said to have preceded the shock entirely; and at Lydney, in the west of Gloucestershire, to have ceased before the principal vibrations were felt. These observations seem at first sight to prove that the velocity of the sound was greater than that of the larger vibrations, but such a conclusion is not sustained by the rest of the evidence. At four other places in the south of Cornwall the epochs of maximum intensity of the sound and shock are said to have coincided, or the end of the sound to have followed that of the shock. It is possible that in this district the epoch of maximum intensity of the sound may really have preceded that of the shock by a short interval, for these epochs are difficult to define with precision. This is what we should expect, for the south of Cornwall lies almost in the continuation of the supposed fault-line, and the loudest sound-vibrations heard there would come from the southern margin of the focus. From the neighbourhood of Lydney there is no other evidence; but if the sound outraced the shock in one direction at right angles to the focus, it would do so also in the other, and the observations from the south-east of Ireland are entirely opposed to this. On the other hand, the records both from Gloucestershire and Ireland are what we should anticipate with a westerly hade of the originating fault.

Another explanation of the observations is not impossible. At Ballywalter (in Co. Wexford) and Newcastle (in Co. Wicklow) two series of vibrations were felt, and the sound was perceived only in the interval between them. Now, if the first and slighter series had escaped notice, as it seems to have done in some places, the sound would to the observers there have appeared to precede the shock

entirely. Though preferring the former, I am unable to decide between these two explanations; but, at any rate, there seems to be no reason for supposing that the sound-vibrations and the larger vibrations travelled with different velocities.

*Sea-Waves and Miscellaneous Phenomena.*—The shock was felt by several persons in boats, the sensation being the usual one of having struck upon a rock. At Bulwell, on the southern shore of Milford Haven, two or three waves were seen to dash up the shore, the sea both before and after being absolutely still. The shock was also felt by the engineer of a steamboat on the river opposite Langwm. 'The water, although perfectly calm before, became suddenly swelled as with a heavy breeze. The boat seemed as if passing over a swell, and then another, and then another—three distinct waves, after which the water was troubled for a few seconds; then it became perfectly calm as before.' The waves lasted from 15 to 20 seconds, and crossed the river from north-west to south-east.<sup>1</sup>

Some hours after the earthquake, one or more so-called tidal waves were observed at various places along the shore of the English Channel, and were generally regarded as an effect of the earthquake. The places from which I have obtained accounts of such waves are (from west to east): Scilly Isles, Porthpean (near St. Austell), Lostwithiel, River Yealm, River Dart, estuary of the Exe at Exmouth and Topsham, Weymouth, Portsmouth, and Bosham (in Sussex). It is unnecessary to enter into any detailed description of the waves, since, whatever their origin may have been, it is difficult for the following reasons to connect them with the Pembroke earthquake:—(1) All the places are situated along the English Channel. (2) The accounts obviously refer to several different waves, but, so far as one wave in particular can be traced, it advanced from east to west. (3) Similar waves were observed on the two days preceding that of the earthquake.

The shock appears to have had some slight effect on underground water. At Green Croft (near Narberth), a well, shortly before the earthquake, contained some water, and when visited soon afterwards was found to be empty. At Marloes, according to an account written about eight weeks after the shock, the springs in the upper part of the village had been dry ever since, while the lower ones were overflowing.

Only two accurate determinations of the time of occurrence appear to have been made—namely, 0h. 24m. at Haverfordwest, and 0h. 26m. at Exeter. Both of these may be relied on, but, being given only to the nearest minute, they are of little value except to show that the surface-velocity of the earth-wave cannot have been less than 2050 feet per second. No traces of the earthquake are to be discerned on the magnetograms of Kew and Greenwich, or on the records of the horizontal pendulums at Strassburg and Nicolaiew.

<sup>1</sup> I am indebted to the Rev. W. M. Morris for this account.

## (iii) After-Shocks.

d. *August 18th* : 0.37 A.M.

Intensity, about 4.—Number of records, 23; from 23 different places.

The disturbed area includes the whole of Pembrokeshire and parts of Caerdiganshire, Caermarthenshire, and North Devon. Its boundary is indicated on the map (Pl. XI) by a dotted and broken line (— . — .), and, though somewhat uncertain on account of the small number of determining stations, it is clear that its centre must lie under the sea, and several miles south of that of the principal earthquake.

The shock consisted of one series of very slight vibrations, the accompanying sound being a low rumble, like a distant thunder-peal.

e. *August 18th* : about 1.5 A.M.

Intensity, 3.—Number of records, 3; from 2 different places.

A very slight shock, felt at Dale and Pembroke Dock, at the latter accompanied by a subdued rumbling sound. The epicentre was probably not far distant from either of these places.

f. *August 18th* : about 1.40 A.M.

Intensity, about 5.—Number of records, 114; from 111 different places.

*Disturbed Area and Sound-Area.*—This was the strongest of all the after-shocks, and, owing to the fact that many observers remained awake and on the watch, it was felt over a comparatively wide area.

The isoseismal 4 (see map, p. 158) can be traced with some accuracy. Except that it extends a little farther westward, it coincides nearly with the isoseismal 7 of the principal earthquake. The shorter axis of the curve is 24 miles in length, the longer axis is directed approximately north and south, and the land-area enclosed by it contains about 510 square miles. The centre is probably close to the coast almost due south of Pembroke, but whether it lies beneath the land or the sea is uncertain.

Outside this isoseismal, the places at which the earthquake was observed are far apart, and it is impossible to draw the boundary of the disturbed area or any other isoseismal. The most distant places at which the shock was felt are Knighton and Glasbury (Radnorshire), Cantref and Aberclydach (Breconshire), Exmouth, St. Austell, and Kyle and Wexford (Co. Wexford). All of these lie outside the isoseismal 5 of the principal earthquake, and one of them, Knighton, is 26 miles beyond it.

The sound was everywhere much less intense than that which accompanied the principal shock. With two exceptions (Llanbyther in Caermarthenshire, and Trenglos near Launceston), it was not heard beyond the isoseismal 6 of that earthquake.

*Nature of the Shock and Sound.*—Detailed accounts of this earthquake are rather rare, but they all agree in representing it as much simpler in character than the principal earthquake. The following may be given as examples :—

Tenby : tremulous motion for a few seconds, ending in a sharp shake ; a low rumbling sound, becoming gradually louder until the shake occurred, and then suddenly ceasing.

Maenclochog : a thud accompanied by a little swaying motion of the ground and tremulous motion.

At most of the places, however, the tremulous motion and low rumbling sound were not observed ; the shock is described simply as a jolt or thud ; the sound as a cannon boom, beginning and ending abruptly, and coinciding with the shock.

The shock was felt on the river opposite Langwm, and was accompanied by a wave, but not nearly so marked as those seen at the time of the principal shock.

*g. August 18th : 2.50 A.M.*

Intensity 3.—Number of records, 69 ; from 67 different places.

The disturbed area includes the whole of Pembrokeshire, most of Caermarthenshire, and parts of the counties of Caeridigan and Glamorgan ; in all, a land-area of about 1680 square miles. The boundary of the area, so far as it can be traced, is shown by a dotted and broken line on the map of the principal earthquake (Pl. XI). Its position can be regarded as only approximately correct, on account of the small number of observations made at a distance from the epicentre. The centre of the area obviously lies under land, and some miles farther north than that of the principal earthquake.

The shock is everywhere described as a slight, tremulous motion.

The accompanying sound was heard at only 17 places, and is always described as a distant, faint sound, or compared to very distant thunder. At 39 other places it is expressly stated that no sound was heard.

The sound-area is elliptical in form, 16 miles long, 13 miles broad, and containing about 175 square miles. The centre coincides almost exactly with the town of Haverfordwest. It will be observed that the axis of the sound-area is situated  $3\frac{1}{2}$  miles west of that of the isoseismal 7 of the principal earthquake, to which it is nearly parallel, and 6 miles west of that of the preliminary earth-sound *b*. (See map, p. 158.)

*h. August 18th : about 4 A.M.*

Intensity, 2 or 3.—Number of records, 10 ; from 10 different places.

Part of the boundary of the disturbed area is shown in the map, p. 158. Only the eastern half of it can be drawn, but this is sufficient to show that the longer axis of the curve runs approximately east and west, coinciding roughly with the axis of Milford Haven. The shorter axis is 9 miles in length. The shock is everywhere described

as a very slight quiver. There are no records of any sound being heard to accompany it, and in this respect it is almost unique in the annals of recent British earthquakes. The chief interest of this shock and of that of Aug. 22nd (*k*) lies in the fact that the longer axes of their disturbed areas are at right angles to those of the preceding earthquakes.

i. *August 19: 9.30 A.M.*

I have received only one record of this earth-sound. At St. David's, Dr. W. P. Propert heard a noise like thunder, but more crashing and grating, without any accompanying vibration. As most of the previous shocks were felt by this observer, it appears to me that, though a solitary record, much reliance may be placed upon it.

k. *August 22nd: about 11.55 A.M.*

Intensity, 4.—Number of records, 21; from 13 different places.

The boundary of the disturbed area is a narrow oval, 19 miles long,  $7\frac{1}{2}$  miles broad, and containing about 112 square miles. Its longer axis runs east and west, and lies about  $1\frac{1}{2}$  mile north of that of the last earthquake (*h*) on Aug. 18. The centre of the curve is at a point  $1\frac{1}{4}$  mile west of Honeyborough. (See map, p. 158.)

The shock consisted of a slight tremor. It was strongest at Pembroke Dock, where three slight shocks of equal intensity were felt at intervals of about 3 or 4 seconds. The sound, a slight rumbling like the firing of a distant gun, was observed at only 6 places.

l. *August 23rd: 4.30 A.M.*

A slight vibration, felt by several observers in one house at Pembroke Dock.

## II.—EARTHQUAKES OF NOVEMBER 2nd–3rd, 1893.

Only four undoubted earthquakes belong to this series. The principal earthquake is indicated by a capital letter.

- A. *Nov. 2nd: 5.45 P.M.*
- b. „ „ 6.1 P.M.
- c. „ „ about 6.15 or 6.30 P.M.
- d. *Nov. 3rd: „ 1 A.M.*

At Kidwelly (Caermarthenshire), a rumbling noise was heard 25 seconds before the principal shock. Also, at Hafren Hall, in the same county, noises like distant thunder were heard at intervals during the afternoon, no tremulous motion being felt. It is doubtful whether these were of seismic origin.

## (i) Principal Earthquake. A: 5.45 P.M.

Intensity, 7.—Number of records, 633, from 494 different places; also 164 records from 161 places at which, so far as known, the earthquake was not observed.

The records of this earthquake are less numerous than those of the principal earthquake of the preceding year, but they are far more evenly distributed over the disturbed area.

*Disturbed Area and Isoseismal Lines.*—On the map of the earthquake (Pl. XI), the isoseismals 6, 4, and 3 are shown, and that part of the isoseismal 5 which lies on land. The number of places at which the intensity was 7 are too few to allow of the corresponding isoseismal being drawn.

Towards the west and south the isoseismal 3 may possibly extend somewhat beyond the limits of the curve laid down, owing to the difficulty or impossibility of obtaining observations in these directions. Judging, however, from the recorded intensity at the places farthest west and south, I do not think that the position assigned to the curve can be greatly in error. The length of the isoseismal as drawn is 313 miles, the breadth 269 miles, and the area enclosed by it about 63,600 square miles, that is, nearly three-quarters of the area of Great Britain. This curve may be considered as the boundary of the disturbed area, for I have received only one record from the region outside, and this one is not free from doubt.

The next isoseismal (intensity 4) depends on a very large number of good observations. Its length is 233 miles, its breadth 196 miles, and the enclosed area about 35,900 square miles. Its longer axis is directed approximately E. 30° N. and W. 30° S. A short distance north of this line there occurs a small isolated area in the neighbourhood of Manchester, in which the intensity was equal, or nearly equal, to 4.

The isoseismal 5 is confined to Wales and the north-western corner of Devon, and it is therefore impossible to complete the curve. The land-area included within it contains about 4680 square miles.

The last isoseismal (intensity 6) that can be drawn is roughly elliptical in form. Its centre is  $3\frac{1}{2}$  miles north of Whitland, and its longer axis is directed E. 15° N. and W. 15° S. The area enclosed by the curve is 41 miles long, 28 miles broad, and contains about 940 square miles. (See map, p. 158.)

The evidence with regard to the position of the originating fault is not very complete. From the direction of the longer axes of the isoseismals 6 and 4, it would follow that the fault-line must run about E. 15° N. and W. 15° S. At several places within this isoseismal a few buildings were slightly damaged, chimney-pots or parts of chimneys were thrown down, but this occurred very rarely. With one exception, all the places lie towards the southern or south-eastern part of the isoseismal, and this would appear to indicate that

the fault fades towards the south. But the inference is far from certain, and, the isoseismal lines being incomplete near the epicentre, no additional evidence is furnished by their relative position. If it be correct, however, the fault-line must be situated a short distance to the north of the centre of isoseismal 6.

*Nature of the Shock.*—The following accounts are given to illustrate the nature of the shock:—

White Lays (Pembrokeshire): a rather severe swaying motion, in two series of vibrations, the second the stronger; durations of the first series, interval, and second series about 3, 4, and 5 seconds respectively: slight trembling and rumbling sound between the two series; the rumbling sound preceded the sensible movement by about 3 seconds, and followed it by the same interval.

Ballyhealy (Co. Wexford): two series of vibrations, the first the stronger; durations of the first series, interval, and second series about 6, 1, and 4 seconds, respectively; slight tremulous motion and rumbling sound before the first series, in the interval between, and after the second series.

At some distance from the epicentre, the tremulous motion between the series was of course imperceptible, and the shock consisted of two detached series of vibrations, generally of unequal strength. At a very large number of places, one of the two series passed unnoticed or unrecorded, but as observations of the double series come from nearly all parts of the disturbed area, even from places so near the boundary as Bournemouth, Ashley, and Derby, the number of such records is 49. In 18 of these the first series is described as the stronger, and in 14 others the second. Within and near the isoseismal 6, the second series is invariably estimated as the stronger; and at a considerable distance, generally, but not always, the first. The observations from neighbouring places are not, however, always concordant, and this prevents the statement of any general law.

Near the epicentre the shock consisted of rapid vibrations, but at some distance from it the period seems to have lengthened out, and the shock is described as a 'swaying motion.' The fifteen places from which such records come lie within an oval area extending from Whitchurch (Salop) on the north to Wells on the south, and from Llangammarch (Brecon) on the west to Hereford on the east.

*Sound-Area.*—Records of the earthquake-sounds come from 253 places, while at 95 others it is stated that no sound was heard. In this case, the boundary of the sound-area (shown by a broken line on the map, Pl. XI) can be drawn with considerable accuracy. Its length is 231 miles, breadth 210 miles, and the contained area about 37,700 square miles. Its form and size are thus approximately the same as those of the isoseismal 4; indeed, if the isoseismal were shifted about 10 or 12 miles north-eastward, it would coincide roughly with the boundary of the sound-area.

*Time-Relations of the Sound and Shock.*—The numbers of places at which the beginning, etc., of the sound preceded, coincided with, or followed the beginning, etc., of the shock are given in the following Table:—

	Beginning.			Epoch of Maximum Intensity.			End.		
	<i>p.</i>	<i>c.</i>	<i>f.</i>	<i>p.</i>	<i>c.</i>	<i>f.</i>	<i>p.</i>	<i>c.</i>	<i>f.</i>
Pembrokeshire and Caermarthenshire.....	49	7	9	4	27	7	3	2	41
Rest of Wales .....	10	6	2	5	3	2	2	5	8
England .....	17	2	4	0	1	0	2	2	6
Ireland .....	4	1	0	0	1	0	0	2	0
Totals .....	80	16	15	9	32	9	7	11	55

These figures lead to the same conclusion as those for the earthquake of 1892—namely, that the beginning of the sound generally preceded that of the shock, their epochs of maximum intensity coincided, and the end of the sound followed that of the shock.

At three places the sound is said to have ceased before, or just as, the shock began. These are Eglwysrwr and Tenby in Pembrokeshire, and Moat Lane Junction in Montgomeryshire. The observations at the first two places contradict others made there and at a large number of places in the immediate neighbourhood, and must therefore be rejected. At and near Moat Lane Junction the records are less discordant, and it is possible that the instant when the sound was loudest preceded that when the shock was strongest. Still farther north-east, at Ellesmere in Shropshire, the epochs of maximum intensity of sound and shock coincided, while the end of the sound followed that of the shock. This was also the case at Courtown, in Co. Wexford.

The most probable conclusion to be drawn from all the observations is that the epochs of maximum intensity coincided in the neighbourhood of the epicentre and near the boundary of the sound-area, while at intermediate stations near the longer axis of the area the epoch of maximum intensity of the sound preceded that of the shock. The explanation would seem to be, not that the velocity of the sound was greater than that of the larger vibrations, but that the north-eastern lateral margin of the focus was of considerable length, so that, at moderate distances, the sound-vibrations which appeared loudest came from a point much nearer than the centre of the focus; while, at great distances, the relative intensities of the sound-vibrations from the lateral margin and from the upper margin of the focus were sensibly the same, so that the principal vibrations were felt during the interval when the sound was loudest.

## (ii) After-Shocks.

b. *November 2nd*: 6.1 P.M.

Intensity, 4.—Number of records, 64; from 57 different places.

This shock was felt over the greater part of Pembrokeshire and Caermarthenshire and in the southern part of Caerdiganshire. The disturbed area is 43 miles long, 29 miles broad, and contains about 1000 square miles. The longer axis is directed about E. 25° N. and W. 25° S., and the centre of the area lies  $2\frac{1}{2}$  miles north-west of Narberth, that is, about 8 miles W. 20° S. of the centre of the isoseismal 6 of the principal earthquake. The line joining the two centres is thus roughly parallel to the longer axes of both curves. (See map, p. 158.)

The shock was felt at 45 places, at 15 of which the sound was not heard. The sound was heard at 22 places, and at 10 of these the shock was not felt. So far as the observations extend, however, the disturbed area and the sound-area approximately coincide.

The shock is always described as a tremulous motion, as a rule exceedingly slight. The rumbling sound was also very faint, and it is not surprising that it should have escaped notice at many places.

c. *November 2nd*: about 6.15 or 6.30 P.M.

This was an exceedingly slight shock. It was felt at Llandyssul and Blaendyffryn in Caerdiganshire, possibly also at Llanstinan and Pen-ty-parc in Pembrokeshire, though the last two places are at some distance from the others. The epicentre obviously lies north-east of that of the principal earthquake.

d. *November 3rd*: about 1 A.M.

The only records of this slight shock come from Llanilar and Rhydlew in Caerdiganshire, and Newcastle Emlyn on the border of that county and Caermarthenshire. They appear to indicate a still further displacement of the epicentre towards the north-east. With regard both to this and the preceding shock, it should be remarked that, except their proximity in time of occurrence and disturbed area, there is no evidence for connecting them with the same fault-system as the first two earthquakes.

## III.—ORIGIN OF THE EARTHQUAKES.

In correlating the earthquakes described above with the faults of the epicentral district, difficulties arise from the great number of known faults in one part and their scarcity in another. The majority so far traced are longitudinal faults, and, in the south of Pembrokeshire, run roughly in an east-and-west direction, trending some degrees north of east in the west of Caermarthenshire. It can hardly be doubted that a series of transverse faults crosses them approximately at right angles, though few are marked on the

Geological Survey map. In the map of the epicentral area (p. 158), the principal faults are indicated by broken lines. They are founded on the Index-map of the Geological Survey (on the scale of 4 miles to 1 inch), on the map which accompanies the paper of Messrs. Marr and Roberts on 'The Lower Palæozoic Rocks of the Neighbourhood of Haverfordwest,'<sup>1</sup> and on information kindly given to me by Mr. Marr. The two faults, whose positions are inferred from the seismic phenomena, are shown by dotted lines *aa*, *ββ*. So far as I am aware, no geological evidence of their existence has been discovered, but in this part of the district the exposures are, I believe, insufficient to give much force to negative evidence.

*Earthquakes of 1892.*—Several of the earthquakes of 1892, including the principal earthquake, are apparently connected with a transverse fault *aa*, hading to the west. There is not sufficient evidence to determine whether this was the case with the first shock (*a*), but, assuming it to be so, there must have been a slight slip a short distance north of Pembroke. This was succeeded in less than an hour by another slip farther south, the centre of the focus being close to the coast. The focus may have extended under both land and sea, but the amount of slip must have been very small, for no tremor was perceptible on the surface.

The function of these preliminary slips seems to have been to relieve the stress at two isolated spots, and thus to equalize the residual stress over a great length of the fault. The total relief was, however, very slight, for, 2 minutes after the second slip, the most important movement took place. Owing to the incompleteness of the isoseismal 7, no estimate can be formed of the length of the focus, but it was certainly many miles. Its centre coincided approximately with that of the earth-sound (*b*), and the focus itself lay partly under land and partly under sea. The double nature of the shock, and the greater intensity of the second series of vibrations in practically all parts of the disturbed area, show that the slip was interrupted, the sliding mass almost halting for a few seconds; but whether the second and more important part of the slip occurred in the same, or a different, region of the fault, there is no evidence to show. The latter alternative seems, I think, the more probable, when we consider the dimensions of the displaced rock-mass.

However great the amount of slip may have been near the centre of the focus, it must have died out before reaching the surface, for no trace of a fault-scarp is recorded within the epicentral tract. The water-waves observed at Bulwell and near Langwm can hardly have been of the nature of a 'great sea-wave,' such as would be produced by a sudden elevation or subsidence of the sea-bed, but rather what Mallet would have called 'forced sea-waves.' They were no doubt due to the wave of direct vibrations transmitted through the water.

<sup>1</sup> Quart. Journ. Geol. Soc. vol. xli. (1885) pp. 476-491.

In less than a quarter of an hour, the first after-shock (*d*) took place. As so little of the disturbed area lay on land, it is impossible to determine the position of the focus, except that the whole or the greater part of it must have lain beneath the sea. If it were connected with the transverse fault *aa*, the chief displacement of the series was evidently followed by a slip farther to the south.

The next after-shock (*e*) had so few observers that its connexion with this fault is also uncertain. All that can be asserted is that its focus lay north of that of the principal earthquake.

Then followed the strongest of the after-shocks (*f*). From the approximate coincidence of its isoseismal 4 with the isoseismal 7 of the chief earthquake, we may infer that it was caused by another slip along the transverse fault *aa*, and in almost exactly the same region.

By the slip which produced this earthquake, the pre-existing stress along the fault *aa* was practically relieved. But the displacements by which this relief was effected increased the stress along adjoining faults, with the result that the fourth after-shock (*g*) points to a slip along another surmised transverse fault  $\beta\beta$ , approximately parallel to the fault *aa* and about 6 miles farther west. The increase of stress having been inconsiderable, one small slip was enough to restore equilibrium along this fracture.

In about  $3\frac{1}{2}$  hours after the principal earthquake, there occurred a slight shock (*h*), which is clearly connected with one of the longitudinal systems of faults running east and west. Four days later, on August 22nd, a somewhat stronger shock (*k*) took place, which may be traced to another fault of the same system, lying a mile or so farther north. On the map (p. 158), two faults are shown, which, if continued, would occupy the required positions; for, as Mr. Marr informs me, they are both thrust-planes hading at a high angle probably to the south.

*Earthquakes of 1893.*—The first two shocks of Nov. 2nd, 1893, are evidently connected with one and the same fault, for the line joining the centres of the isoseismal 6 of the principal earthquake (*A*) and of the disturbed area of the first after-shock (*b*) is approximately parallel to the longer axes of the same curves. The direction of the originating fault must be about E.  $15^\circ$  N. and W.  $15^\circ$  S., but with regard to its hade the evidence is doubtful. The fault  $\epsilon\epsilon$  (see map, p. 158) is a thrust-plane hading probably to the north; the fault  $\zeta\zeta$  is also a thrust-plane, but probably hading in the opposite direction. As traced on the map it is possibly incomplete, for Messrs. Marr and Roberts's map does not extend beyond the eastern end shown; but its course so far is parallel to the fault-line implied by the seismic evidence. Neither this fault nor the preceding will, however, satisfy the required conditions, for they both dip away from the common axis of the isoseismal lines; but the district between them, as Mr. Marr informs me, 'is simply wattled with minor faults,' and it is probably to movements along one of these that the earthquake of 1893 must be assigned.

There can be little doubt, I think, that the fault-slips of 1892 affected the conditions of stress along this neighbouring fault, so that the displacements along it occurred earlier than they might otherwise have done. There is no evidence of any preliminary slips, the first that took place being the most important of the series. As in the principal earthquake of 1892, the slip was discontinuous : but whether the focus consisted of two detached portions, or whether the slip was repeated at the same or a different part of the fault, is doubtful, for the records of the relative intensity of the two parts of the shock are discordant. The principal part of the focus may have been as much as 10 or 12 miles long, but the length of its eastern margin must have been considerable, and much greater than that of the western margin. This is shown by the position of the boundary of the sound-area with respect to that of the isoseismal 4, and also by the time-relations of the sound and shock.

The stress being more completely relieved on the eastern side of the focus, we should expect the next slip to take place on the opposite side. And this we find to have been the case, for in the first after-shock (*b*), which occurred a quarter of an hour later, the epicentral area was shifted to the W.S.W. Though much less in amount of slip, the focus must have been of almost the same length as that of the principal earthquake, and partly overlapping it, but with its centre lying about 8 miles farther to the W.S.W.

Assuming, as is very probable, that the second and third after-shocks are connected with the same fault, the next slip occurred on the eastern side of the principal focus and at increasing distances from it. The great rock-mass, once set in motion, thus appears to have oscillated slowly, first to one side and then to the other, before finally coming to rest.

*Conclusion.*—I have not yet been able to study in any detail the seismic history of the district principally affected by these two series of earthquakes. Several shocks have been felt in Pembrokeshire and Caermarthenshire during the present century, some of which had their origins elsewhere, and at least three (in 1802, 1832, and 1840) possibly in the latter county. For more than 50 years, however, there appear to have been no slips of any consequence along the fault-system here considered, and the following facts are therefore worthy of notice :—(1) that, after this prolonged interval of repose, the earlier movements took place along transverse, and the later along longitudinal, faults : (2) that the three faults of the latter series lie successively the one to the north of the other, as if the abrupt displacement of a rock-mass over one thrust-plane impelled the further advance of those immediately below.

#### PLATE XI.

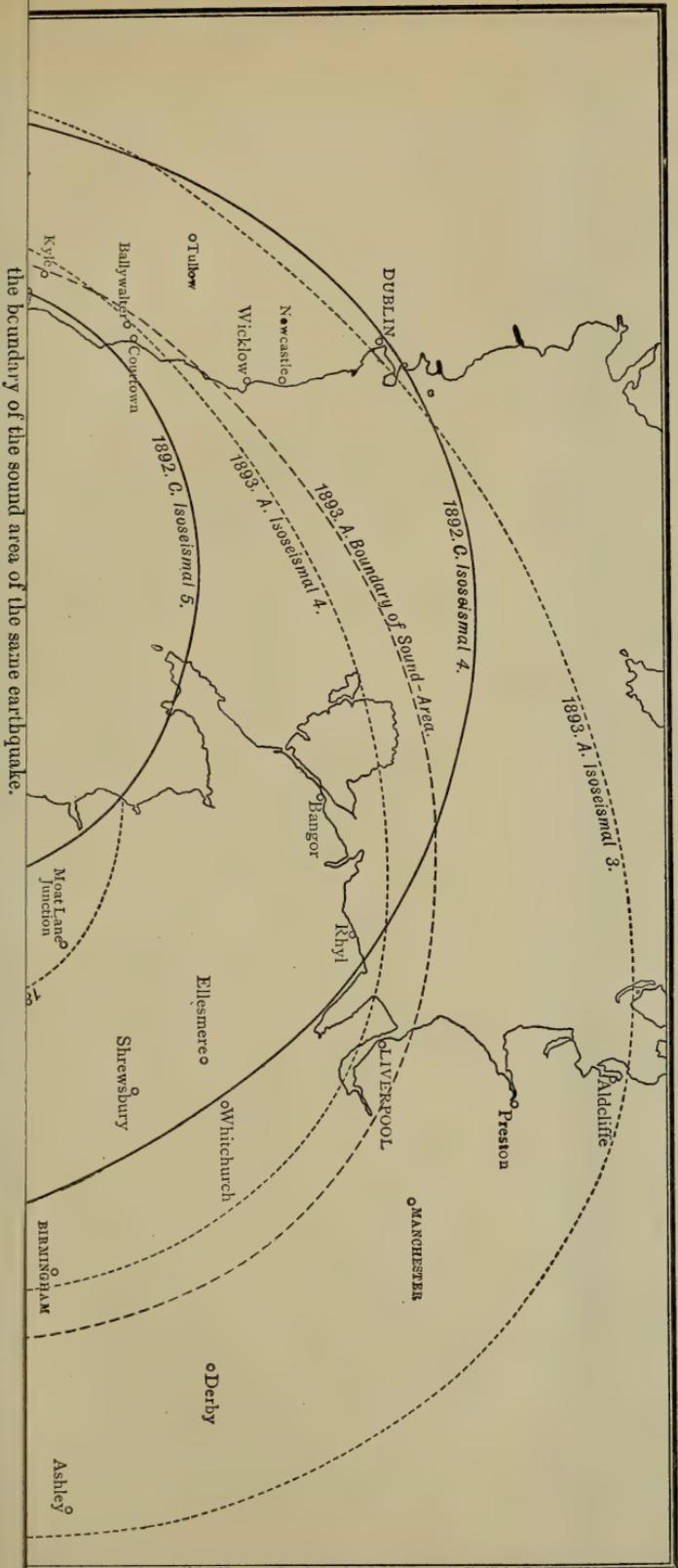
Map of the Pembroke Earthquakes of August 1892 and November 1893, on the scale of 40 miles to 1 inch.

## DISCUSSION.

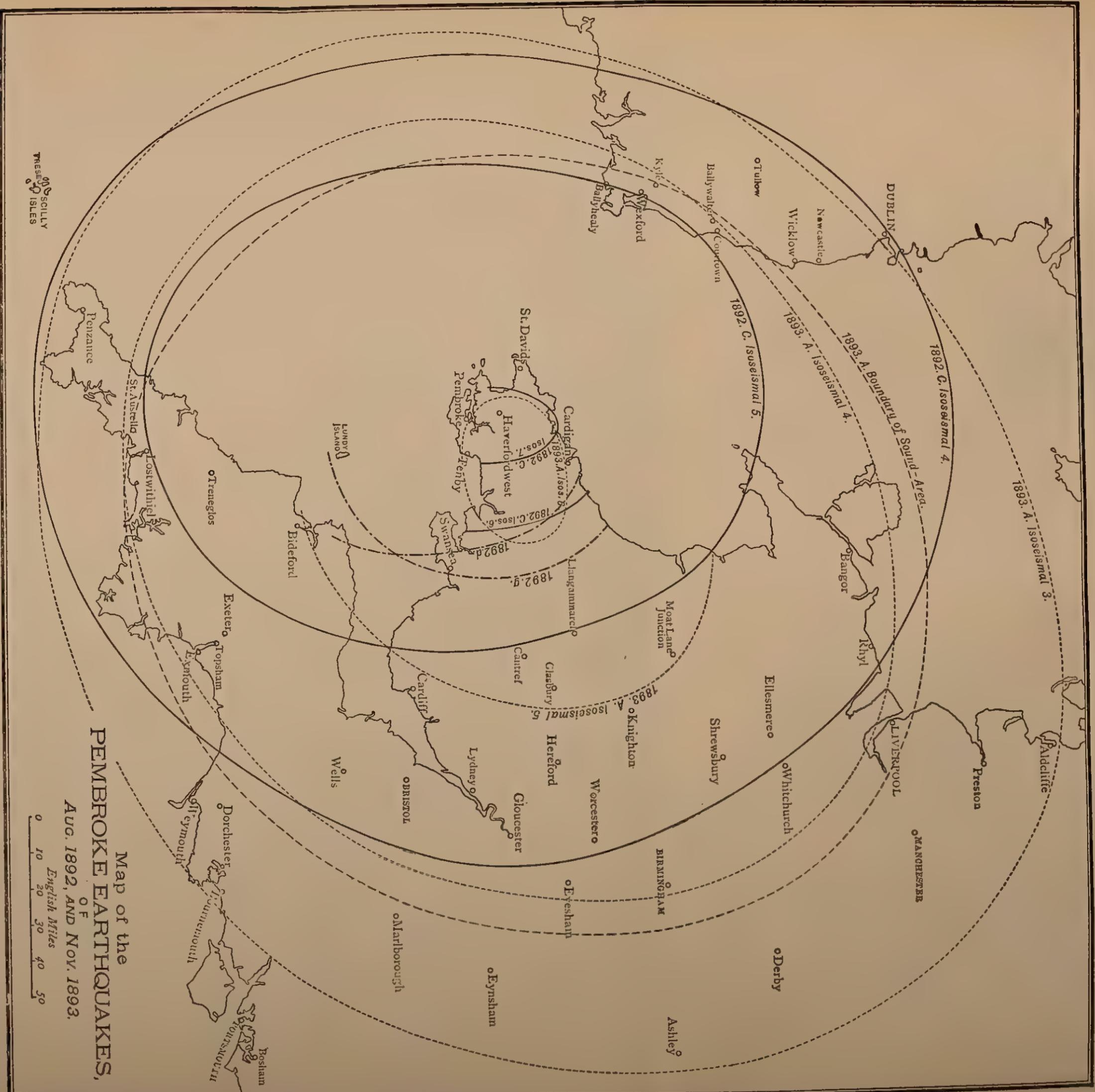
The PRESIDENT said that the Author's enquiries into the relationship between earthquakes and faults were of great interest. It is well known that the older rocks in Pembrokeshire have been much crushed and broken, and that thrust-faults of great magnitude occur there. It is also a fact that the area has been frequently affected by earthquake-shocks, one of which, many years ago, caused serious damage to the Cathedral of St. David's.

The Rev. J. F. BLAKE remarked upon the apparent absence of any signs of disturbance on the surface. If these earthquakes were due to slips, it was strange that none of them should yield this evidence. In the cases previously described by the Author the principal evidence was the association with well-known faults, which might be lines of fresh dislocation; but in the present instance faults had to be hypothecated. Though, therefore, the speaker believed the theory to be the true one, the evidence for it appeared extremely weak.

Mr. H. H. STATHAM, Mr. W. WHITAKER, and Mr. MARE also spoke.







SCILLY  
PRESBYTERIAN ISLES

Map of the  
OF  
PEMBROKE EARTHQUAKES,  
Aug. 1892, AND Nov. 1893.  
English Miles  
0 10 20 30 40 50

Note.—The continuous lines ——— represent isoseismal lines of Earthquake C (Aug. 18th, 1892). Parts of the boundaries of the after-shocks *d* and *g* of the same series are indicated by broken lines and dots - - - - - The dotted lines ..... represent isoseismal lines of Earthquake A (Nov. 2nd, 1893). The broken line - - - - - shows the boundary of the sound area of the same earthquake.



13. *On the STRUCTURE of the SKULL of a PLIOSAUR.* By C. W. ANDREWS, Esq., B.Sc., F.G.S., Assistant in the Geological Department, British Museum. (Read January 6th, 1897.)

## [PLATE XII.]

IN the present communication I propose to give a short account of the cranial structure of the Plesiosaurian reptile known as *Pliosaurus ferox* (Sauvage),<sup>1</sup> a very fine skull of which has recently been acquired by the British Museum. Like so many other reptilian fossils from the Oxford Clay, this specimen was obtained in the neighbourhood of Peterborough by A. N. Leeds, Esq., F.G.S., who has expended much time, patience, and skill in fitting together the numerous fragments into which the bones were found broken. The result, however, is well worth the trouble taken, and the specimen is now perhaps the finest Pliosaur skull known. The extreme length from the occipital condyle to the anterior extremity is 112 cm., while the width at the quadrate region, perhaps somewhat exaggerated by crushing, is 50 cm.

The description of this skull is facilitated by the great similarity which exists between it and that of *Peloneustes philarchus*, of which an account has already appeared.<sup>2</sup> This similarity is so striking that it seemed not impossible that the present specimen might be merely the skull of an old individual of *Peloneustes*: but there are a number of differences which tend to show that such is not the case. In the first place, the total number of teeth in the upper jaw of *Peloneustes* is greater, and there are six instead of five in the premaxilla; it is, however, possible that a premaxillary tooth might be lost in growth, since this actually occurs in *Crocodylus porosus*,<sup>3</sup> so that this latter point is of less importance than might be supposed. Again, in *Peloneustes* there is no diastema between the premaxillary and maxillary alveoli, and the variation in the size of the teeth in different parts of the jaw is less. The form of the palatines and transpalatines is also different. Unfortunately the lower jaw and all the rest of the skeleton is missing in the present instance, so that the length of the symphysis and other characters pointed out by Lydekker are not available for the determination of this specimen.

It may be remarked that, although the teeth of this form from the Oxford Clay of Peterborough agree precisely with those described by Sauvage from the same horizon at Boulogne, under the name *Liopleurodon ferox*,<sup>4</sup> they differ considerably from those from the Kimeridge Clay, upon which Owen founded the genus *Pliosaurus*,

<sup>1</sup> See Brit. Mus. Cat. Foss. Rept. pt. ii. (1889) p. 145.

<sup>2</sup> Andrews, Ann. Mag. Nat. Hist. ser. 6, vol. xvi. (1895) p. 242.

<sup>3</sup> Boulenger, 'Fauna and Flora of British India: Reptilia and Batrachia' (1890) p. 5.

<sup>4</sup> Bull. Soc. géol. France, ser. 3, vol. i. (1873) p. 378.

being circular in section instead of trihedral. They, however, show a distinct tendency towards this typical form in the absence, or at least scanty development, of ridges on their outer surface; and since the skull and skeleton of the Oxfordian and Kimeridgian forms, so far as known, are closely similar, I prefer, for the present at least, to follow the British Museum Catalogue in referring both to one genus—*Pliosaurus*.

#### DESCRIPTION OF THE SKULL.

Most unfortunately, this skull was not found associated with any other portions of the skeleton, even the mandible being entirely absent. As already mentioned, it is much crushed, nevertheless all the more important points in the structure can be made out. A number of the characteristic teeth, beautifully preserved, occurred in close proximity to the skull, but only one or two broken bases remain actually in the alveoli.

The basi-occipital (Pl. XII. fig. 1, *oc.c.*) is very similar to that of *Peloneustes*, but the condyle is relatively rather larger, and is also rounder and more prominent; it has a well-marked dimple-like depression marking the former position of the notochord. The arrangement of the very massive ventro-lateral processes is the same as in the smaller form; in the present specimen the pterygoids, which terminate posteriorly in a strong transverse ridge, have been crushed up upon them. The surfaces for union with the exoccipital look upward and somewhat outward; they are separated by a narrow interval only.

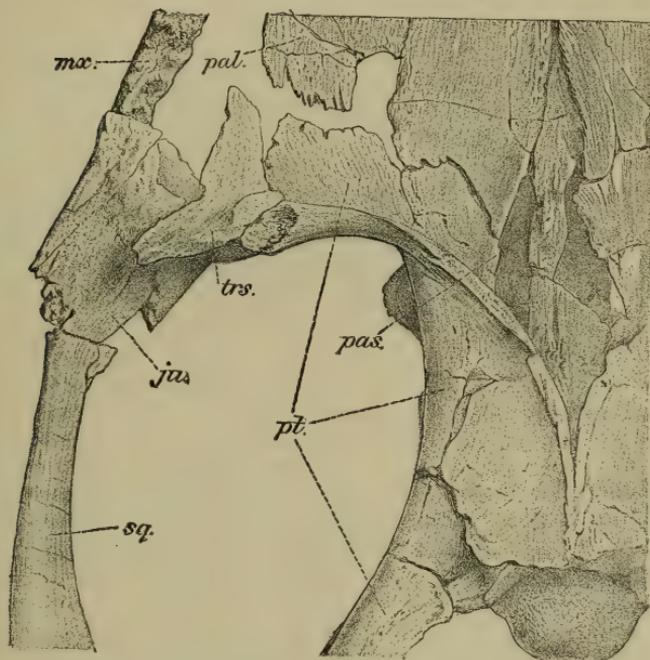
The exoccipitals (fig. 2, p. 181, *ex.oc.*), which form the sides of the foramen magnum, are stout solid bones, the upper ends of which have been broken away by the crushing down of the dorsal surface of the skull. Laterally they, or, more correctly speaking, the opisthotic elements fused with them, bear extremely long (15 cm.) paroccipital processes (fig. 2, *p.oc.*). The distal extremity of these is somewhat expanded into a spatulate form, the outer surface of the expanded portion being flattened and rugose. This surface appears to have formed a close union with the inner surface of the anteriorly-directed process of the quadrate, by which that bone unites with the posterior pterygoid ramus; possibly, however, a portion of the overlapping 'squamosal' may intervene to some extent between the outer end of the paroccipital process and the quadrate.

The supra-occipital is too much crushed for description, and the basisphenoid is completely concealed above by the depressed roof of the skull and ventrally by the pterygoids.

In front of the basisphenoid, the ventral axis of the skull is prolonged forwards by the bone which, for reasons given elsewhere, I regard as the parasphenoid (fig. 1, p. 179, *pas.*). The hinder portion of this is partly concealed by the pterygoids, and indeed the exact line of division between the median expansion of these bones and the parasphenoid is not in this case to be made out. Anteriorly

the latter element runs forward in the form of an elongated spear-head, of which the postero-lateral borders form the inner margin of the posterior palatine vacuities, while the antero-lateral borders form a sutural union with the pterygoids (see fig. 1). On the upper surface

Fig. 1.—*Posterior portion of palate, showing the relations of the parasphenoid and transverse bones.*



*ju.* = jugal.  
*pal.* = palatine.  
*pas.* = parasphenoid.

*pt.* = pterygoid.  
*sq.* = squamosal.  
*trs.* = transverse bone.

[About  $\frac{1}{2}$  nat. size.]

of the posterior portion of the parasphenoid is a mass of osseous tissue of somewhat irregular form. This is probably the remains of the anterior portion of the true basis cranii derived from the trabeculæ, and either forms an anterior portion of the basisphenoid or an imperfectly ossified presphenoid. The length of the exposed portion of the parasphenoid is roughly 19 cm., its width between the post-palatine vacuities 1.8 cm., and its greatest width between the pterygoids 2.2 cm.

The pterygoids (*pt.*), in their general form and relations, are closely similar to those of *Peloneustes*, but there are one or two well-marked differences. The anterior rami, which are very stout and massive, widen gradually from before backward, and unite externally with the palatines in a straight suture (convex externally

in *Peloneustes*); they do not appear to have met on the middle line, at least anteriorly, as in the smaller form, so that for some distance there was a narrow median vacuity. Behind this, however, they unite with one another for about 4 cm., behind which again they are separated by the parasphenoid. About opposite the anterior border of their lateral ramus, that is relatively farther forward than in *Peloneustes*, their median borders diverge from the parasphenoid, and enclose with it the posterior palatine vacuities (Pl. XII, *p.vac.*), which are here about 10 or 11 cm. in length. The posterior union of the pterygoids over the basisphenoid and part of the basioccipital forms a suture about 9 cm. in length, the posterior portion of which for about 6 cm. is raised into a thick and prominent ridge. In front this forks into a pair of crests, which curve outward through about a quarter of a circle, forming externally the hinder border of the lateral ramus of the bone. This crest terminates in a massive tuberosity, the flattened top of which looks downward and outward; this, together with a similar prominence on the transpalatine, forms the downwardly-directed process corresponding to that seen on the palate in *Peloneustes*, *Sphenodon*, and many other reptiles.

The outer border of the posterior ramus (fig. 2, p. 181, *p.pt.*) is thick and rounded; posteriorly, it passes into the backwardly-produced process, the distal portion of which underlies and unites in close suture with the broad, forwardly-directed process from the inner border of the quadrate, the two meeting in an oblique suture.

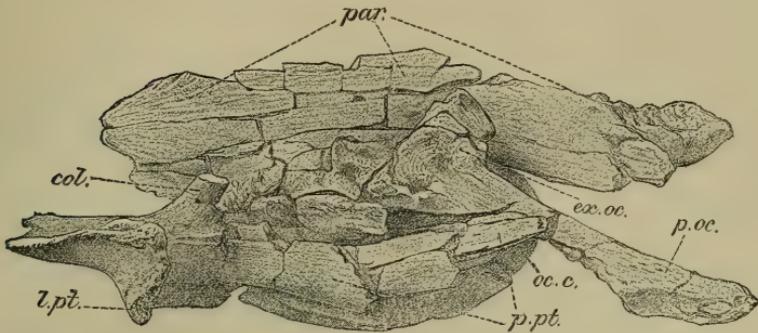
The lateral ramus of the pterygoid (fig. 2, *l.pt.*), the hinder border of which is formed by the curved ridge, as above described, has a thin external edge overlapping the inner edge of the transpalatine. The anterior border is at right angles to the skull-axis, and unites with the palatine.

The transpalatine (Pl. XII & fig. 1, p. 179, *trs.*) is an L-shaped bone, having a prominent tuberosity at the angle. This tuberosity, as above mentioned, forms the anterior half of the downwardly-directed process of the palate. One of the limbs of the L is directed forward, the other outward and a little backward. Of the former, the inner edge forms a sutural overlap upon the pterygoid, while the outer forms the inner border of the suborbital vacuity. The outer arm joins the maxilla and possibly, to some extent, the jugal, but its exact relations to this latter are not clear; it forms the posterior boundary of the suborbital vacuity.

On the dorsal surface of the pterygoid, there is on the left side of the present specimen the well-preserved lower half of the epipterygoid or *columella cranii* (fig. 2, *col.*). Its basal portion is an elongate oval, with its long axis antero-posterior, and its anterior edge opposite the hinder margin of the lateral ramus of the pterygoid; this expanded basis forms a firm junction with the upper surface of the pterygoid. In its middle portion the bone contracts considerably in width, but its antero-posterior diameter is still far greater than its width from side to side. On the right side of the skull it can be seen that the upper end of the epipterygoid is

again expanded and unites with the downwardly-directed lateral region of the parietals; the actual suture is unfortunately not visible.

Fig. 2.—Lateral view of cranium, showing the relations of the columella and paroccipital process.



*col.* = columella.  
*ex.oc.* = exoccipital.  
*oc.c.* = occipital condyle.  
*par.* = parietal.

*l.pt.* = lateral ramus of pterygoid.  
*p.pt.* = posterior ramus of pterygoid.  
*p.oc.* = paroccipital process.

[About  $\frac{1}{4}$  nat. size.]

The palatines (Pl. XII, *pal.*) are elongated bones bordered internally by the pterygoids and, probably for a short distance in front, by the vomers; externally by the maxillæ, and posteriorly by the lateral wing of the pterygoids and the suborbital vacuities. Anteriorly they probably formed part of the hinder border of the internal nares, but their relations in this region are obscured by the crushing that has taken place. Each palatine is perforated by a foramen, about 2 cm. in diameter, lying 4 cm. from the hinder and 1 cm. from the inner margin of the bone; these foramina do not occur in the palatines of *Peloneustes*.

The vomers (*vo.*), which for the anterior four-fifths of their length are anchylosed with one another, are very large bones, about 40 cm. long. Anteriorly they run up some distance (13 cm.) between the premaxillæ, behind which they are bordered by the maxillæ. They are overlapped to a considerable extent by both these elements, and opposite the alveoli of the second maxillary teeth they only appear in the middle of the palate as a narrow strip about 6 mm. in width. As in *Peloneustes*, the united vomers form the median bar, convex from side to side, between the internal narial openings, opposite the middle of which they are together about 3 cm. in width. Posteriorly they widen out to about 4.8 cm., and behind the nares they terminate in a fan-shaped splintery suture against the pterygoids and palatines. It should be noted, however, that the relations of the hinder end of these bones are not quite clear, but there is no reason to suppose that their

arrangement differs in any way from that described in the skull of *Peloneustes*, in which this portion of the palate is well preserved, and its structure perfectly clear.

The premaxillæ (Pl. XII, *p.mæ.*) are very large bones, each consisting of a dentigerous body, which is produced backward on the palate into a short palatine process, and an enormously elongated facial process which extends far behind the external nares and terminates in a suture with the frontals.

The teeth borne by each premaxilla are five in number. The first pair are comparatively small, directed forwards, and almost in contact in the middle line. The second, third, and fourth increase in size in the order named, while the fifth is considerably smaller than the fourth. Between the last premaxillary tooth and the first in the maxilla there is a diastema about 6 cm. long, which is crossed near its middle point by the premaxillo-maxillary suture. Immediately internal to the alveoli there is a deep groove, at the bottom of which the tips of the successional teeth may be seen. The inner wall of this groove is formed by a prominent ridge, which, joining that of the opposite side, forms an elongated triangular raised area in the middle of the anterior end of the palate. By the divergence of the ridges posteriorly a short groove is formed, which is closed behind by the prominent anterior end of the vomers. The upper surface of the body of the premaxillæ is rough and pitted with numerous foramina. The immense facial processes together form a broad convex ridge along the upper surface of the snout; behind they form a complicated zigzag suture with the frontals. The suture between the premaxillæ is persistent.

The maxilla (Pl. XII, *mæ.*) in its general form closely resembles that of *Peloneustes*, but instead of bearing from twenty-eight to thirty teeth as in that genus, there are only about twenty. Of these the first two were small, the next two very large. Behind these there is a gradual decrease in size as far as the ninth. The tenth and eleventh are again larger, and behind these the series decreases gradually, the hindermost teeth being very small. The whole alveolar margin of the jaw, seen from the side, is sinuous in outline: the first convexity occurring in the premaxilla, the next opposite the second and third maxillary teeth, the last and least marked opposite the tenth and eleventh.

As already mentioned the anterior palatal portion of the maxilla forms an extensive overlap upon the vomer. Opposite the internal nares its inner border is raised into a high, thin ridge, which forms a kind of outer wall to the opening. Behind the nares the maxilla first joins the palatine, then forms the outer boundary of the sub-orbital vacuity, behind which, again, it is joined by the trans-palatine. It terminates posteriorly in a slender prolongation which underlies the lower border of the jugal, and nearly reaches the anterior end of the squamosal. Immediately within the alveolar region, throughout its whole extent, there is a deep groove similar to that seen in the premaxillæ.

The facial surface of the maxilla, like that of the premaxilla, is

roughened and pitted by many foramina. Internally it is bounded by the premaxilla and the nostril, of which it forms the outer margin. Posteriorly it appears to meet the nasal (?), supra-orbital, and lachrymal.

The arrangement of the bones in the upper surface of the skull is difficult to determine with certainty, owing to the crushing that has taken place.

The fused parietals (fig. 2, p. 181, *par.*) form a high massive crest between the temporal fossæ; posteriorly they widen out to a considerable degree, and no doubt their outer angles joined the upper rami of the squamosals, which in the present specimen have been dislocated in such a way as to overlap the hinder portion of the skull. The inferior borders of the parietals slope outward so as to form a roof to the brain-case; anteriorly they unite with the expanded upper end of the epipterygoid. The boundary between the parietals and frontals is not clearly defined, and probably the bones were, in fact, ankylosed. There are, however, traces of the suture between them on the sides of the large pineal foramen (about 5 cm. in length), the walls of this opening being formed by both these elements.

About 2 cm. external to the pineal foramen there is a suture dividing from the frontals and (?) parietals a bone which is clearly the post-frontal. Anterior to this, and lying immediately external to the frontal, there is a long, narrow bone, apparently the prefrontal. In front of this again there is another element which seems to be continuous with a narrow strip which thrusts itself between the external nares and the facial process of the premaxilla: this I regard as the nasal. External to the nasal and prefrontal there is a broad, thin plate of bone, the limits of which are not clear. This bone overhangs the orbit, or at least the anterior part of it, and is a supra-orbital.

The external nares (Pl. XII, *e.na.*) are oval apertures, about 5 cm. in length. They are separated from one another by an interval of about 9.5 cm.,<sup>1</sup> occupied by the facial processes of the premaxilla and probably also by the nasals. They lie 57 cm. behind the tip of the snout, and, as in *Peloneustes*, some distance behind the internal nares.

The antero-inferior portion of the orbital margin is formed by a massive bone which joins the supra-orbital above, the maxilla and probably also the jugal below: this element is no doubt a lachrymal (*l.*). It is produced inward, into a broad ridge which forms an anterior wall to the orbit, and, curving upward and backward, becomes continuous with a rounded crest on the inferior surface of the cranial bones forming the inner limit of the orbit.

The form of the post-orbital and jugal (*ju.*), as well as their relations to one another and to the 'squamosal,' are as in *Feloneustes*.

The 'squamosal' (*sq.*) consists of an anterior ramus relatively more slender than in the smaller form, and an upper ramus which no

<sup>1</sup> Probably somewhat exaggerated by crushing.

doubt joined the outer ends of the parietals, but which has been broken from its union with them and crushed down upon their dorsal surface. In consequence of this dislocation the quadrate region is much fractured, but it can be seen that the squamosal sends down a broad plate which is closely applied to and apparently fused with the posterior surface of the quadrate. This portion of the squamosal terminates ventrally in a convex border which forms a rounded ridge on the quadrate a short distance above the articular condyle of that bone. This ridge is most prominent internally where, between it and the upper border of the condyle, there is a deep groove.

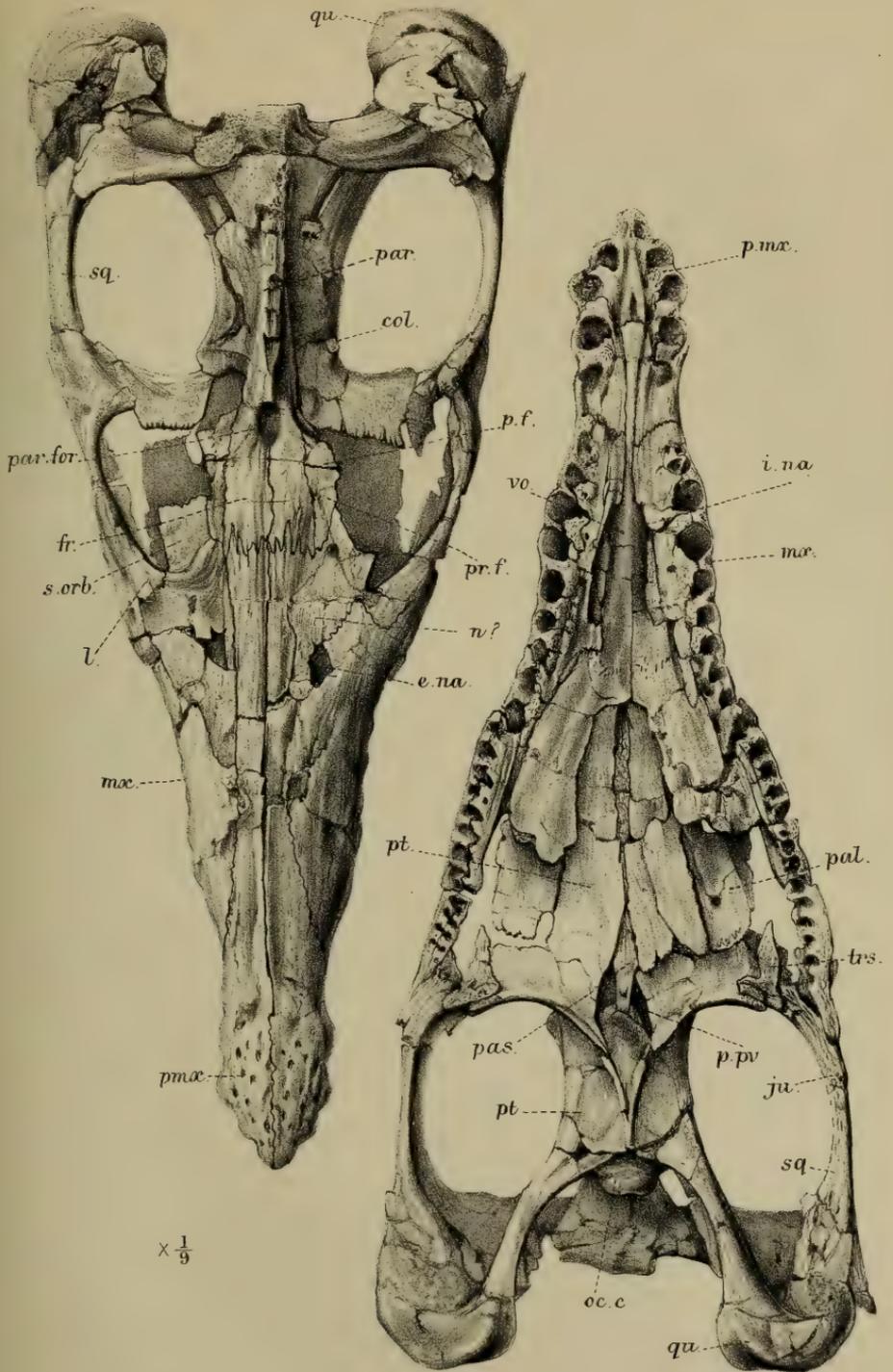
The quadrate (*qu.*) itself is extremely large and massive. The body of the bone is concave from side to side anteriorly, convex in the same direction posteriorly. As just noted, the posterior surface is largely overlaid and concealed by the squamosal. The distal end forms an extremely large articular condyle, the form of which is shown in Pl. XII. It will be seen that this articular surface is divided by an oblique ridge into a smaller postero-internal and a larger antero-external portion. From the inner border of the bone immediately above the distal condyle there arises a strong process directed inward and forward; this unites in an oblique suture with the backward process of the pterygoid.

The teeth call for no special notice, since they agree precisely with those described and figured by Lydekker.<sup>1</sup> The largest specimen preserved is probably one of the large anterior (3rd or 4th) maxillary teeth; its total length along the outside of the curve is 23.5 cm., length of crown 8.5 cm., and the diameter at the base of the crown 2.8 cm. The smallest complete tooth measures 6.2 cm. in length along the outside of the curve, the crown occupying one-third of the length; the diameter at the base of the crown is 1.1 cm.

The chief measurements of this skull are as follow:—

Length from tip of snout to occipital condyle .....	cm.	112
"    "    "    anterior angle of external nares ...		57
"    "    "    "    "    internal nares ...		36
"    "    "    "    "    hinder end of facial process of		
premaxilla .....		74
"    of external nares .....		5
"    "    internal nares .....		6.5
"    "    posterior palatine vacuities .....		11
Width of skull at quadrates (perhaps slightly exaggerated by		
crushing) .....		50
"    "    at level of transpalatine bone .....		48
"    "    at middle of internal nares .....		19
"    "    at diastema .....		11.3
"    "    at widest part of premaxilla .....		12
"    of quadrate articulation .....		12
Greatest diameter (transverse) of occipital condyle .....		6.5

<sup>1</sup> Quart. Journ. Geol. Soc. vol. xlv. (1890) p. 49, pl. v. fig. 1.



J. Green del. et lith.

Mintern Bros imp.

SKULL OF PLIOSAURUS.



## EXPLANATION OF PLATE XII.

Skull of *Pliosaurus ferox* (Sauvage) from the Oxford Clay of Peterborough. $\frac{1}{3}$  Nat. size.

1. From below. | 2. From above.

## REFERENCE LETTERS.

*col.* = columella (epipterygoid).*e.na.* = external nares.*i.na.* = internal nares.*ju.* = jugal.*l.* = lachrymal.*mx.* = maxilla.*n.?* = nasal (?).*oc.c.* = occipital condyle.*pal.* = palatine.*par.* = parietal.*par.for.* = parietal foramen.*pas.* = parasphenoid.*pf.* = post-frontal.*pr.f.* = pre-frontal.*p.mx.* = premaxilla.*p.p.v.* = posterior palatine vacuities.*pt.* = pterygoid.*sq.* = squamosal.*s.orb.* = supra-orbital.*vo.* = vomer.

## DISCUSSION.

Mr. LYDEKKER and Mr. MARR spoke, and the AUTHOR briefly replied.

14. *The SUBGENERA PETALOGRAPTUS and CEPHALOGRAPTUS.* By MISS G. L. ELLES. (Communicated by J. E. MARR, Esq., M.A., F.R.S., F.G.S. Read February 3rd, 1897.)

## [PLATES XIII. &amp; XIV.]

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## I. INTRODUCTION.

MUCH confusion has arisen in our own country and on the Continent with regard to the use of the names *Petalograptus* and *Cephalograptus* for certain subgenera of Graptolites. Both names have sometimes been employed for the very same species. Such an error can only have arisen through ignorance of the detailed structure of the type-forms. Thus, for example, in 1873 Lapworth<sup>1</sup> gave *Petalograptus folium* (His.) as the type of the subgenus *Petalograptus*. In 1882 Tullberg, in his paper on the 'Graptolites described by Hisinger,' called it *Cephalograptus folium*, and classed it with *Cephalograptus cometa* (Gein.). No wonder, then, that Geinitz, writing later,<sup>2</sup> adopted the safer plan of ignoring both subgenera, and referred the species to the more embracing genus *Diplograptus*.

The object of this paper is to bring out the following facts:—

- (1) That both *Petalograptus* and *Cephalograptus* should be regarded as subgenera of the genus *Diplograptus*.
- (2) That these subgenera are perfectly distinct, and can readily be distinguished one from the other.
- (3) That certain species should be referred to one or other subgenus.
- (4) The detailed structure of the various species, showing the relationship existing between them.

I have endeavoured to make my work on these subgenera as complete as possible by examining specimens from many British and foreign localities. Many of the British specimens were collected by myself in the field, while others are to be found in the collections of the Woodwardian Museum at Cambridge, and in the British Museum (Natural History). During a recent visit to Sweden I was enabled, through the great kindness of Dr. Törnquist, of Lund, to study his magnificent collection of graptolites. This collection not only contains specimens from almost every locality in Sweden where graptolites are to be found, but is also rich in typical forms from many other European areas (Bohemia, Thuringia, etc.). From some Swedish localities I obtained specimens for myself, and

<sup>1</sup> Geol. Mag. pt. ii. p. 555.

<sup>2</sup> 'Graptoliten des k. Mineralog. Mus. Dresden,' 1890.

Dr. Törnquist was good enough to supply me with material that has been invaluable to me in my work.

Owing to the fact that the Swedish specimens are found in almost every case in a better state of preservation than the British, I have from them been able to make out with comparative ease many important structural details which must otherwise have remained obscure. This applies especially to the details of structure of the proximal end, which in the Swedish specimens is often preserved in relief. It will, I hope, be evident from what follows that a knowledge of the structure of the proximal end is of the greatest importance for accurate specific determination of these forms.

*Historical.*—As early as 1851 Süss<sup>1</sup> used the term *Petalolithus* as a synonym for M'Coy's *Diplograptus*, but it should be noted that the forms which he considered typical of this genus were: *P. palmeus* (Barr.), *P. folium* (His.), *P. parallelocostatus* (sp. nov.), *P. ovatus* (Barr.).

In 1868 Carruthers<sup>2</sup> recognized the peculiarity of the form *Diplograptus cometa* (Geinitz, 1852), and suggested that perhaps it should be made the type of a new genus. Acting on this suggestion, Hopkinson founded the genus *Cephalograptus* for this form.<sup>3</sup> He also recognized that the form was distinct from what he erroneously calls *D. folium* (His.).

In 1873 Lapworth, in his 'Classification of the Rhabdophora,'<sup>4</sup> placed both *Petalograptus* (Süss) and *Cephalograptus* (Hopk.) as subgenera of *Diplograptus* (M'Coy), and considered *Petalograptus folium* (His.) as a type of the subgenus *Petalograptus*, and *Cephalograptus cometa* (Gein.) as a typical *Cephalograptus*. He stated that such subgenera are of value merely 'as enabling us to group together, for convenience of reference, species having a certain amount of similarity in their external features.' But this 'similarity in external features' is accompanied by certain structural modifications.

Accepting the definition of *Diplograptus* as given by Lapworth (*op. cit.*), both *Petalograptus* and *Cephalograptus* must be included in it. In structure also they follow, broadly speaking, the same general plan. Hence they should, I think, be regarded as subgenera of that genus. But because they possess many characters in common with all forms of *Diplograptus*, and yet have some peculiar to themselves, I venture to think that these subgenera have great value as representing a distinct phase in graptolite phylogeny. The *Petalograpti* are the closest to those forms of *Diplograptus* which we regard as normal; these are included in Lapworth's *Orthograptus* and *Glyptograptus*.

It will be shown in the sequel that *Petalograptus* must have been derived from *Orthograptus*, and *Cephalograptus* from *Petalograptus*, as the result of development along certain lines. *Cephalograptus* may be regarded as the most extreme *Diplograptus*-type.

<sup>1</sup> 'Ueber Böhmishe Graptolithen.'

<sup>2</sup> Geol. Mag. p. 131.

<sup>3</sup> See Journ. Quek. Microsc. Club, 1869.

<sup>4</sup> Geol. Mag. pt. ii. p. 555.

## II. DEFINITION OF THE SUBGENERA.

## PETALOGRAPTUS.

*Rhabdosoma foliiform*. Sicula embedded, completely visible only on one side of the rhabdosoma. Proximal end somewhat protracted, never rounded. Thecæ of various lengths, all with the same general characters. Long tubes with concave apertures, situated obliquely to the general direction of the rhabdosoma. Septum complete or partial. Type, *Petalograptus folium* (His.).

To this subgenus may also be referred:—

*Petalograptus palmeus* (Barr.); *P. p.* var. *latus* (Barr.); *P. p.* var. *tenuis* (Barr.); *P. p.* var. *ovato-elongatus* (Kurck); *P. ovatus* (Barr.); *P. minor* (sp. nov.).

## CEPHALOGRAPTUS.

*Rhabdosoma fusiform* or triangular. Sicula exposed, completely visible on both sides of the rhabdosoma. Proximal end very protracted. Thecæ long, tubular, with concave apertures almost perpendicular to the long axis of the rhabdosoma. Septum incomplete. Type, *Cephalograptus cometa* (Geinitz); also *C. petalum*, sp. nov.

The species are particularly characteristic of the Middle and Upper Birkhill Shales; some survive into the Lower Gala-Tarannon, and one appears to be confined to that horizon.

I now proceed to a description of the species, beginning with the type-species of the subgenus *Petalograptus*.

## III. DESCRIPTION OF THE SPECIES.

Subgenus *Petalograptus*.

## PETALOGRAPTUS FOLIUM (Hisinger). (Pl. XIII. figs. 1-5.)

1837. *Prionotus folium*, Hisinger, 'Lethæa Suecica,' Suppl. p. 114, pl. xxxv. fig. 8.  
 1843. *Prionotus folium*, Portlock, 'Geol. Report Londonderry,' p. 321, pl. xx. fig. 5.  
 1851. Non *Diprion folium*, Harkness, Quart. Journ. Geol. Soc. vol. vii. p. 63, pl. i. fig. 12.  
 1851. Non *Diplogr. folium*, Scharenberg, 'Ueber Graptolithen,' p. 16, pl. i. figs. 13, 14, pl. ii. figs. 15, 16.  
 1851. Non *Prionotus folium*, Bœck, 'Bemærkninger angaaende Graptolitherne,' pl. i. fig. 8.  
 1868. Non *Diplogr. folium*, Nicholson, Quart. Journ. Geol. Soc. vol. xxiv. p. 524, pl. xix. figs. 4-7.  
 1868. Non *Diplogr. folium*, Carruthers, 'Syst. Position of the Graptolites,' Intellectual Observer, xi. pl. ii. figs. 4 a-c, 5 a-d.  
 1876. Non *Diplogr. folium*, Lapworth, 'Grapt. of Co. Down,' Proc. Belfast Naturalists' Field Club, p. 133, pl. vi. fig. 16.  
 1880. *Diplogr. folium*, Törnquist, Geol. Fören. Förhandl. vol. v. p. 442, pl. xvii. fig. 7.  
 1882. *Cephalogr. folium*, Tullberg, K. Svenska Vet. Akad. Handl. vol. vi. no. 13, p. 15, pl. i. figs. 15-19.  
 1890. *Diplogr. folium*, Geinitz, 'Graptoliten des k. Mineralog. Mus. Dresden,' p. 26, pl. A. figs. 44-46.

This species, though very well known in Scandinavia, seems never to have been clearly recognized in this country. It has most frequently been confounded with *Petalograptus palmeus* (Barr.). It may be said to show some general relationships to that species, but it has peculiar characteristics which mark it out as a perfectly distinct form.

Tullberg, in his paper on the 'Graptolites described by Hisinger,' has grouped it with *Cephalograptus cometa* (Gein.) in the subgenus *Cephalograptus* (Hopk.). To this I cannot agree. In the development of the earliest thecæ, in the position of the sicula, and in the relation of the thecæ to the sicula, *Petalograptus folium* is far more closely allied to *Petalograptus palmeus* (Barr.) than to *Cephalograptus cometa* (Gein.).

Hisinger's original figures were generalized from many imperfect specimens, but during my recent visit to Sweden I had the opportunity of studying more perfect specimens of the species, collected at the same time as Hisinger's types.

The forms from different localities vary within certain narrow limits as regards width, but the difference is so slight that the forms can hardly be considered worthy of being ranked as distinct varieties. The circumstance of variation in width depends merely on the amount of curvature of the thecæ. If the curvature is rather more pronounced the width is increased.

Some of my specimens are in half-relief, and exhibit details of structure which have not hitherto been noticed.

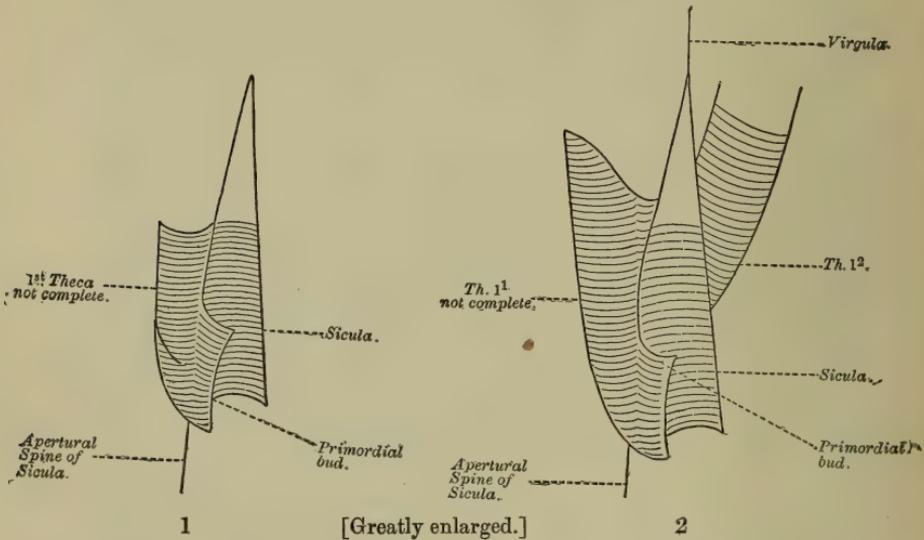
*Structure of the Proximal End.*—The sicula is somewhat slender, but is short compared with the great length attained by the thecæ. It never exceeds  $\frac{1}{2}$  inch in length, and is usually rather more than  $\frac{1}{8}$  inch long (about 2 mm.).

It certainly possessed an apertural spine, though this is not seen in all specimens, since it would seem to have been easily broken off. From a short distance above the base of the sicula and on the same side as the apertural spine the 'primordial bud' is produced. This gives rise to the first theca of the primordial series, and also to the connecting-canal, from which the first theca of the second series is developed.

Here I must explain a few of the terms of which I shall make use in the following pages. The term 'primordial series' is used in Törnquist's sense to denote all the thecæ lying on the same side of the sicula as the first. For the sake of brevity these are represented in the tables by the following symbols: 1<sup>1</sup>, 2<sup>1</sup>, 3<sup>1</sup>, etc.; while those which lie on the opposite side are termed the 'second series,' since they contain the second theca. These are denoted by the symbols 1<sup>2</sup>, 2<sup>2</sup>, 3<sup>2</sup>, etc. That side of the rhabdosoma on which the sicula is completely visible is termed the 'obverse' side. In such an aspect the first theca of the primordial series (1<sup>1</sup>) is always on the left side. The other aspect of the rhabdosoma is termed the 'reverse' side. The 'connecting-canal' is a convenient term to use for the canal, at or near the base of the sicula, which connects the

first theca of the primordial series with the first of the second series. Dr. Holm has used it in this sense. It is completely visible on the reverse side of the rhabdosoma. The later that theca 1<sup>2</sup> develops from theca 1<sup>1</sup>, the shorter is the connecting-canal. If 1<sup>2</sup> does not arise till after theca 1<sup>1</sup> has grown past the apex of the sicula, the connecting-canal is practically reduced to nothing. It is generally

*Two early stages in the development of Petalograptus folium (His.).*



indicated by the growth-lines running in a direction different from those of theca 1<sup>1</sup> and 1<sup>2</sup>.

In this species the sicula is never completely enveloped by the thecae of the rhabdosoma, even at its apex; it is visible for its entire length on the obverse side. In this position it appears to be free on the right side for about  $\frac{1}{3}$  of its length; after that it occupies a position midway between theca 1<sup>1</sup> and 1<sup>2</sup>. In the reverse aspect only the base of the sicula and a very small portion of the side are visible, the rest being here concealed by the connecting-canal and by the initial part of the second and subsequent thecae.

The first theca of the primordial series seems to grow both upwards and downwards in a manner similar to that described by Dr. Wiman as characteristic of the genus *Diplograptus*. The downward-growing part in this case extends a little way below the base of the sicula.

The first theca of the primordial series is usually rather less than three times as long as the sicula. It attains a length just short of  $\frac{1}{4}$  inch; the thecae developed later are slightly longer. All have a distinct concave curvature; proximally the apertures overlap each other from about  $\frac{1}{2}$  width, but distally the overlap is less. The width of the rhabdosoma opposite the aperture of the first theca of the

primordial series is  $\frac{1}{8}$  inch. Exceptionally it is as much as  $\frac{1}{6}$  inch. Below that point the rhabdosoma tapers somewhat abruptly.

*Character of Mature Rhabdosoma.*—The greatest length attained by the mature rhabdosoma is 1 inch. The width increases rapidly up to the 4th theca (4<sup>1</sup>), but afterwards the increase is so slight and so gradual that the sides appear approximately parallel for a greater or shorter distance, according to the length of the rhabdosoma. The maximum width attained is about  $\frac{1}{4}$  inch. Some forms barely attain  $\frac{3}{16}$  inch, while one form which I saw in Dr. Törnquist's collection at Lund attained its maximum width opposite theca 4<sup>1</sup>, and then again diminished near the distal end: the resulting form resembling that variety of *P. palmeus* (Barr.) to which Kurck has given the name *ovato-elongatus*.

The thecæ of the middle of the rhabdosoma are slightly longer than the two earliest thecæ; they are about  $\frac{1}{4}$  inch long, distally they are less, and at the actual extremity are quite short. The relation between thecal length and breadth is as 6 : 1.

The thecæ are alternate; they are tubular, and appear to be square in section. The apertures are slightly concave; they are perpendicular to the long axis of the theca, and oblique to the general direction of the rhabdosoma, except at the distal end. They are often striated parallel to the aperture; these striæ are growth-lines. There are twenty-five apertures in the space of 1 inch. The outer wall of each theca is free for a small fraction of its length, except at the distal extremity. The angle at which the thecæ are inclined to a median line varies; it is about 5° at the proximal end, it then increases to about 20° in the middle of the rhabdosoma, and again decreases to 5° near the distal end. The thecæ are all concavely curved, but not equally so. The curve is greatest in the earliest thecæ, but subsequently diminishes, giving to the whole rhabdosoma the characteristic foliate appearance to which it owes its name.

The appearance of rounding off at the distal end is due to decrease in curvature and diminution in length of the thecæ in that direction. In no specimen have I seen any indications of the presence of a septum, and I certainly do not think that one can ever have been present. One reason in support of this view is the quite irregular course taken by the virgula from its point of origin at the sicular apex to the point at which it emerges from the rhabdosoma at the distal end. This irregularity would seem to point to its having been perfectly free in the rhabdosoma, and I cannot believe that the appearance, which is the same in many differently preserved specimens, is merely a result of the conditions of preservation. The virgula is often distally prolonged for a considerable length, and not infrequently is split at one or more points along its length. It must have been very near the obverse surface of the rhabdosoma for at least the earliest part of its course.

The following table records the measurements of a few typical forms:—

Spec.	Locality.	Lgth.	W. opp. ap. 2 <sup>l</sup> .	Opp. 4 <sup>l</sup> .	Opp. 8 <sup>l</sup> max.	L. 1 <sup>l</sup> .	L. 1 <sup>2</sup> .	Max.	No. to inch.
A.	Belcraig ...	$\frac{7}{8}$	$\frac{1}{8}$	$\frac{3}{16}$	$\frac{1}{4}$	$\frac{1}{4}$	$+\frac{1}{4}$	$+\frac{1}{4}$	24
C <sup>l</sup> .	Kallholn...	$\frac{3}{4}$	$\frac{1}{8}$	$\frac{3}{16}$	$\frac{1}{4}$	$\frac{3}{16}$	$-\frac{1}{4}$	$\frac{1}{4}$	25
O <sup>2</sup> .	"	$\frac{1}{2}$	$\frac{1}{8}$	$\frac{3}{16}$	...	$\frac{3}{16}$	$\frac{1}{4}$	$\frac{1}{4}$	
D.	"	$\frac{3}{4}$	$\frac{1}{4}$	$\frac{3}{16}$	$\frac{7}{32}$	$\frac{3}{16}$	$\frac{1}{4}$	$\frac{1}{4}$	25
E.	"	1	$\frac{1}{8}$	$\frac{3}{16}$	$\frac{1}{4}$	$\frac{3}{16}$	$\frac{1}{4}$	$\frac{1}{4}$	25
F.	"	$\frac{5}{8}$	$\frac{1}{8}$	$\frac{3}{16}$	$-\frac{1}{4}$	$-\frac{1}{4}$	$+\frac{1}{4}$	$+\frac{1}{4}$	25
G.	Kongslena	$\frac{3}{4}$	$\frac{1}{8}$	$\frac{3}{16}$	$\frac{3}{16}$	$\frac{3}{16}$	$\frac{1}{4}$	$\frac{1}{4}$	
I.	Belcraig ...	$\frac{1}{2}$	$\frac{1}{8}$	$\frac{3}{16}$	$-\frac{1}{4}$	$\frac{3}{16}$			
K.	Duffkinnell	$\frac{5}{8}$	$\frac{1}{4}$	$\frac{1}{8}$	$+\frac{1}{8}$	$\frac{1}{4}$	...	...	24

NOTE.—The sign + in the above table is intended to represent that the measurement is slightly in excess of the figure which it precedes; the sign - denotes that the measurement is slightly below that figure. Thus  $+\frac{1}{4}$  means that the measurement is more than  $\frac{1}{4}$  inch, and  $-\frac{1}{4}$  that it is less than  $\frac{1}{4}$  inch.

*General Characters.*—In summing up the chief characteristics of this species it will be convenient to compare it with *Petalograptus palmeus* (Barr.), the form with which it has so often been confounded by British authors.

(1) The characteristic foliate form is more marked than in *P. palmeus* (Barr.).

(2) The form attains a greater width than *P. palmeus*.

(3) The proximal end is far more protracted than in the latter species.

(4) The thecæ in *P. folium* (His.) are much longer, the angle of inclination is less, and there are fewer in the space of an inch.

(5) There exists quite a different ratio between the length of the sicula and the length of the thecæ.

*Horizon.*—In the Moffat district *P. folium* (His.) occurs in a band of black shale distinctly below the horizon of *C. cometa* (Gein.). In the Lake District it occurs in Marr and Nicholson's zone of *M. convolutus* (His.), a zone which occupies a similar position.<sup>1</sup> This species also occurs in a band below the *C. cometa*-zone in the *Rastrites*-Shales of Kallholn,<sup>2</sup> Furudal (Dalarne), Kongslena (Vestergötland), and at Röstånga, Kiviks Esperöd, and Tommarp in Skåne.

The species is also known in the 'colonie Haidinger' in Bohemia.

*British Localities.*—Moffat District: Dobb's Linn, Belcraig Burn, Duffkinnell Burn, near Wamphray. Lake District: Skelgill.

<sup>1</sup> See Quart. Journ. Geol. Soc. vol. xlv. (1888) p. 711.

<sup>2</sup> Geinitz, 'Graptoliten des k. Mineralog. Mus. Dresden,' 1890, states that Hisinger's types came from Fågelsång in Skåne. This is an error; the original specimens came from Furudal in the province of Dalarne.

## PETALOGRAPTUS PALMEUS (Barr.).

1850. *Graptolithus palmeus*, Barrande, 'Grap. de Bohême,' p. 59, pl. iii. figs. 1-7.  
 1851. *Petalolithus palmeus*+*parallelocostatus*, Süss, 'Ueber Böhmische Graptolithen,' pp. 20, 21, pl. viii. figs. 1, 2, 4.  
 1852. *Diplograptus palmeus*, Geinitz, 'Die Graptolithen,' p. 21, pl. i. figs. 5-19.  
 1853. *Diplograptus palmeus*, Richter, Zeitschr. d. Deutsch. Geol. Gesellsch. vol. v. p. 455, pl. xii. figs. 8-10.  
 1876-1880. *Diplograptus palmeus*, Zittel, 'Traité de Paléont.' vol. i. p. 305, fig. 214, d, e.  
 1880-81. *Diplograptus palmeus*, Linnarsson, Geol. Fören. Förhandl. vol. v. p. 522, pl. xxiii. figs. 28-28.  
 1887. *Diplograptus palmeus*, Törnquist, Geol. Fören. Förhandl. vol. ix. pp. 478, 481.  
 1890. *Diplograptus palmeus*, Geinitz, 'Graptoliten des k. Mineralog. Mus. Dresden,' p. 26, pl. A. figs. 39, 41-43.  
 1893. *Diplograptus palmeus*, Törnquist, 'Structure of some Diprionidæ,' K. Fysiogr. Sällskap. Handl., Lund, vol. iv. p. 9, figs. 29-35.

This species has been very generally recognized, but the details with regard to the structure of its proximal end have never received proper attention. The form which Törnquist referred to this species in 1893 (*op. supra cit.*) cannot, I think, be retained in it, as it differs in many important particulars, and must, in my opinion, be regarded as a distinct species.

I can find no evidence in support of the separation of *P. parallelocostatus* from the true *P. palmeus* (Barr.). The characters upon which Süss founded this species have been shown to belong equally to *P. palmeus* (Barr.). Therefore I think that the species must be abolished.

Barrande, in his work on the Graptolites of Bohemia, suggested two varieties of the species *palmeus*. These varieties were based on the difference in width of the rhabdosome in different individuals, and were termed respectively (1) var. *lata* and (2) var. *tenuis*. He does not describe these varieties in detail; but from his description of *Petalograptus palmeus* we must, I think, conclude that he meant the forms that exceeded  $\frac{1}{8}$  inch (3 mm.) to be termed var. *latus*, and those which were less than  $\frac{1}{12}$  inch (2 mm.) to be called var. *tenuis*. Hence it follows that the actual specific name *Petalograptus palmeus* (Barr.) must be restricted to those forms which exceed  $\frac{1}{12}$  inch in width and which do not exceed  $\frac{1}{8}$  inch. Each of these three forms has a slightly different range in time.

In addition to the three forms mentioned above there exists one to which Kurck has given the name *ovato-elongatus*.

He ranked it as a distinct species, but, for reasons which will be given later, I think that it cannot be regarded as more than a variety. Barrande recognized the form, but did not give it a separate name.

I now proceed to describe in some detail the structure of the different forms of *P. palmeus* (Barr.).

## PETALOGRAPTUS PALMEUS (Barr.) (restricted). (Pl. XIV. figs. 1-4.)

*Structure of the Proximal End.*—The sicula is fairly long, and is broader than that of *P. folium* (His.). It is usually rather less than  $\frac{1}{2}$  inch long (about 2 mm.). It reaches up to the third theca of each

series. The sicula is very long relatively to the length of the thecæ, compared with *P. folium* (His.). It is furnished with an apertural spine, which seems to have been particularly stout and strong in the forms which lived in the Gala-Tarannon times, but which is also found in the forms of other horizons. All the Gala-Tarannon specimens have the spine exceedingly well-preserved, even when the fossils are not very clear in other respects. But in the case of forms occurring at lower horizons the spine seems to have been broken off altogether in some specimens, while in others only a small portion of it remains.

The first theca of the primordial series arises at the base of the sicula and grows outward almost at once, making a very decided concave curve. There appears to be no downward growth in this case below the base of the sicula. The second theca ( $1^2$ ) arises very much as in *P. folium* (His.) except that the curvature is greater and takes place sooner than in that species, so that the sicula is not free for so large a fraction of its length on the right side. Viewing the rhabdosoma from the obverse side, the sicula is free for rather less than  $\frac{1}{4}$  of its length; on the reverse side only the base is seen to the left, the rest being concealed by the connecting-canal, the initial part of theca  $1^2$ , and subsequent thecal bases. The theca  $1^2$  here follows the outline of the sicula for a short distance before curving outward, so that less of the sicula is seen on the reverse than on the obverse side. The two earliest thecæ are rather less than  $\frac{1}{12}$  inch in length, and are equally curved, giving a symmetrical appearance to the proximal end. Subsequent thecæ are not so much curved as the earliest ones. The angle at which the thecæ are inclined is approximately constant in the narrower forms at  $35^\circ$ , but in the wider forms the angle becomes steeper towards the distal end, though it never diminishes below  $20^\circ$ . Taken as a whole, the proximal end may be said to be short and blunt.

*Character of Mature Rhabdosoma.*—The mature rhabdosoma generally attains the length of about 1 inch, but in some specimens has been known to be as much as  $1\frac{1}{4}$  inch long. The maximum width is attained almost at once; it varies between  $\frac{1}{12}$  and  $\frac{1}{8}$  inch. The sides are parallel. This is noticeable even in quite young forms, which maintain a constant width right up to the distal end. That end may be truncate or slightly rounded.

The thecæ are alternate; they consist of short tubes three times as long as wide, whose outer wall is free for a small fraction of its length near the distal end, but at the proximal end the tubes are often in contact throughout their length. The thecæ are adorned with lines of growth parallel to the aperture. The apertures are slightly concave, and are perpendicular to the long axis of the thecæ; they overlap somewhat, at the proximal end, but this diminishes distally. There are 32 thecal apertures in the space of an inch.

There appears to have been a continuous septum through the rhabdosoma. The virgula is, as a rule, very conspicuous in all specimens; it is usually prolonged distally and is often split at

various points along its length, both inside and outside the rhabdosoma (see Pl. XIV. fig. 3). In this case as in all others, the sicula is completely exposed on the obverse side; the virgula, for the earlier part of its course, must run very near the obverse surface. Barrande suggested that the appearance of splitting might be due to a process of exfoliation of the component layers, which could come about only after the death of the animal.

*General Characters.* This species is characterized by—

- (1) The short and abruptly-terminated character of the proximal end.
- (2) Length of the sicula relatively to the thecæ.
- (3) Short thecæ and the ratio between their length and breadth.
- (4) Relative length and width of rhabdosoma as a whole.

*Horizon.*—The species seems to have had a long range. It ranges in Britain from the bottom of the Middle Birkhill Shales up into the Lower Gala-Tarannon beds. In Scandinavia it occurs immediately above the zone corresponding to that of *Diplograptus vesiculosus* (Nich.) at Röstånga, and is common in the *Rastrites*-Shales of Tommarp, Bollerup (Skåne), and Kongslena (Vestergötland). It occurs with *M. turriculatus* (Barr.) at Klubudden (Vestergötland), and with *M. turriculatus* and *M. exiguus* at Osmundsberg (Dalarne).

It occurs also at similar horizons at Berown and Zerkovice in Bohemia, and in the *Rastrites*-Shales of Heinrichsruhe in Thuringia.

*British Localities.*—Moffat District: Dobb's Linn, Beleraig Burn, Garple Linn, etc., Lundhope-on-Yarrow. Lake District: Skelgill, Browgill, Pull Beck, Kentmere, Ashgill. Wales: in Birkhill and Tarannon Shales at Conway.

PETALOGRAPTUS PALMEUS, var. LATUS (Barr.). (Pl. XIV. figs. 5-8.)

*Structure of the Proximal End.*—In nearly all the details of structure of the proximal end *P. palmeus*, var. *latus*, agrees with *P. palmeus* (restricted). The sicula is about the same length, and reaches up to the third theca of the primordial series, as in that form. It has an apertural spine, although this is but rarely preserved.

It differs in the fact that the earliest thecæ make a greater curve from their origin and are rather longer, so that the width of the rhabdosoma is increased.

*Character of Mature Rhabdosoma.*—This variety very seldom attains a length as great as that of the longest forms of *P. palmeus* (restr.); it is most commonly found with a length of about  $\frac{1}{2}$  inch. The maximum width, generally nearly  $\frac{1}{6}$  inch, is attained at once and continues quite up to the distal end, which has a broadly truncate form in most specimens, but occasionally is somewhat rounded.

The thecæ are alternate; they are about three times as long as wide, and are fully  $\frac{1}{2}$  inch long, except at the distal end. The apertures are slightly concave; they are perpendicular to the thecal length,

and oblique to the long axis of the rhabdosoma. There are about 36 thecal apertures in the space of an inch. The thecæ are inclined at their origin at the proximal end at an angle of about  $45^\circ$ , but curve very distinctly after this in an outward direction. The angle of inclination changes uniformly from the proximal up to the distal end, where it is about  $20^\circ$ . There appears to be a continuous septum in this variety, but its course is rather irregular (see Pl. XIV. fig. 8). The virgula is conspicuous, is distally prolonged, and may be split as in *P. palmeus* (restricted).

*General Characters.*—This variety differs from *P. palmeus* (restr.) in

- (1) Greater width.
- (2) Greater number of thecal apertures in the space of an inch.
- (3) The greater angle at which the thecæ are inclined at the proximal end.
- (4) The greater curvature of the same thecæ.

*Horizon.*—This variety has a rather shorter range than *P. palmeus* (restr.). It first appears about the middle of the zone of *M. gregarius* (Lapw.), and is most abundant throughout the middle and upper parts of that zone. I have never found a specimen in the Lower Gala-Tarannon beds. It seems to be specially characteristic of the Middle Birkhill Shales.

It occurs in Scandinavia in the *Rastrites*-Shales of Tommarp and Bollerup in Skåne, at Kongslena in Vestergötland, and at Enån in Dalarne.

In Bohemia it occurs with *M. proteus* (Lapw.) at Litohlav, and with *M. fimbriatus* at Berown and Zerkovice.

In Thuringia it has been found in the *Rastrites*-Shales of Rückersdorf and Heinrichsruhe.

*British Localities.*—Moffat District: Dobb's Linn, Garple Linn, etc., wherever the *M. gregarius*-zone is typically developed. Lake District: Skelgill. Ireland: Coalpit Bay, Co. Down.

PETALOGRAPTUS PALMEUS, var. TENUIS (Barr.). (Pl. XIV. figs. 9-10.)

*Structure of the Proximal End.*—The details of the structure of the proximal end are similar to those in *P. palmeus* (restr.). The sicula is perhaps a very little shorter than in the two forms previously described. It is furnished with a long apertural spine.

The earliest thecæ are shorter than in *P. palmeus* (restr.), and are almost straight; they are also much broader in proportion to their length.

The sicula is rather more than  $\frac{1}{16}$  inch long. The first theca is the most curved; it is about  $\frac{1}{24}$  inch in length.

*Character of Mature Rhabdosoma.*—This form is often small, but it may be as much as  $\frac{1}{2}$  inch in length. The width of  $\frac{1}{16}$  inch is maintained throughout its length. The thecæ are alternate; they

are short tubes  $\frac{1}{24}$  inch long, and are twice as long as broad. Their outer walls are free for a small fraction of their length. The thecæ are often seen to be adorned with striæ parallel to the direction of the apertures, which are concave and perpendicular to the long axis of each theca, but oblique to the general direction of the rhabdosoma (Pl. XIV. fig. 10). The thecæ are widest at their apertures; they are inclined at a constant angle of about  $35^\circ$ . The earliest thecæ are curved very slightly, but subsequent ones are almost straight. There are about 36 apertures in the space of an inch. A septum is present, but it seems to be only a partial one. The virgula is often distally prolonged.

*General Characters.*—This variety differs from *P. palmeus* (restr.),

- (1) In its extreme narrowness;
- (2) In the number of thecal apertures in the space of an inch;
- (3) The shortness of the thecæ and the absence of curvature;
- (4) The proportions of the thecæ.

*Horizon.*—This variety ranges from the top of the zone of *M. gregarius* (Lapw.) into the Lower Gala-Tarannon Shales.

It occurs with *M. convolutus* in Scandinavia, at Tommarp, Röst-ånga, Kongslena, and Enån. In Bohemia it occurs with an Upper Birkhill fauna at Berown, Zelkovice, etc., and with *M. turriculatus* at Lítóhlay.

It also occurs in the *Rastrites*-Shales of Heinrichsruhe in Thuringia.

*British Localities.*—Moffat District: Dobb's Linn, Belcraig, etc. Lake District: Skelgill, Pull Beck. Wales: Lower Tarannon-Shales, Conway.

**P. PALMEUS, var. OVATO-ELONGATUS (Kurck). (Pl. XIV. figs. 11-14.)**

1850. *Diplograptus palmeus*, Barrande, 'Grap. de Bohême,' i. pl. iii. fig. 7.

1852. *Petalolithus palmeus*, Süss, 'Ueber Böhmische Grapt.' pl. viii. fig. 1.

1868. *D. palmeus*, Nicholson, Quart. Journ. Geol. Soc. vol. xxiv. p. 523 & pl. xix. figs. 2, 3.

1876. *D. palmeus*, Lapworth, 'Cat. Western Scottish Fossils,' pl. i. fig. 27.

1881. *Cephalograptus ovato-elongatus*, Kurck, 'Några nya Graptolitarter från Skåne,' Geol. Fören. Förhandl. vol. vi. p. 303, pl. xiv. fig. 10.

1890. *D. ovato-elongatus*, Geinitz, 'Graptoliten des k. Mineralog. Mus. Dresden,' pl. A. fig. 40.

When Kurck described this form in 1881, he acknowledged that he was ignorant of any of the details of the structure of the proximal end. Had he been acquainted with these he would surely have detected the very close relationship existing between this form and *Petalograptus palmeus*, var. *latus* (Barr.), and would probably then have described the form merely as another variety of *P. palmeus* (Barr.).

*Structure of the Proximal End.*—The sicula is distinctly seen in many specimens; it is rather less than  $\frac{1}{12}$  inch long and is placed exactly as in *P. palmeus*, var. *latus* (Barr.), except that in this

case it scarcely reaches the level of the base of theca 3<sup>2</sup>. The earliest thecæ are strongly curved, as in *P. palmeus*, var. *latus*, and in all details of development are precisely similar. The earliest thecæ are rather shorter than those subsequently developed.

*Character of Mature Rhabdosoma.*—The length of the mature rhabdosoma is generally between  $\frac{1}{2}$  and 1 inch. The form varies within certain limits in the relative amounts of what may be termed the 'ovate' or the 'elongate' parts.

As in *P. palmeus*, var. *latus* (Barr.), the maximum width is attained almost at once, usually opposite the aperture of the second theca of the primordial series. The width attained is  $\frac{1}{6}$  inch, the same as in var. *latus*. Thus, in all the early stages, it is very hard to distinguish *P. p.* var. *latus* from *P. p.* var. *ovato-elongatus*. The maximum width may be maintained for a short distance if the 'ovate' part is long, or else a diminution in width takes place directly.

The decrease is sometimes gradual, sometimes rather abrupt. This decreased width is then maintained up to the distal end.

The thecæ are alternate; they are  $\frac{1}{12}$  inch long, and four times as long as wide in the 'ovate' part, but rather less near the distal end. The thecæ are widest at the apertures, and frequently show growth-lines. The apertures near the proximal end are almost parallel with the long axis of the rhabdosoma, but become more oblique towards the distal extremity. Near the proximal end the thecæ are inclined at 45°, and describe a decided curve as they grow outward, but the angle of inclination diminishes to 20° near the distal end, and the thecæ throughout the 'elongate' part are almost straight. Hence the form is attained by an alteration in the amount of curvature and inclination, accompanied by a slight diminution in the length of the thecæ.

There seems to have been a continuous septum (see Pl. XIV. fig. 14).

*General Characters.*—The form of the mature rhabdosoma is sufficient to distinguish it from all other varieties of *P. palmeus* (Barr.).

*Horizon.*—The species has a long range. It appears early in the zone of *M. gregarius* (Lapw.), and survives into the Lower Galatarranon beds.

It is common in the *Rastrites*-Shales of Tommarp, Bollerup, and Klubudden, and has been recorded from Zelkovice, Berown, etc., in Bohemia.

*British Localities.*—Moffat District: Dobb's Linn, Garple Linn, etc. Lake District: Skelgill, Mealy Gill. Wales: Conway (Tarannon Shales).

TABLE OF MEASUREMENTS OF DIFFERENT VARIETIES OF  
*P. PALMEUS* (Barr.).

No.	Species.	Lngh.	L. of sicula.	W. opp. ap. 1 <sup>a</sup> .	Max. width.	Thecal length.	No. of thecae.	No. to inch.	Locality.
a.	<i>P. palmeus</i> ...	$\frac{3}{4}$	...	...	$\frac{1}{2}$	$-\frac{1}{2}$	...	32	Conway.
1b.	<i>P. palmeus</i> ...	$\frac{5}{8}$	$-\frac{1}{2}$	$\frac{1}{8}$	$\frac{1}{2}$	$\frac{1}{2}$	...	...	Zelkovice.
2.	var. <i>tenuis</i> ...	$\frac{3}{16}$	...	$\frac{1}{24}$	$\frac{1}{16}$	$\frac{1}{24}$	13	36	Belcraig.
3.	var. <i>tenuis</i> ...	$\frac{1}{8}$	$\frac{1}{16}$	$\frac{1}{24}$	$\frac{1}{16}$	$\frac{1}{24}$	11	36	Dobb's Linn.
6 <sup>o</sup> .	var. <i>latus</i> ...	$\frac{1}{3}$	...	$\frac{1}{2}$	$\frac{1}{6}$	$+\frac{1}{2}$	26	36	
10.	var. <i>latus</i> ...	$+\frac{1}{4}$	$-\frac{1}{2}$	$\frac{1}{8}$	$\frac{1}{6}$	$+\frac{1}{2}$	23	36	"
9.	var. <i>ovato-elongatus</i> }	?	$-\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{6}$	$+\frac{1}{2}$	26	36	"
36.	var. <i>ovato-elongatus</i> }	$+\frac{3}{8}$	$-\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{6}$	$+\frac{1}{2}$	...	...	Skelgill.

PETALOGRAPTUS OVATUS (Barr.). (Pl. XIV. figs. 15-16.)

1850. *Graptolithus ovatus*, Barrande, 'Grapt. de Bohême,' i. p. 63, pl. iii. figs. 8, 9.  
 1851. *Petalolithus ovatus*, Süss, 'Ueber Böhmische Grapt.' p. 21, pl. viii. fig. 3.  
 1852. *Diplograpsus ovatus*, Geinitz, 'Die Graptolithen,' p. 20, pl. i. figs. 3 & 4.  
 1890. *Diplograptus ovatus*, Geinitz, 'Graptolithen des k. Mineralog. Mus. Dresden,' p. 25, pl. A. fig. 37.

With the exception of one very doubtful form from the Tarannon Shales of Conway, North Wales, I have never seen a British specimen that could correctly be referred to *P. ovatus* (Barr.). As far as our present knowledge goes, the typical form at any rate does not seem to have been recognized outside Bohemia.

The species is exceedingly characteristic, and can readily be distinguished from all other forms; but, in spite of this, many young forms of other species have been erroneously referred to it. The specimens from Bohemia in the British Museum (Natural History) have had for some unaccountable reason Barrande's original labels corrected, and now bear the name *D. folium* (His.), though they are typical forms of *P. ovatus* (Barr.), and bear little or no resemblance to Hisinger's species.

*Structure of the Proximal End.*—The sicula has a peculiar shape; it is broad, curved, and about  $\frac{1}{16}$  inch long. It reaches up to the third theca of each series, and is furnished with a short apertural spine. The earliest thecae are both very curved; the first of the primordial series arises near the base of the sicula, and is so much curved that the aperture is almost on a level with the point at which the 'primordial bud' arose. The second theca (1<sup>2</sup>) is very nearly as much curved. Sometimes these two earliest thecae are very short, at others they do not differ greatly in length from those thecae which arise later.

On the obverse side the sicula appears to be free for  $\frac{1}{3}$  of its length on the right side, and the same amount is seen on the reverse side.

*Character of the Mature Rhabdosoma.*—The species varies somewhat in shape; it is typically as broad as it is long, but in some specimens it is rather longer, and the shape then is a broad oval. I have never seen a specimen that exceeded  $\frac{1}{4}$  inch in length. The width varies in different specimens from  $\frac{1}{8}$  to  $\frac{1}{4}$  inch.

Near the proximal end the thecæ are alternate; where the thecæ become horizontal they are almost opposite, but the alternation is again visible at the distal end. The thecæ are  $\frac{1}{12}$  inch long except at the distal extremity, and in typical forms are four times as long as they are broad; in the more oval forms the dimensions are slightly less. The thecæ are widest at their apertures, and overlap somewhat. The apertures are concave, and near the proximal end they are directed downward, but towards the distal end this is not so marked. There are about 42 apertures in the space of 1 inch. The angle of inclination of the thecæ varies greatly at different points along the length of the rhabdosoma. It changes as follows:— $70^{\circ}$ – $90^{\circ}$ – $55^{\circ}$ – $45^{\circ}$ . The thecæ are all concavely curved, but the curvature is greatest near the proximal end. The virgula is prolonged beyond the distal extremity.

When the form is longer in proportion to its width, this seems to be due to the fact that there is a difference in direction of growth of the thecæ; fewer thecæ are curved downward, so the upward inclination begins earlier.

*General Characters.*—This species differs from all others

- (1) In the various angles at which the thecæ are inclined in different parts of the rhabdosoma;
- (2) In the number of thecæ;
- (3) In having the apertures of the thecæ recurved towards the base.

*Horizon.*—This species occurs in Bohemia in shales with *M. turriculatus* (Barr.), and *M. exiguus* (Nich.). These beds are probably the equivalents of our Lower Gala-Tarannon beds.

*British Locality.*—(?) Conway, North Wales.

TABLE OF MEASUREMENTS.

No.	Length.	L. of sicula.	Width. opp. 1 <sup>st</sup> .	Max. width.	Thecal length.	No. of thecæ.	Locality.
a ...	$\frac{1}{2}$	$\frac{1}{16}$	$\frac{1}{2}$	$\frac{1}{8}$	$+\frac{1}{12}$	22	Zelkovice, Bohemia.
b ...	$\frac{1}{4}$	$\frac{1}{16}$	$\frac{1}{2}$	$\frac{1}{8}$	$\frac{1}{12}$	24	" "
c ...	$+\frac{1}{8}$	...	...	$+\frac{1}{8}$	$\frac{1}{12}$	16	" "
d ...	$\frac{1}{8}$	...	$\frac{1}{2}$	$-\frac{1}{8}$	$\frac{1}{12}$	15	" "
e ...	$\frac{1}{4}$	...	$\frac{1}{16}$	$\frac{1}{8}$	$\frac{1}{12}$	22	" "

## PETALOGRAPTUS MINOR, sp. nov. (Pl. XIV. figs. 17-21.)

=*Diplograptus palmeus*, Törnquist, 'Structure of some Diprionidæ.'

This small species has usually been regarded as merely a young stage of *P. palmeus* (Barr.), or *P. palmeus*, var. *latus* (Barr.), but it differs from these in many important particulars.

I had noted this form some little time previous to my visit to Sweden, but through lack of good material I did not like to venture upon its description. While in Sweden I was fortunate enough to see several excellent specimens preserved in relief; and having since my return examined some better material obtained from the Moffat district, I no longer hesitate to assert that it must be regarded as a new species.

*Structure of the Proximal End.*—The sicula is slender and very long. It tapers so finely in an upward direction that in many specimens it is exceedingly hard to say where the sicula ends and the virgula begins. In some specimens it is certainly  $\frac{1}{8}$  inch long, but in others it is slightly less; its apex usually lies on a level with the 4th theca of the primordial series and half way up the central part of the 3rd theca of the second series; it was furnished with an apertural spine.

The sicula is completely visible only when the rhabdosoma is viewed from the dorsal side. From its base on the left side arises the 'primordial bud' whence the first theca originates. It grows parallel with the sicula for a short distance, and then describes a gentle concave curve outwards. It never exceeds  $\frac{1}{12}$  inch in length, and is commonly rather less. The sicula is apparently free on the right side for  $\frac{1}{3}$  of its length, but when viewed on the reverse side only the sicula-base and a small portion of the side are visible, since the rest is concealed by the connecting-canal and the initial part of the theca 1<sup>2</sup>. In its earliest stage this theca closely follows the outline of the sicula for a short distance. This fact is only seen on the reverse side, so that, viewing the rhabdosoma from the obverse side, theca 1<sup>2</sup> appears to originate at about  $\frac{1}{3}$  way up the sicula, while in reality it has originated earlier. This theca is also concavely curved, but the curve is less than that described by theca 1<sup>1</sup>; and therefore the aperture of theca 1<sup>2</sup> rises to a greater height than does that of 1<sup>1</sup>, though both are of approximately the same length.

The aperture of theca 1<sup>1</sup> is always more than  $\frac{1}{24}$  inch above the base of the sicula.<sup>1</sup> It rises to a level of  $\frac{1}{16}$  inch from the sicula-base, and is at a distance of  $\frac{1}{8}$  inch from it.

*Character of Mature Rhabdosoma.*—The rhabdosoma is always small; it is commonly  $\frac{1}{4}$  inch long, but a few specimens have been found in which this dimension is slightly exceeded. It is

<sup>1</sup> In all forms of *P. palmeus* (Barr.), the first thecal aperture is always less than  $\frac{1}{24}$  inch from the base of the sicula.

concavo-convex, with great convexity on the reverse side. Mature forms are oblong, and have a rounded, narrow distal end. The maximum width is attained very gradually; it is never reached till half way up the rhabdosoma, that is,  $\frac{1}{8}$  inch from the proximal end. It never exceeds  $\frac{1}{8}$  inch, but is usually about that measurement.

In the longer forms the rhabdosoma remains at the maximum width for a very short distance, but more commonly begins at once to diminish again. In some specimens, as a result of the extreme convexity, the distal end of the reverse aspect is seen to have a pointed appearance, but this is not usually the case.

The thecæ are alternate; they are  $\frac{1}{2}$  inch long and  $4\frac{1}{2}$  times as long as wide; their apertures are very slightly concave, and are perpendicular to the long axis of the theca. There are 36 apertures in the space of an inch. There is not much difference in the width at the aperture and the width at the initial part. Growth-lines parallel to the aperture are often seen. The thecæ are inclined to a median line at a constant angle of about  $45^\circ$ . The amount of curvature decreases towards the distal end. On the obverse side there are indications of the presence of a septum, but on the reverse side in a specimen preserved in relief there is no trace of one, so that it must be incomplete.

Törnquist has shown that this is the case. It appears from his work that the septum extends half way through the rhabdosoma, but it may be still further reduced.

The virgula is conspicuous, and is often distally prolonged.

#### MEASUREMENTS OF VARIOUS FORMS.

Spec.	Length.	Thecal length.	No. of thecæ.	Width opp. 1 <sup>l</sup> .	2 <sup>l</sup> .	3 <sup>l</sup> .	Max. width.	L. of sicula.	Locality.
*1 ...	$\frac{3}{16}$	$\frac{1}{2}$	15	$\frac{1}{2}$	$\frac{1}{8}$	$\frac{5}{32}$	$\frac{5}{32}$	$-\frac{1}{8}$	Dobb's Linn.
*2 ...	$\frac{3}{16}$	$\frac{1}{2}$	14	$\frac{1}{2}$	$-\frac{1}{8}$	$\frac{1}{8}$	$\frac{1}{8}$	$\frac{1}{8}$	" "
*4 ...	$+\frac{1}{8}$	$\frac{1}{2}$	20	$\frac{1}{2}$	...	...	$\frac{1}{8}$	$\frac{1}{8}$	" "
14 ...	$+\frac{1}{4}$	$\frac{1}{2}$	19	$+\frac{1}{16}$	$-\frac{1}{8}$	$\frac{1}{8}$	$\frac{1}{8}$	...	Skelgill.
16 ...	$\frac{1}{8}$	$\frac{1}{2}$	21	?	$-\frac{1}{8}$	$\frac{1}{8}$	$+\frac{1}{8}$	...	Dobb's Linn.
23 ...	$\frac{1}{4}$	$\frac{1}{2}$	18	$\frac{1}{2}$	$-\frac{1}{8}$	$\frac{1}{8}$	$+\frac{1}{8}$	...	" "
25 ...	$\frac{1}{4}$	$\frac{1}{2}$	19	$\frac{1}{2}$	$-\frac{1}{8}$	$\frac{1}{8}$	$\frac{1}{8}$	...	" "
29 ...	$\frac{1}{4}$	$\frac{1}{2}$	18	$+\frac{1}{16}$	$+\frac{1}{2}$	$-\frac{1}{8}$	$\frac{1}{8}$	...	Skelgill.
A.....	$\frac{5}{16}$	$\frac{1}{2}$	19	$\frac{1}{2}$	...	...	$\frac{1}{8}$	$\frac{1}{8}$	Tommarp.

I have also taken measurements of a number of species of all ages, and the following table shows the relation between the number of thecæ and the length:—

No.	No. of thecæ.	Length.	Locality.
26.	5	$\frac{1}{2}$	Dobb's Linn, Moffat.
12.	7	$-\frac{1}{8}$	" " "
2.	8	$-\frac{1}{8}$	" " "
13.	10	$\frac{1}{8}$	" " "
8.	11	$\frac{1}{8}$	" " "
21.	12	$\frac{1}{8}$	" " "
18.	13	$\frac{1}{8}$	" " "
4 <sup>1</sup> .	14	$\frac{3}{16}$	" " "
7.	14	$\frac{3}{16}$	" " "
1.	15	$\frac{3}{16}$	" " "
11.	15	$\frac{3}{16}$	" " "
3.	16	$\frac{3}{16}$	" " "
9.	16	$+\frac{3}{16}$	" " "
10.	16	$+\frac{3}{16}$	" " "
29.	18	$\frac{1}{4}$	Skelgill.
23.	18	$\frac{1}{4}$	Dobb's Linn, Moffat.
14.	19	$+\frac{1}{4}$	Skelgill.
A.	19	$\frac{5}{16}$	Tommarp, Skåne.
17.	20	$\frac{5}{16}$	Dobb's Linn, Moffat.
4 <sup>2</sup> .	20	$\frac{1}{2}$	Skelgill.
16.	21	$\frac{1}{2}$	"

*General Characters.*—This species has sometimes a superficial resemblance to young forms of *P. palmeus* (Barr. restr.), and *P. palmeus*, var. *latus* (Barr.), but can be readily distinguished from them.

- (1) The sicula is longer, and attains\* a greater height in the thecal series than in any varieties of *P. palmeus* (Barr.).
- (2) The proximal end is more protracted than in those varieties.
- (3) The maximum width is attained later than in either *P. palmeus* (restr.), or *P. palmeus*, var. *latus* (Barr.). In this species it is never attained till half way up the rhabdosoma, while in all forms of *P. palmeus* (Barr.) it is attained at once.
- (4) There is no trace of a septum on the reverse side. In *P. palmeus* (restr.) and in var. *latus* (Barr.) a continuous septum is present.
- (5) In this species the distal end is gently rounded off, and the rhabdosoma decreases in width distally. In the forms of *P. palmeus* (Barr.) the rhabdosoma retains its maximum width quite up to the distal end, which is usually abruptly truncate.

*Horizon.*—This species seems to be confined to the zone of *Monograptus gregarius* (Lapw.). It is most abundant at the horizon corresponding to Marr and Nicholson's zone of *Monograptus fimbriatus* (Nich.), in the Lake District.

It occurs at the same horizon in the *Rastrites*-Shales of Sweden at Tommarp and Kongslena; and I have also seen specimens from the 'colonie Haidinger' and Berown in Bohemia, and from the *Rastrites*-Beds of Böhmsdorf in Thuringia.

*British Localities.*—Moffat District: Dobb's Linn (Long Cliff), Garple Linn., etc. Lake District: Skelgill.

### Subgenus *Cephalograptus*.

CEPHALOGRAPTUS COMETA (Gein.). (Pl. XIII. figs. 10–16.)

1852. *Diplograptus cometa*, Geinitz, 'Die Graptolithen,' p. 26, pl. i. fig. 28.  
 1853. *Diplograptus cometa*, Richter, Zeitschr. d. deutsch. geol. Gesellsch. vol. v. p. 457, pl. xii. figs. 16–17.  
 1867. *Diplograptus tubulariformis*, Nicholson, Geol. Mag. p. 109, pl. vii. fig. 15.  
 1868. *Diplograptus cometa*, Carruthers, Geol. Mag. p. 131, pl. v. fig. 4.  
 1869. *Cephalograptus cometa*, Hopkinson, Journ. Quek. Microsc. Club, p. 159, pl. viii. fig. 14.  
 1873. *Cephalograptus cometa*, Lapworth, Geol. Mag. p. 555 & Proc. Geol. Assoc. vol. iii. p. 167.  
 1876. *Cephalograptus cometa*, Lapworth, 'Graptolites of Co. Down,' p. 132, pl. vi. fig. 4; 'Cat. Western Scottish Fossils,' pl. ii. fig. 31.  
 1878–79. *Diplograptus cometa*, Törnquist, Geol. Fören. Förhandl. vol. iv. p. 456.  
 1882. *Cephalograptus cometa*, Tullberg, K. Svenska Vet. Akad. Handl. vol. vi. no. 13, p. 15.  
 1890. *Diplograptus cometa*, Geinitz, 'Graptoliten des k. Mineralog. Mus. Dresden,' pl. A. fig. 47.  
 1893. *Cephalograptus cometa*, Törnquist, 'Structure of some Diprionidæ,' K. Fysioгр. Sällsk. Handl., Lund, vol. iv. p. 11, figs. 36–41.

The distinctive character of the external form of this species was recognized by Hopkinson when he founded the subgenus *Cephalograptus*, in order to separate the form from the ordinary types of *Diplograptus*. He did not, however, recognize all its structural characteristics. It was left to Törnquist to do this in his work on the 'Structure of some Diprionidæ.' Geinitz's original description, and, indeed, all the earlier descriptions, were founded on incomplete specimens, and the figures given are therefore not characteristic. In his more recent work Geinitz acknowledges the figures of later authors; but I do not think that these either are based upon complete specimens. Törnquist's are the only figures on which reliance may be placed. One of his figures certainly shows a complete specimen, and he alone gives figures showing the characteristic structure of the proximal end. I have but little to add to Törnquist's work in this respect.

*Structure of the Proximal End.*—As Törnquist has shown, the sicula is completely visible in both obverse and reverse positions of the rhabdosoma. It is short, compared with the great length attained by the earliest thecæ. It is about  $\frac{1}{16}$  inch long. When

viewed from the obverse side it is free for the whole of its length on the right-hand side, recalling strongly the position of the sicula in all forms of *Monograptus*.

The first theca of the primordial series arises close to the base of the sicula and grows slightly downward, so as to be a little below the base of the sicula; it grows also upward (apparently) simultaneously, making a very gentle outward curve.

The first theca of the second series does not develop from theca 1<sup>1</sup> till it has grown some considerable way past the sicula. Hence the reason why the sicula is completely visible in both aspects of the rhabdosoma. The virgula is seen, as usual, to arise at the apex of the sicula, and it is worthy of note that at first it runs along the dorsal side of the first theca for some little distance; then, however, it is seen to pass into the centre of the rhabdosoma. It is very slender in this species, especially at its origin. The entire proximal end is slender, being much protracted; the attenuation is especially conspicuous at a short distance from the proximal end, and it is at this point that the rhabdosoma is so frequently broken off. When the rhabdosoma is perfect there is seen to be a slight dilatation at the extreme proximal end where the sicula is placed.

The whole proximal end would seem to have been flexible, for the most slender forms are often seen to be somewhat sinuous.

The two earliest thecæ are both very long and narrow. The first of the primordial series is ordinarily  $\frac{7}{16}$  inch long, but may be as much as  $\frac{1}{2}$  inch. All the thecæ subsequently developed are shorter.

*Character of Mature Rhabdosoma.*—The whole rhabdosoma, when mature and complete, seems always to have exceeded  $\frac{1}{2}$  inch in length, and is often nearer 1 inch. Owing, however, to the extremely rare occurrence of a complete specimen, it usually appears much less. Specimens from different localities are apt to vary slightly in width, but never to any very marked extent.

The maximum width of  $\frac{1}{12}$  inch is attained opposite the aperture of the first theca of the primordial series. This width is sometimes maintained as far as the aperture of the first theca of the second series, and then decreases, or a decrease in width may have taken place before the aperture of the first theca of the second series is reached.

The thecæ are always few in number; I have never seen a specimen in which there were more than 6 on each side. The apertures are all within a small fraction of the distal extremity, forming a kind of crown; they are arranged alternately. The thecæ are very long and tubular. They are usually rather less than  $\frac{1}{2}$  inch long and are 12 times as long as wide. The thecal apertures are perpendicular to the long axes of the thecæ, and often nearly perpendicular to the long axis of the rhabdosoma itself. Growth-lines are often beautifully seen in specimens preserved in relief. The angle at which the thecæ are inclined is very steep;

it varies from  $5^{\circ}$  to  $10^{\circ}$ . The thecæ are but very slightly curved; those at the distal end are short and straight.

As Törnquist has shown, the septum is invisible on the reverse side of the rhabdosoma; in fact it is so reduced that it can scarcely be said to be more than a mere fold of the periderm on the obverse side. The median fold is not continued to the proximal end of the rhabdosoma.

The virgula is distally prolonged, and not infrequently split at some point along its length.

No.	Lgth.	L. 1 <sup>1</sup> .	Width opp. 1 <sup>1</sup> .	2 <sup>1</sup> .	2 <sup>2</sup> .	No. of thecæ.	Locality.
1 <sup>a</sup> .	$\frac{1\frac{1}{8}}$	$\frac{7}{16}$	$+\frac{1}{12}$	...	...	6+5	Hartfell.
1 <sup>b</sup> .	$\frac{1}{2}$	...	...	...	...	...	"
2.	$\frac{9}{16}$ ?	$\frac{7}{16}$	$\frac{1}{12}$	...	$\frac{1}{16}$	5+4	Belcraig.
3.	$\frac{9}{16}$	$\frac{7}{16}$	$\frac{1}{12}$	$\frac{1}{12}$	$\frac{1}{16}$	...	"
4.	$\frac{3}{8}$	...	$\frac{1}{12}$	...	...	...	Browgill.
6.	...	...	$\frac{1}{12}$	$\frac{1}{12}$	$-\frac{1}{16}$	4+3	Tonmarp, Skåne.
7.	$\frac{2}{8}$	$\frac{7}{16}$	$\frac{1}{16}$	$\frac{1}{16}$	$-\frac{1}{16}$	4+3	" "
11.	$\frac{1\frac{1}{8}}$	$-\frac{1}{2}$	$\frac{1}{12}$	$\frac{1}{12}$	$\frac{1}{16}$	5+4	Kongslena, V. G.
12 <sup>a</sup> .	$\frac{2}{8}$	$\frac{9}{16}$	$\frac{1}{12}$	$\frac{1}{12}$	$\frac{1}{16}$	5+4	" " "
12 <sup>b</sup> .	$\frac{5}{8}$	...	$\frac{1}{12}$	...	...	4+3	" " "
13 <sup>a</sup> .	$\frac{9}{16}$	$-\frac{1}{2}$	$-\frac{1}{12}$	$\frac{1}{12}$	$\frac{1}{16}$	5+4	" " "
13 <sup>b</sup> .	$\frac{5}{8}$	$\frac{1}{2}$	$\frac{1}{12}$	$\frac{1}{12}$	?	4+3	" " "
14.	...	...	$\frac{1}{12}$	$\frac{1}{12}$	$\frac{1}{16}$	4+4	" " "
15.	$\frac{7}{12}$	$\frac{1}{2}$	$\frac{1}{12}$	$\frac{1}{16}$	$\frac{1}{16}$	4+3	" " "

*Horizon.*—This species has long been recognized as belonging to a distinct horizon at the base of the zone of *M. spinigerus* (Nich.), both in this country and on the Continent.

*British Localities.*—Lake District: Browgill. Moffat District: Dobb's Linn, Belcraig. Ireland: Coalpit Bay.

#### CEPHALOGRAPTUS PETALUM, sp. nov. (Pl. XIII. figs. 6-9.)

= *Diplograptus tubulariformis*, Nich., Geol. Mag. 1867, pl. vii. figs. 12 & 13.

In 1867 Prof. Nicholson described a form to which he gave the name *Diplograptus tubulariformis*. Subsequent authors have taken this name as a synonym for *C. cometa* (Gein.), and the description given by Nicholson certainly corresponds closely with that species. Having examined the specimens, which I believe to be those figured by him as *D. tubulariformis*, I am convinced that they belong to three distinct species. The specimens from which figs. 12 & 13 (*op. supra cit.*) were drawn belong to a species hitherto undescribed; fig. 14 is that of a young form of *Petalograptus folium* (His.); and fig. 15 is probably meant to represent the true *Cephalograptus*

*cometa* (Gein.). Under such circumstances it seems best to adopt a new name for the species represented by figs. 12 & 13, specimens of which I have also procured for myself from Dobb's Linn and Beleraig Burn. The species in question is undeniably a link between the Petalograpti and the Cephalograpti, as represented on the one hand by *Petalograptus folium* (His.), and on the other by *Cephalograptus cometa* (Gein.).

Speaking generally, we might say that this species is distally a *Petalograptus* and proximally a *Cephalograptus*, since the characters of the thecæ show that it is closely related to *P. folium* (His.), but the character of the proximal end proclaims it a true *Cephalograptus*.

*Structure of the Proximal End.*—The position of the sicula again strongly recalls the *Monograptus*-type. It is entirely free on one side in either aspect of the rhabdosoma. It is furnished with an apertural spine. The whole proximal end is slender and protracted as in *C. cometa* (Gein.), but it is not so long as in that species. The first theca of the primordial series appears to arise slightly above the base of the sicula; it describes a decided outward curve, and attains a length of  $\frac{1}{3}$  inch.

The first theca of the second series arises from 1<sup>1</sup> just after the first of the primordial series has grown past the sicula.

The proximal end is straight, as in *P. folium* (His.), not sinuous as in *C. cometa* (Gein.).

*Character of Mature Rhabdosoma.*—The forms of the mature rhabdosoma are very varied. Some approach more nearly to *P. folium* (His.), others are more like *C. cometa* (Gein.). The greatest length attained by any specimen that I have seen was 1 inch; this is exceptionally long: the specimens are more commonly about  $\frac{1}{2}$  inch in length.

The maximum width of  $\frac{1}{3}$  inch is not attained opposite the aperture of the first theca, but the rhabdosoma gradually increases in width as far as the third theca of either series; a constant width is then maintained up to the distal end.

The thecæ are alternate; they are tubular; the earliest ones are  $\frac{1}{3}$  inch long, but those in the middle of the rhabdosoma have a constant length of  $\frac{1}{6}$  inch; there is a further diminution in length at the distal extremity. The thecæ on an average are 8 times as long as they are wide. The apertures of the earliest thecæ are oblique to the general direction of the rhabdosoma, but near the distal end they become more nearly perpendicular; they are always perpendicular to the long axis of the theca. The apertures of the earliest thecæ overlap  $\frac{1}{2}$ , but this decreases distally.

There are 24 apertures in the space of an inch, and they are not all near the distal end as in *C. cometa*, but the rhabdosoma has apertures for fully half its length on either side. The angle of inclination is about 10° in the middle of the rhabdosoma, but it is less proximally and distally. The thecæ are almost straight.

There are no indications of the presence of a septum. The virgula is, as a rule, prolonged beyond the distal extremity. Its course is similar to that described in the case of *C. cometa* (Gein.).

TABLE OF MEASUREMENTS.

Spec. nov.	Lgth.	L. of sic.	L. 1 <sup>l</sup> .	W. opp. 1 <sup>l</sup> .	Opp. 3 <sup>l</sup> .	No. of thece.	Localities (Moffat District).
P [1882] ...	$\frac{7}{12}$	$\frac{1}{6}$	$\frac{1}{3}$	$\frac{1}{12}$	$\frac{1}{8}$	14	Frenchland Burn.
P [1875] ...	$\frac{7}{12}$	$\frac{1}{6}$	$\frac{1}{3}$	$\frac{1}{12}$	$\frac{1}{8}$	17	Duffkinnell Burn.
B .....	$\frac{23}{24}$	$\frac{1}{6}$	$\frac{1}{3}$	$\frac{1}{12}$	$\frac{1}{8}$	30?	Dobb's Linn.
D .....	$\frac{5}{12}$	...	$\frac{1}{3}$	$\frac{1}{12}$	...	9	Duffkinnell Burn.

*Horizon.*—The specimens obtained from Dobb's Linn and Belcraig Burn were found just below the zone of *C. cometa* (Gein.), but the species probably ranges up into the latter zone.

*British Localities.*—All the specimens known to me were found in the Moffat district; they come from Dobb's Linn, Belcraig Burn, Frenchland Burn, and the Duffkinnell Burn near Wamphray.

TABLE SHOWING RATIO OF THECAL LENGTH AND BREADTH IN THE VARIOUS SPECIES.

Species.	Ratio.
<i>P. palmeus</i> , var. <i>tenuis</i> .....	2 : 1
<i>P. palmeus</i> .....	3 : 1
<i>P. p.</i> var. <i>ovato-elongatus</i> (a) .	$3\frac{1}{2}$ : 1
"    "    (b) ...	4 : 1
<i>P. palmeus</i> , var. <i>latus</i> .....	4 : 1
<i>P. ovatus</i> .....	4 : 1
<i>P. minor</i> .....	$4\frac{1}{2}$ : 1
<i>P. folium</i> .....	6 : 1
<i>C. petalum</i> .....	8 : 1
<i>C. cometa</i> .....	12 : 1

TABLE SHOWING RATIO BETWEEN THECAL LENGTH AND LENGTH OF SICULA.

Species.	Ratio.
<i>P. palmeus</i> , var. <i>tenuis</i> ...	$\frac{2}{3}$ : 1
<i>P. minor</i> .....	$\frac{2}{3}$ : 1
<i>P. palmeus</i> .....	1 : 1
<i>P. p.</i> var. <i>ovato-elongatus</i>	1 : 1
<i>P. p.</i> var. <i>latus</i> .....	1 : 1
<i>P. ovatus</i> .....	2 : 1
<i>P. folium</i> .....	4 : 1
<i>C. petalum</i> .....	5 : 1
<i>C. cometa</i> .....	8 : 1

## IV. GENERAL CONCLUSIONS.

From the descriptions that have been given, there can, I think, be no doubt that the forms referable to the subgenera *Petalograptus* and *Cephalograptus* differ from those more common forms of *Diplograptus*, included in Lapworth's subgenera *Orthograptus* and *Glyptograptus*, which we are accustomed to regard as typical of the genus. The structure of the proximal end of such forms has been described in detail by Dr. Wiman ('Ueber Diplograptidæ').

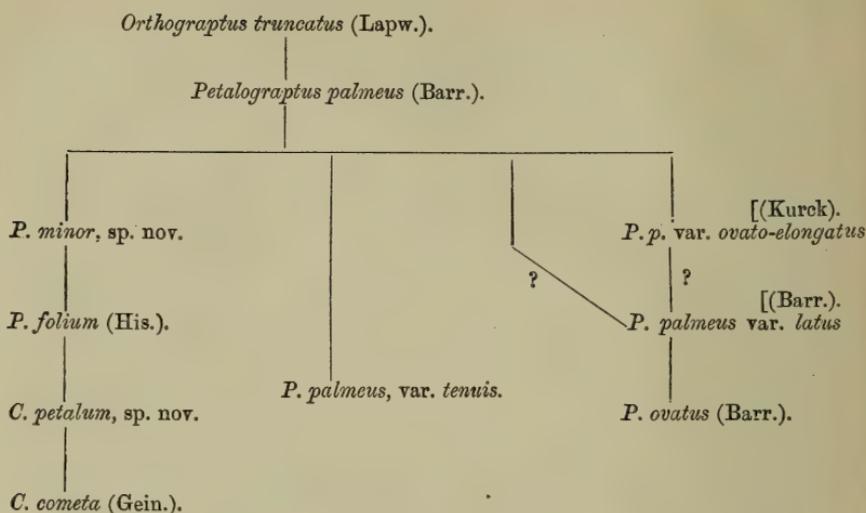
*Orthograptus foliaceus* (Murch.) and *Orthograptus truncatus* (Lapw.) fall into such a class, and the external resemblance of these species to some of the *Petalograpti* is evident at a glance. In these forms the proximal end is not protracted, and the sicula is not completely visible in either aspect of the rhabdosoma, but the characters of the thecæ are strikingly similar to those of *Petalograptus palmeus* (restr.). I regard this as significant; the differences separating the forms can so easily be brought about by very slight alteration in the mode of development that I cannot refrain from offering the suggestion that the *Petalograpti* have been derived from *Orthograptus foliaceus*, and that *Orthograptus truncatus* is merely a step on the way.

In *O. truncatus* (Lapw.) the canal connecting  $1^1$  with  $1^2$  is almost horizontal, so that the theca  $1^2$  arises at nearly the same level as  $1^1$ . If the connecting-canal became more oblique, and the thecæ more concavely curved, a form identical with *P. palmeus* (restr.) would be the result. If the theca  $1^2$  arises still later, and the thecæ at first grow parallel with the sicula and then curve, the resulting form is identical with *Petalograptus minor* (sp. nov.). The thecæ in this form are longer.

A further increase in thecal length would give the form *P. folium* (His.). Now we have reached an important stage. Should the theca  $1^2$  develop so late from the first that the first has already grown past the apex of the sicula, the sicula will be entirely free on the side remote from that on which the first theca of the primordial series arises. Such a form we have in *Cephalograptus petalum*, other changes being a diminution in the angle of inclination and further increase in thecal length. The extreme type is reached in *Cephalograptus cometa*, in which the theca  $1^2$  arises still later, the thecæ are still longer, and are almost parallel to the long axis of the rhabdosoma. The other forms of *Petalograptus* may be derived from *P. palmeus* by slight alterations in the amount of curvature.

That the *Petalograpti* have a *Phyllograptus* as a remote ancestor seems very likely, but the evidence for this is at present incomplete. Neither am I able to state whether the *C. cometa* (Gein.) type has a further stage in a form of *Dimorphograptus* or not. I know no *Dimorphograptus* which resembles it, and it seems possible that, owing to the excessively fragile nature of the proximal end, this form was not that most fitted to survive in the struggle for life.

## SUGGESTED PHYLOGENY.



In conclusion I offer my grateful thanks to Prof. T. McK. Hughes, F.R.S., for much kind encouragement; to Prof. Lapworth, F.R.S., and Mr. J. E. Marr, F.R.S., for kind help and advice, and for the loan of specimens; and to Prof. Otto Torell, Director of the Swedish Geological Survey, Dr. G. Holm, and Dr. Törnquist for facilitating my work in every way during my stay in Sweden.

## EXPLANATION OF PLATES XIII. &amp; XIV.

All the figures are  $\times 2$ . Those marked \* are in the British Museum (Nat. History).

## PLATE XIII.

Figs. 1-5. *Petalograptus folium* (His.).

- Fig. 1. Reverse aspect of mature specimen, showing the base of the sicula on the left. Beleraig.
2. Obverse aspect, in relief, of mature specimen, showing the position of the sicula and the character of the proximal end. Thecal striæ well seen. Kallholn.
3. The same, in relief. Kallholn.
4. Reverse aspect of the proximal end, showing the base of the sicula with the apertural spine. Kallholn.
- \*5. Obverse aspect of a young specimen. Duffkinnell Burn, near Wamphray.

Figs. 6-9. *Cephalograptus petalum*, sp. nov.

- Fig. \*6. Obverse aspect of foliate form, showing the position of the sicula and the course of the virgula. Duffkinnell Burn.
- \*7. Reverse aspect of a young specimen incomplete at the proximal end, showing only the apex of the sicula. Duffkinnell Burn.
- \*8. Reverse aspect, showing the splitting of the virgula outside the rhabdosoma. Frenchland Burn.
9. Reverse aspect of a very long specimen. Dobb's Linn.

Figs. 10-16. *Cephalograptus cometa* (Gein.).

- Fig. \*10. Obverse aspect of an incomplete specimen. Duffkinnell Burn.  
 11. Obverse aspect of a curved specimen; proximal end wanting. Belcraig Burn.  
 12. Obverse aspect of a complete specimen, showing the position of the sicula. Kongslena.  
 13. Distal end, preserved in relief, showing characteristic thecal striations. Tommarp.  
 14. Reverse aspect of proximal end, showing position of the sicula and course of the virgula. Preserved in relief. Tommarp.  
 15. Obverse aspect of proximal end; preserved in relief. Tommarp.  
 16. Obverse aspect of proximal end of a curved specimen; preserved in relief. Tommarp.

## PLATE XIV.

Figs. 1-4. *Petalograptus palmeus*, sensu stricto (Barr.).

- Fig. \*1. Reverse aspect of a mature specimen, showing the sicula with the apertural spine. Owing to the mode of preservation, the sicula is seen through from the obverse side. Zelkovice.  
 2. Obverse aspect of mature specimen, showing the sicula and the general characters of the proximal end. Conway.  
 3. Obverse aspect, showing the splitting of the virgula within the rhabdosoma. Dobb's Linn.  
 \*4. Obverse aspect of wide specimen. Zelkovice.

Figs. 5-8. *P. palmeus*, var. *latus* (Barr.).

- Fig. \*5. Obverse aspect, showing the characters of the proximal end. Frenchland Burn.  
 6. Reverse aspect of a young specimen; base of sicula seen on the left. Dobb's Linn.  
 7. Obverse aspect of mature specimen, showing the sicula with the apertural spine. Preserved in half relief. Tommarp.  
 8. Transverse section through the middle of a mature specimen, showing the septum and the position of the virgula. Specimen preserved in iron pyrites. Skelgill.

Figs. 9, 10. *P. palmeus*, var. *tenuis* (Barr.).

- Fig. 9. Obverse aspect of mature specimen, showing the sicula with the apertural spine. Skelgill.  
 10. Obverse aspect, in relief, of a young specimen, showing the sicula, the general characters of the proximal end, and the growth-lines on the thecae. Dobb's Linn.

Figs. 11-14. *P. palmeus*, var. *ovato-elongatus* (Kurck).

- Fig. 11. Reverse aspect of a mature specimen, with the apertural spine. The cells on the right side have been affected by pressure. Dobb's Linn.  
 12. Obverse aspect, in relief, of a young specimen not complete. Skelgill.  
 13. Obverse aspect, in relief, of a mature specimen. Skelgill.  
 14. Transverse section of a specimen, preserved in relief, showing the continuous septum and the position of the virgula. Skelgill.

Figs. 15, 16. *Petalograptus ovatus* (Barr.).

- Fig. \*15. Reverse aspect, showing the sicula through from the obverse side; typical form showing alteration in the angle of inclination. Zelkovice.  
 \*16. Reverse aspect of a more oval form, showing alteration in the angle of inclination. Zelkovice.

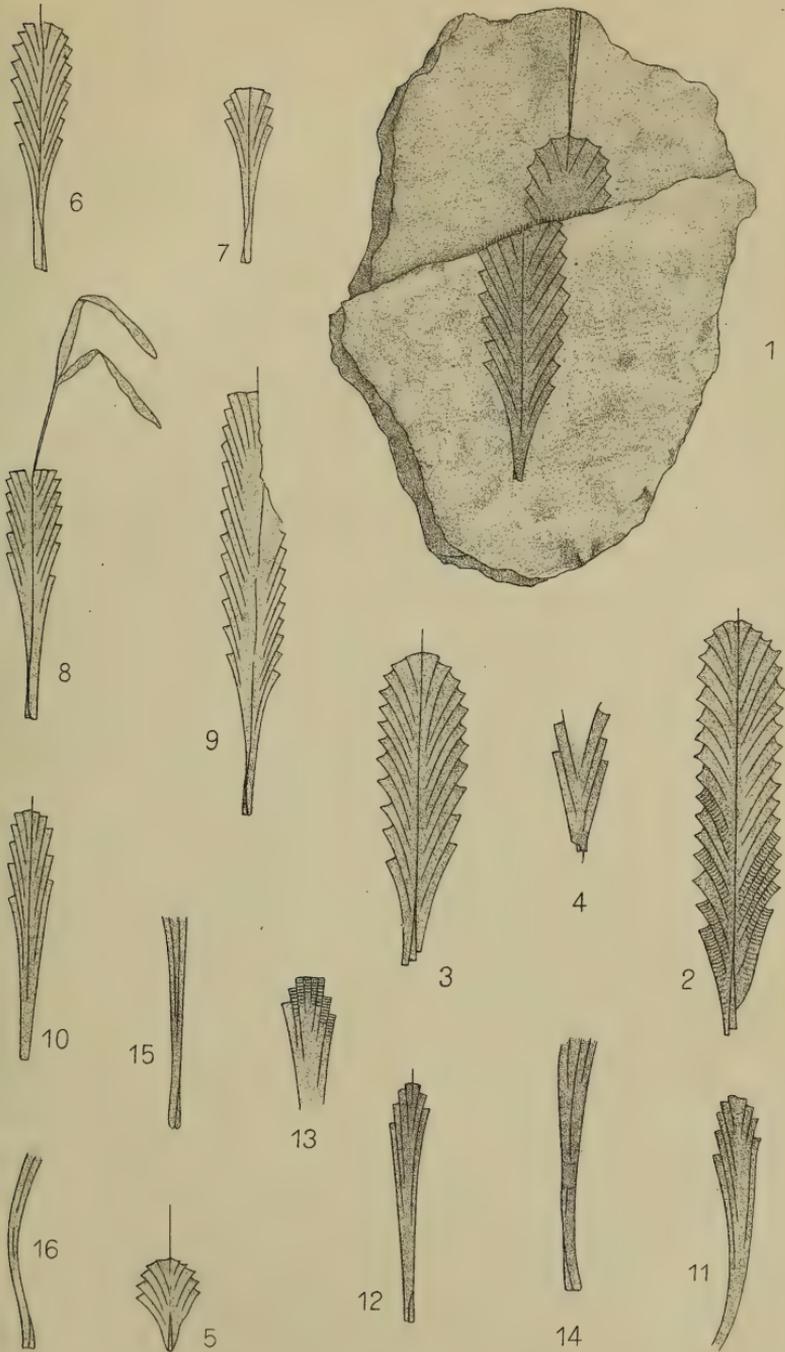
Figs. 17-21. *Petalograptus minor*, sp. nov.

- Fig. 17. Obverse aspect of a typical form, showing the long sicula and the general characters of the proximal end. Dobb's Linn.
18. Obverse aspect of a mature specimen; the thecæ on the right side are not perfectly preserved. Tommarp.
19. Reverse aspect, in relief, of a typical form. Note the absence of the septum. Skelgill.
20. Specimen preserved so as to show some internal structure. Note the long sicula and the origin of the lowest theca on the right. Dobb's Linn.
21. Reverse aspect of a young specimen. The sicula is seen through from the obverse side. Dobb's Linn.

## DISCUSSION.

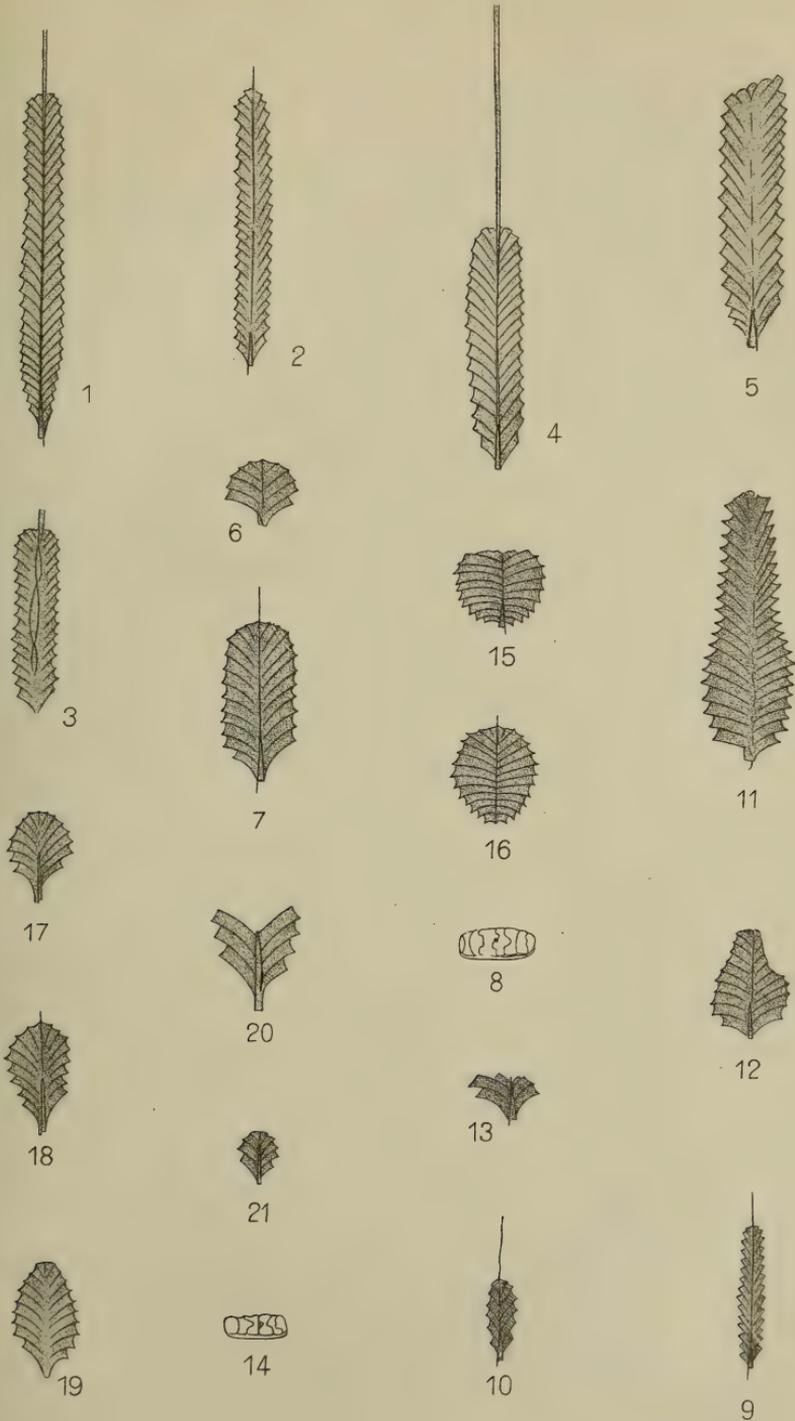
Mr. HOPKINSON said that this paper was of much interest, and he considered it to be an important contribution to the history of the small section of the Diplograptidæ of which it treated. The details of the structure had been well worked out, evidently from better specimens than he had had an opportunity of examining. He agreed with the Author as to the derivation of *Cephalograptus* from *Orthograptus* through *Petalograptus*; but he thought that she did not attach sufficient importance to the absence of a longitudinal septum in *Cephalograptus*, which was one of the main points upon which he relied in founding the genus. There appeared to be such a septum in all other Diplograptidæ, and on this account *Cephalograptus* was farther removed from *Petalograptus* than was that subgenus from *Orthograptus*. In some cases there could be no doubt about the phylogeny of the Graptolites. For instance, *Dicranograptus* was evidently derived from *Olimacograptus* by the distal portion of the hydrosoma dividing into two branches, and the hydrothecæ becoming slightly modified; while *Dicellograptus* was derived from *Dicranograptus* by the further division of the hydrosoma into two entirely separate branches, and the further modification of the hydrothecæ in the same direction (from an angular to a rounded outline) resulting in a two-branched graptolite which has no relation to *Didymograptus*. The Author's final suggestions had no such clear foundations as this; and he did not think it at all likely that *Petalograptus* was derived from *Phyllograptus*, nor could he see how *Cephalograptus* could be the ancestor of *Dimorphograptus*.

Mr. MARR bore testimony to the scrupulous care with which the Author had conducted her researches. He was not interested in the separation of *Cephalograptus* from *Petalograptus*, for he believed that most of these terms were temporary in the case of the Graptolites; but he felt that the Author, by her careful examination of the whole structure of one group of the Diplograptidæ, had given geologists a detailed study in phylogeny of great importance.



Edwin Wilson, Cambridge.





Edwin Wilson, Cambridge.

PETALOGRAPTUS.



15. *On TWO BOULDERS of GRANITE from the MIDDLE CHALK of BETCHWORTH, SURREY.* By W. P. D. STEBBING, Esq., F.G.S. (Read February 24th, 1897.)

## [PLATE XV.]

BOULDERS of various Palæozoic rocks, other than mere pebbles, in the Upper Cretaceous and in some other strata have at different times been described, but they are acknowledged to be of comparatively rare occurrence in rocks of Mesozoic age. It may be of interest to summarize briefly the chief finds of this kind which have been made up to the present in this country.

In 1827 Mantell<sup>1</sup> observed that 'In this country the Chalk very rarely contains traces of older deposits: the only instances of extraneous rocks that have come under my observation are pebbles of quartz and some fragments of green schist.'

In 1850 Dixon<sup>2</sup> wrote:—'Small pebbles and large rolled fragments of sandstone and quartz-rock are occasionally discovered in the centre of the Upper Chalk. Mr. Coombe found one specimen, weighing near 14 lbs., at Houghton, Sussex, and I have seen others from the same pit of 2 or 3 lbs. weight. Several also have been sent me by Mr. Catt from the pits near Lewes.'

In 1857 the well-known Purley boulder was found, of which this Society is fortunate enough to possess the principal remains. R. A. C. Godwin-Austen in vol. xiv. of the Quarterly Journal, p. 253, says 'the boulder . . . . was found in a chalk-pit by the side of the old London and Brighton road, near Purley. . . . The portion of the Chalk-formation in which the pit is worked is the lower part of that containing flints.' After the boulder was removed there were found associated with it a mass of fine, waterworn, siliceous beach-sand, evidently derived from the waste of a coast-line of crystalline rocks; a quantity of coarse sand-like material, which on examination proved to be decomposed rock of the same kind as the boulder; and a collection of blocks of smaller dimensions, also waterworn. Most of these were composed of a peculiar and very different rock, consisting of augite, with lath-shaped, twinned crystals of felspar; but some were of greenstone. The largest of them must have weighed as much as 20 to 25 lbs.; all were very much decomposed.

The form of the boulder itself, which had been broken up by the workmen, seems to have been roughly egg-shaped, and it was evidently a rounded waterworn block of crystalline granitoid rock. The colour is red, and the weight of the fragment in the Geological Society's Museum is about 45 lbs.

In 1860 Godwin-Austen recorded the occurrence<sup>3</sup> of a mass of

<sup>1</sup> 'The Geology of the South-East of England,' p. 78.

<sup>2</sup> 'Geology of Sussex,' p. 69.

<sup>3</sup> Quart. Journ. Geol. Soc. vol. xvi. p. 326.

bituminous coal, with veins of ferruginous clay, in the Upper Chalk of Kent. This mass, which weighed about 4 cwt., and was from 4 to 10 inches thick and about 4 feet square, was discovered at a depth of 180 feet in the process of tunnelling for the L. C. and D. Railway, between Lydden Hill and Shepherdswell, a few miles from Dover. It was probably of Oolitic or Wealden age.

Messrs. Jukes-Browne and W. Hill mention<sup>1</sup> that they were informed, by a man working in a Totternhoe Stone pit at Isleham, of the find of a number of large stones mixed with material that looked like rotten wood, in a cavity in undisturbed Chalk.

I noticed last September in the Brighton Museum a block of quartzite, weighing 13 lbs. 14 oz., from the Middle Chalk of Houghton, Sussex. It was exhibited by Mr. Henry Willett when Godwin-Austen read his paper on the Purley boulder before this Society. It has the lower valve of a *Spondylus*, a Polyzoan, a Serpula, and the remains of several other bodies still adhering to it. The same museum contains also a pebble of clay-slate, weighing about 1 lb., found in the Lower Chalk at North Stoke.

The Museum of Practical Geology, Jermyn Street, possesses a large ovoid quartzite-boulder from West Thurrock, discovered 30 feet below the surface, and two of quartzite and greenstone from Gayton, Norfolk.

Many fragments of foreign rocks have been found at various times in the Cambridge Greensand.<sup>2</sup> In 1872<sup>3</sup> Messrs. W. J. Sollas and A. J. Jukes-Browne described several different examples from their own collections and the Woodwardian Museum, Cambridge. These were of various shapes, nearly all being sub-angular, with only one or two rounded specimens. They ranged in size from 1 cubic foot downwards, some being very much decomposed. Others were scratched as if by ice, while almost all were encrusted with *Ostræa* and *Plicatulae*. The following rocks, among others, were represented: coarse yellowish grit, purplish-red slate, grey and reddish sandstones, a fine conglomerate, Magnesian, black and brown siliceous limestones, granites, black basalt, green mica-schist, greenstone, obsidian, and labradorite-rock, also joints of *Poteriocrinus* and fossil resin. One of the granites, marked 12 in their paper, much decomposed, consisted of felspar, black mica, masses of fibrous hornblende, and irregular crystals of quartz.

It should also be mentioned that a large boulder of spherulitic rhyolite, much rounded and worn, with attached *Plicatulae*, was found in the Cambridge Greensand at Ashwell, Herts, and is described by Prof. Bonney in Proc. Camb. Phil. Soc. vol. v. p. 65.<sup>4</sup>

<sup>1</sup> Quart. Journ. Geol. Soc. vol. xliii. (1887) p. 554.

<sup>2</sup> T. G. Bonney, Proc. Geol. Assoc. vol. iii. p. 1.

<sup>3</sup> Quart. Journ. Geol. Soc. vol. xxix. (1873) p. 11.

<sup>4</sup> Among examples of boulders in rocks composed of fine sedimentary or organic material may be mentioned the following:—Quartzite, granitoid and other rocks in the Coal Measures, E. W. Binney, Mem. Lit. & Phil. Soc. Manch. 1851, vol. ix. ser. 2, p. 306; T. G. Bonney, Geol. Mag. 1873, p. 289, and Rep. Brit. Assoc. (Birmingham), 1886, Pres. Addr. Sect. C, p. 601; J. Radcliffe, Quart. Journ. Geol. Soc. vol. xliii. (1887) p. 599; J. Spencer, *ibid.* p. 734;

We turn now to the main subject of this communication—the boulders obtained by me at Betchworth.

According to a tradition which I have been unable to authenticate, Betchworth chalk-pit, which is about 4 miles from Dorking, was worked in the time of the Romans. Whether this be true or not, there is no doubt that quarrying has been in operation there for a very long period. The section exposed in the pit extends from very near the base of the Chalk to the top of the zone of *Terebratulina gracilis*. The two blocks (A and B) which form the subject of this communication were obtained last April from one of a gang of men working on the western side of the pit, and engaged in clearing away the chalk above the zone of *Holaster subglobosus*. They came from the zone of *Terebratulina gracilis*, and were found after a blast. Unfortunately both of them are broken. It is likely, as they are very much decomposed, that they were broken through their fall after the blast, or by the blast itself: the boulders may, of course, have been broken by the men themselves before they were observed; but the workmen assured me that they saw no other fragments.

The weight of the larger boulder (A) was 7 lbs. 7 oz. when it first came into my hands. In shape it is roughly quadrangular, measuring  $5.8 \times 6.25 \times 4.125$  inches. It is a fine-grained granite, so very much decomposed that it will hardly bear handling, and is rotten enough to be rubbed away by the finger. It has the remains of several lower valves of *Spondylus latus* and some *Serpulæ* still attached. On the broken side it is stained with streaks and spots of iron oxide. There are also parallel to that side one or two small cracks.

The other fragment (B), which seems to be the half of a roughly ovoid mass, weighed 3 lbs. 12 oz., and measured  $3.6 \times 5.8 \times 4.5$  inches. This also is a granite; but it is interesting to observe that it is of altogether different character from the other, there being large irregular crystals of quartz visible on part of the exterior, while on the broken surface mica is very distinct in places. It is not nearly so much decomposed as the other specimen.

I am indebted to Prof. Bonney's kindness for the following notes on the microscopic structure of the rocks:—

'Boulder A.—Structure granular, with some irregularity in size and an occasional slight tendency to clustering of grains which are alike in size or nature: seldom any approach to idiomorphism. Constituents: quartz (not very abundant), sometimes with slight strain-shadowing, occasional microlithic inclusions, and very minute cavities. Felspar: ordinary plagioclase, microcline, and probably orthoclase: often embedding small grains of quartz; also some

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M. Stirrup, Rep. Brit. Assoc. (Manchester) 1887, p. 686, and Trans. Manch. Geol. Soc. vol. xxi. 1891, p. 172, etc.; and angular fragments of granite, quartzite, etc., in the Carboniferous Limestone, V. Ball, Quart. Journ. Geol. Soc. vol. xlv. (1888) p. 371. To the ice-borne masses of rock of the Glacial Beds it is needless to refer.

grains of a mineral having a very slight earth-brown tint in ordinary light, and appearing (with crossed nicols) as an aggregate of minute specks inclining to flaky or fibrous, which have weak depolarizing power: probably a pinite (? after cordierite). A very little of rather altered biotite and iron oxide, also zircon, and (?) rutile, both small and rare. The structure of the rock is not that of a normal granite, but more nearly resembles one of those which are often banded, and commonly occur in a complex of the older Archæan, such as the so-called Laurentian or Hebridean (see fig. 1).

'*Boulder B.*—The constituents in this specimen differ, in that much of the felspar is ordinary plagioclase, and orthoclase is more certainly present; the pinitic mineral is doubtfully present; there is very

Fig. 1.—*Microscopic section of Boulder A.*



× 30.

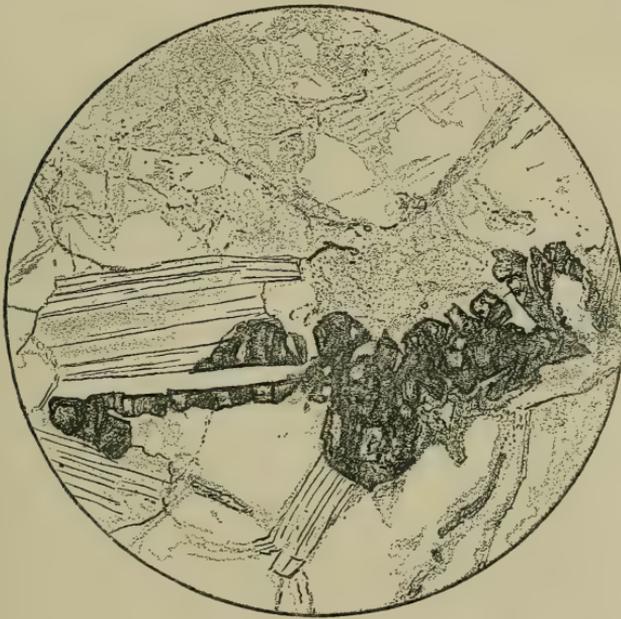
The dark grain at the edge, about S.S.W. of the centre, is blackened biotite, and there are some small films to the N.W. of it. The lighter grains are quartz; the rest is felspar. A trace of minute micrographic structure is visible. The rock is cracked, but the peculiarly formed clear space between S.E. and E.S.E. is caused by a breakage in the slice.

little biotite, but much white mica. A little of this may be bleached biotite, and in one or two cases I think that small flakes of biotite are interlaminated. There is a small elongated cluster of impure red garnets, pierced longitudinally by a thin tongue of quartz (see fig. 2). In this rock signs of mechanical action are clear. The mica is sometimes bent or 'rucked,' the quartz and

felspar are more or less cracked and recemented; there are some strain-shadows in the former, and I am disposed to attribute a cross-hatched structure, which occurs 'sporadically' in the latter, to the same cause. The rock, in short, is gneissoid from pressure, and resembles those which are rather common in the same regions as the last-named.

'I have compared these slices with one from the original Purley boulder given to me by Prof. Judd. In this the felspar is more distinctly idiomorphic, the quartz has slightly larger cavities, there is hardly any mica (biotite), and one small grain, I think, of hornblende. One or two zircons occur, and also a few very small

Fig. 2.—*Microscopic section of Boulder B.*



× 30.

The dark grains are garnets containing much opacite. The clear grains are quartz. The white mica can be recognized by its cleavage-lines. The rest of the slide is felspar. The rather wavy dusty lines are cracks, stained or bordered with decomposition-products.

minerals, probably of secondary origin, together with one slightly larger, which is oblong in form; these I cannot identify with certainty, and need not discuss on the present occasion. This rock, though less affected by pressure, might have come from the same region as the others. I have also compared Mr. Stebbing's specimens with a slice from a boulder obtained by Mr. Starkie Gardner from the Kentish Gault, which is almost wholly composed of quartz and felspar, and is much pressure-modified.'

The existence of these extraneous fragments suggests some interesting questions. We should like to know from what special localities, and by what controlling agencies, such foreign substances came into their present positions, though I have no doubt that over and beyond these a multitude of other questions might be raised.

With respect to the various theories that have been mentioned, so far as I may venture to offer an opinion, the agency of berg-ice does not appear likely to have come into play in the movement of boulders such as those from Betchworth.

Coast-ice appears to have been the probable medium of conveyance. The same explanation is applicable to such a case as that of the Purley boulder, where there was a mass of stones of various sizes with beach-sand, and also to the Cambridge specimens. Some of the latter have scratches on them, which in a few cases are covered by *Plicatulae* affixed after they were made. The scratches were very likely caused by the grinding up and down of the ice holding them on the shore before it floated off. Shore-ice has occurred on the East coast of England, and is known to have carried away shingle frozen into it. Specimens in this case need not be much rolled, as fresh material is nearly always being added from the foreshore and cliffs.

Another very probable agency would be the entanglement of earth and stones in the roots of trees. The mass of stones mingled with what looked like rotten wood, noticed by a workman in a Totternhoe Stone pit at Isleham, and recorded by Messrs. Jukes-Browne and W. Hill, would appear to have been so transported. Darwin, in his 'Journal of the Voyage of the *Beagle*,' mentions the occurrence of a piece of greenstone on a coral-island in the Indian Ocean, which clearly could not have been brought there by any other agency. Analogous to that manner of conveyance would be the clinging of seaweed to stones and rock, either below or between tide-marks.

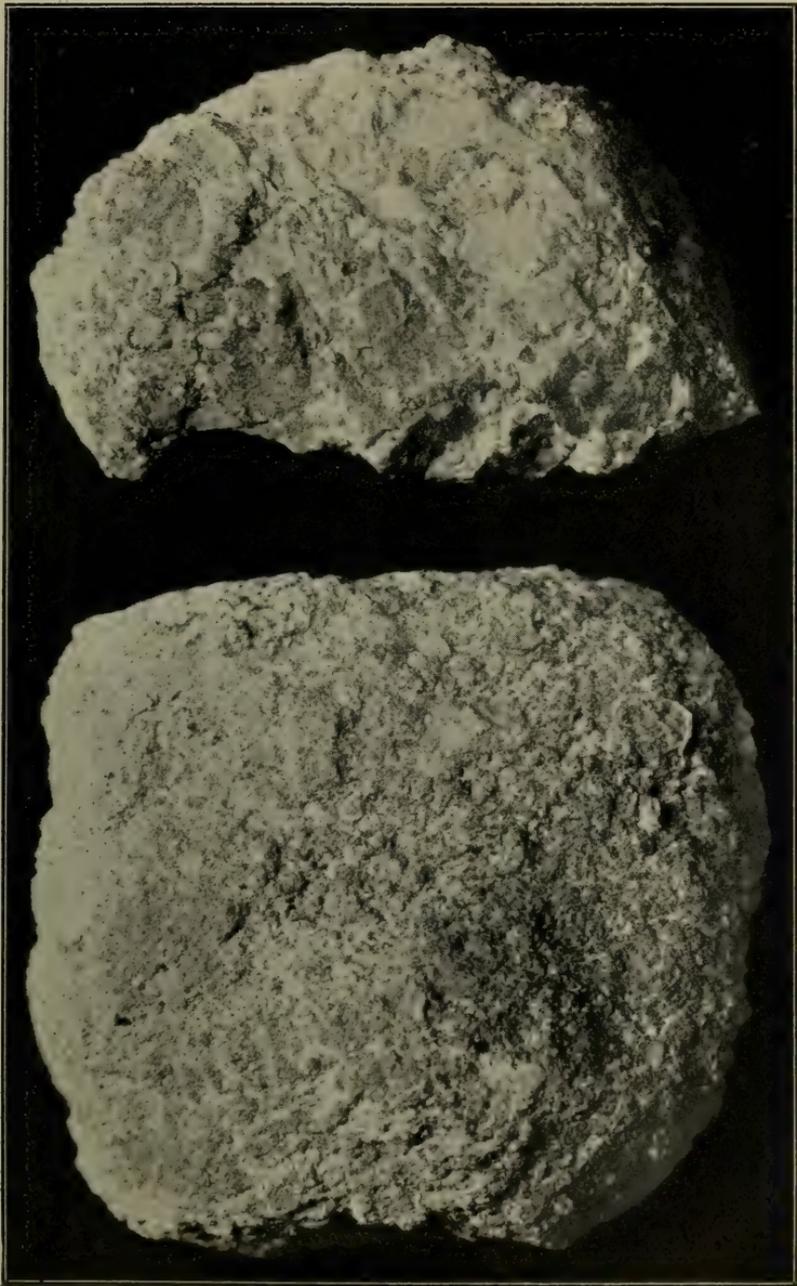
Most of the boulders that I have mentioned would exceed the weight that could have been so shifted, but not so the granite-fragments in the Carboniferous Limestone near Dublin, which Valentine Ball supposed to have been thus distributed. The same theory would also explain the occurrence of some of the various small pebbles of quartz, etc., in the Chalk.

It may be thought rather fanciful to add the hypothesis, suggested by one enquirer, of marine animals as such carriers. At all events, that would be compatible only with the transport of few and minute pebbles.<sup>1</sup>

The mass of supposed Mesozoic coal found in the Chalk near Dover may very well have been transported by coast-ice, being gently deposited when the ice melted.

As for extraneous boulders, they seem to come chiefly from the Middle Chalk and about the zone of *Terebratulina gracilis*. To my knowledge only three specimens of granite have been obtained from the Chalk, namely the Purley boulder and these two Betchworth

<sup>1</sup> For a recent instance of this kind, in which penguins and fur-seals are the carriers, see the *Challenger Reports*, Zoology, vol. ii. (1881), Birds, p. 126.



THE BETCHWORTH BOULDERS.

[From a Photograph.]



specimens. Granite seems to be rare in the Coal Measures also, quartzite being by far the commonest rock in both deposits.

One of the Betchworth specimens, the quartzite in the Brighton Museum, and most of the Cambridge boulders have shells, etc., still affixed. They are typical Middle Chalk and Cambridge Greensand forms, and evidently grew there after the boulders were dropped on the sea-bottom.

A further question of interest in relation to these and other fragments is the identification of the places whence they set out. Present evidence seems to point to the north as the starting-point of most of them; but there is no certainty about the particular localities. Godwin-Austen supposed the Purley boulder to have come from Scandinavia, which also appears to be the origin of many of the Cambridge Greensand fragments, though some at any rate may be presumed to have originated in Scotland. To the Scottish Highlands or, in Prof. Bonney's judgment, more probably to Scandinavia may be assigned also the birthplace of these two Betchworth boulders.

#### PLATE XV.

Reproduction of photographs of the Betchworth boulders,  $\frac{5}{8}$  nat. size.

#### DISCUSSION.

Prof. BONNEY said that these rocks showed the granular structure often seen in rocks of Laurentian type, contained microcline, white mica slightly bent up, and, to a certain extent, a mosaic of quartz. The felspar in the Purley boulder was more idiomorphic. He thought that the subject had been very clearly and well brought before the Society.

The PRESIDENT remarked that Mr. Stebbing and Prof. Bonney had opened out a question of great interest. Few probably were prepared to admit the existence of a glacial period in the heart of the Cretaceous, but the hypothesis of floating ice came up here. Masses so transported must have come from a considerable distance: there was indeed room for much imagination and much discussion. The Author had mentioned transport by marine animals, driftwood, seaweed, and finally ice—which latter appeared to be the most reasonable.

Mr. STRAHAN complimented the Author on his careful record of the circumstances under which these boulders had been found. It seemed curious that such foreign bodies were not found more frequently, considering how vast a number of Chalk-exposures occurred throughout the country. In other marine formations, moreover, they are almost unknown—possibly, however, in consequence of the difficulty of detecting them.

The complete rounding of many of the boulders, and the adhesion to them of Chalk organisms, pointed to their derivation from a shore; and this, taken in connexion with the large size of some of them, made it difficult to understand that they had been floated

out to sea entangled in the roots of trees. On the other hand, the theory of glacial transport needed confirmatory evidence.

Dr. HUME thought that the presence of these boulders in the Chalk could not be taken as evidence of the existence of a Cretaceous glacial period. There is a total absence of the traces of a glacial current, and the fauna observed points rather to the conclusion that, if a current existed, it would more probably have come from the south. The large size of the Purley boulder makes it difficult to assume the transport by seaweed, trees, and especially fishes, so that at present the action of ice as an agent cannot be absolutely dismissed.

Prof. JUDD maintained that the size of the boulders from Croydon was such that it was impossible to account for their transport by floating trees or floating seaweeds over great areas of the ocean. He considered that the larger blocks could only have been carried by ice—though the paucity of blocks pointed to the conclusion that, while the Cretaceous sea was occasionally traversed by stray icebergs, there could have been nothing like a glacial period.

Mr. A. E. SALTER thought that the smaller pebbles found in the Chalk were deserving of attention and study. They were more numerous and of greater variety than the large boulders, and might, on careful microscopical examination, yield valuable evidence as to the source of origin of these erratic bodies. Mr. Dibley had recently obtained more than a dozen pebbles of various rocks from the same pit near Croydon as that whence the large, so-called 'Purley boulder' came. He had also obtained several from Northfleet. A now disused portion of the great chalk-pit at Burham had yielded several some years ago, and Prof. Wiltshire also obtained a large number from Northfleet which are now in the Woodwardian Museum.

Mr. WHITAKER also spoke.

The AUTHOR, in reply, explained that he had never supposed a glacial period to be a condition of the migration of these boulders, since any winter would have sufficed. On behalf of the hypothesis of coast-ice which had been criticized, he reminded the Society of the presence of beach-sand with the Purley boulder. The question of small pebbles had been left untouched by him as being outside the sphere of the present paper, which was concerned only with the larger specimens.

16. IZALCO *and* OTHER VOLCANOES *in* CENTRAL AMERICA. By A. GOSLING, Esq., H.M. Minister and Consul-General in Central America. (Communicated by the PRESIDENT. Read March 10th, 1897.)

[Extract from a letter addressed to H.M. Secretary of State for Foreign Affairs.]

It may not be wholly devoid of speculative interest to learn that the volcano of Izalco, in the Republic of Salvador, which has been in active eruption for over one hundred years, suddenly ceased to be so in the early days of December 1896.<sup>1</sup>

Izalco, rightly named 'the Beacon of Central America,' is one of the most recent and interesting volcanoes in that part of the world; and I venture to quote some remarks respecting it which I contributed in January of last year to the North American Review:—

'Nowhere on this planet, the island of Java, perhaps, excepted, are volcanoes so numerous and of such varied and eccentric conformation as in Guatemala. The most notable are Agua and Fuego, respectively 12,310 and 13,976 feet in height. During last century the former vomited forth volumes of igneous matter, beneath which lies buried the old Spanish city of Ciudad Vieja. Guatemala la Antigua, the former capital and seat of government under a Spanish viceroy, with its hundreds of fine churches and religious establishments, was, upwards of a hundred years ago, totally destroyed by earthquakes caused by the sudden and terrible activity of Fuego. Of recent years seismic disturbance has been of such rare occurrence in Guatemala that houses of two or three stories have replaced the low and substantial structures of former times, built to withstand the much-dreaded violence of the *tierra mota*.

'In the Republic of Salvador, a volcano of recent formation, named Izalco, by whose agency the capital, San Salvador, was nearly destroyed in 1873, serves the useful purpose of a beacon for this iron-bound coast on the Pacific. Towards the end of last century the site on which it is situated was a fertile knoll where the Indians cultivated their corn, and where the frequent destruction of their crops by fire was attributed to acts of vengeance by neighbouring tribes, giving rise to many a free fight, in which that deadly weapon the *machete* played a prominent part; nor was it until a gradual upheaval of the soil was observed that it occurred to anyone that these supposed acts of incendiarism were due to subterranean ignition. Izalco has now attained an altitude of some 5000 feet, and coasting navigators watch its rapid growth from year to year. Its nocturnal ebullitions form a spectacle of more imposing grandeur than the eruptions of Vesuvius; explosions occur every 12 or 15 minutes, day and night, with extraordinary regularity, accompanied by noises likened to the discharge of heavy artillery, followed by the escape of volumes of dense smoke and flame, carrying with it hundreds of tons of rock and lava, which on a dark night presents a most weird appearance.'

<sup>1</sup> [The Author draws attention to the fact that an earthquake-shock was experienced in England on the 17th of the same month.—Ed.]

17. *CHANGES of LEVEL in the BERMUDA ISLANDS.* By Prof. RALPH S. TARR, of Cornell University. (Communicated by the Secretary. Read January 6th, 1897.)

[Abstract.]

THE Author gives a summary of previous writings bearing upon the geology of the Bermudas; but his own researches point to a rather more complicated series of changes than those which have been inferred by other writers. The formation of the 'base-rock' or 'beach-rock' occurred at some period which cannot be accurately ascertained at present, owing to the fragmentary nature of the included fossils. It may have been formed in Pleistocene or even late Tertiary times. After its formation it was converted into a dense limestone and then eroded, probably by subaerial agents, and finally attacked by the waves at an elevation of at least 15 feet above present sea-level; during this stage it was covered by beach-deposits of pebbles and shells, which were accumulated in a period so recent that the contained fossils are of the same species as the organisms living in the neighbouring sea. Then followed an uplift, during which land-shells lived on the beach-deposits; but these were soon covered by blown sand—the principal accumulations of the islands, and the outline of the islands was perfected by the action of the winds. This was done at an elevation which was at one time certainly as much as 40 or 50 feet above present sea-level. The author adduces evidence of a depression since this accumulation, causing land to disappear and the outline of the area to become very irregular; and he proves that these changes cannot be accounted for solely by erosion, as some have maintained. There are indications that the land is at present quiescent. It appears, then, that most of the work of construction of the Bermudas has been done in recent times.

#### DISCUSSION.

Dr. J. W. GREGORY thought it appropriate for the paper to be sent to this Society, as one of the earliest fossil-collections from Bermuda was in the Society's Museum, and as the geological structure of the islands had been described in the Society's Transactions by Capt. Nelson. He had hoped that the age of the basal rock of Bermuda might have been settled by this paper, as this would have precisely limited the short period during which had occurred the movements described by the Author.

Capt. STIFFE said that, having given some attention to the subject while at the Bermudas, he had formed the opinion that recent elevation or depression was not necessary to account for the present condition of the islands. Æolian agency was quite adequate to produce the present state of things. The blown calcareous sand associated with recent shells has been consolidated into a very porous limestone, apparently by pluvial and chemical action.

18. *On some SUPERFICIAL DEPOSITS in CUTCH.* By the Rev. J. F. BLAKE, M.A., F.G.S. (Read February 3rd, 1897.)

[Abridged.<sup>1</sup>]

DURING a recent visit to Cutch for the purpose of studying the Jurassic<sup>2</sup> rocks there exposed, my attention was naturally attracted to a number of superficial deposits, which in some cases concealed, and in others were associated with, the solid rocks beneath. I cannot pretend to have made an exhaustive study of them, as I have only examined such parts as may be found in the Jurassic area; but these have suggested certain theories of their origin, which I have not seen proposed elsewhere, and as these theories depend on observations which I do not find recorded, it may at least be hoped that an account of such observations may throw light on the origin of the deposits. The matters with which I propose to deal may be classed under the following heads:—

- (1) Subrecent concrete.
- (2) The boulder-beds associated with this concrete.
- (3) Infratrappean grits.
- (4) Laterite.
- (5) Alluvium and Ran.

Of all these, except No. 2, there are to be found brief descriptions in Mr. A. B. Wynne's memoir on the geology of Cutch,<sup>3</sup> but, as a rule, that author does not venture on any suggestion as to their origin, and in no case does he appeal to the particular causes to which I have been led to refer them.

### (1) The Subrecent Concrete.

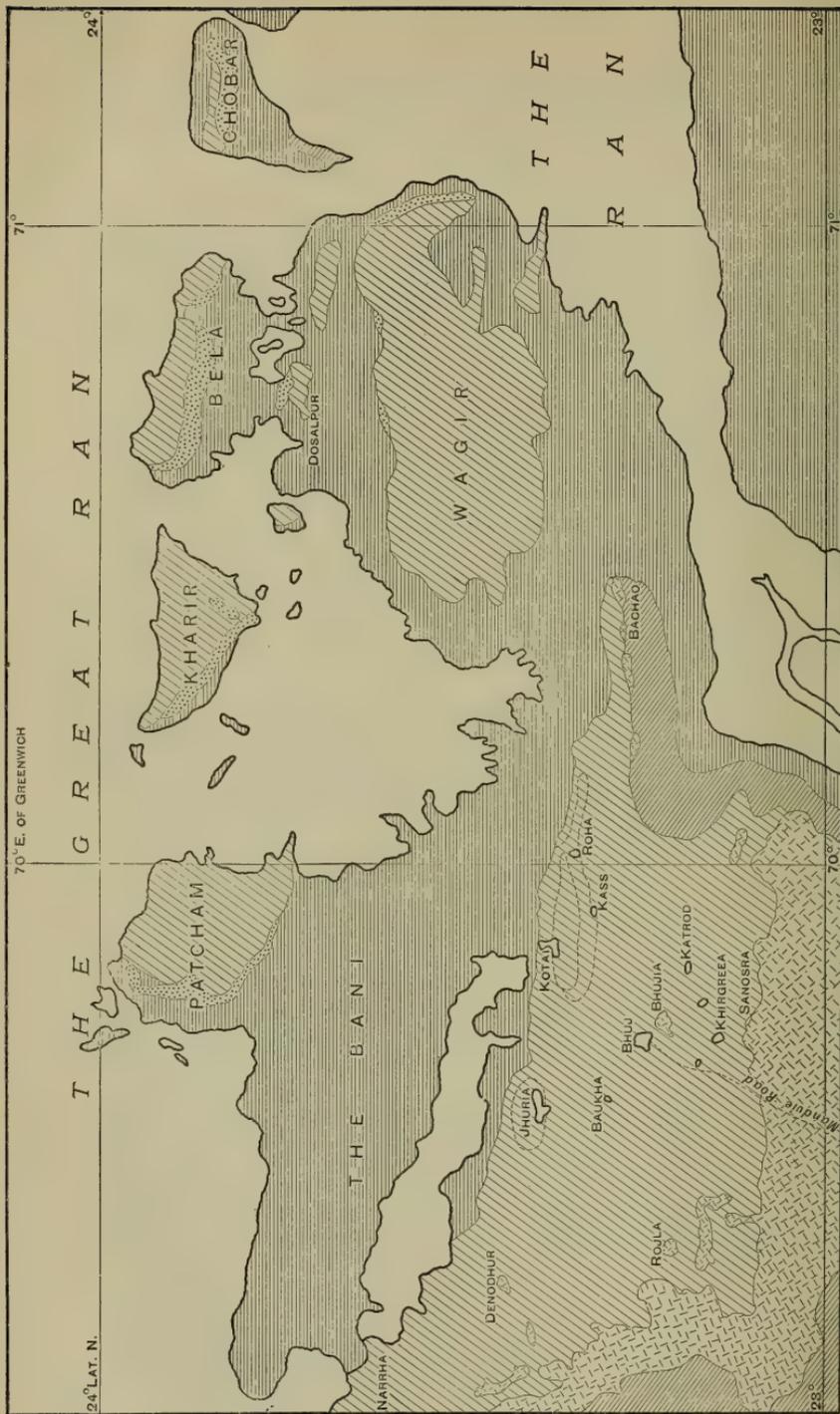
Under this name Mr. Wynne describes some remarkable deposits of which he writes as follows:—'Very generally distributed over the hilly country is the subrecent calcareous deposit already alluded to. The white sandstones of which it consists are sometimes sufficiently coherent to be used for building, and it is very commonly burnt for lime all over the province. No fossils have ever been found in it, but on some slabs from the deposit in Western Cutch tracks of crustacea or of annelids have been observed. It is not limited to a uniform level in its various situations, having been met with in the low ground at the foot of the hills bordering the Runn, as well as high in their glens. Its aspect is always very much the same, though its texture is varied, being sometimes conglomeratic or finely oolitic, and generally it presents some oblique lamination.'<sup>4</sup>

<sup>1</sup> [By the omission of that portion of the paper in which the quartzite-reefs and their mode of formation were discussed.]

<sup>2</sup> Throughout this memoir I use the word 'Jurassic' for all the rocks so coloured on Mr. Wynne's map, without prejudging the question as to how many of them may be, as some certainly are, of Neocomian age.

<sup>3</sup> Mem. Geol. Surv. India, vol. ix. pt. i. (1872).

<sup>4</sup> *Ibid.* p. 81.



[For the Survey spelling of some of the names on this Map, see text.]

This description, which is the fullest in the memoir, does not in any way indicate the author's view of their origin. Indeed he elsewhere says: 'The . . . subrecent deposits, except in their most superficial portions, contain no evidence as to the conditions under which they were accumulated.'<sup>1</sup>

Although in one sense it is true that they are very generally distributed, there are only ten definite localities where these deposits are sufficiently important to be noticed. Of these one is said to be of 'quartz-gravel,' and is thus, as will be seen, of a character different from the rest. There are also six other localities where I have noticed them, making in all fifteen to be considered, situated as follows:—1. The northern slopes of the Kala Dongar, in Patcham.<sup>2</sup> 2. The summit of the Gora Dongar, north of Andhou. 3. In the glens at a considerable elevation in Bela. 4. On the northern flanks of the Habo Hills, near Kotae. 5. Below Roha Hill. 6. High up on the Kas scarp. 7. On the south side of the Jurio Hills. 8. In the valleys of Varar Hill. 9. At Baukha, where it is quarried. 10. On Bhujia Hill. 11. At the base of Katrod Hill. 12. In the Katrod Hills between Ler and Jadura. 13. In a valley north-west of Godpur. 14. On the Mandvi road, where it is quarried. 15. At the base of the trap-escarpment at Khedoi. It will be observed that the deposits are all very local, and usually associated with some hill. They appear also to be absent or inconspicuous on the western side of Cutch. (See Map, opposite.)

If we examine now more closely their mode of occurrence, some remarkable peculiarities become obvious, which should be some guide as to their origin. Thus the Kala Dongar Hills<sup>3</sup> have a steep escarpment on their northern side, and the slopes below have usually a direction parallel to it, but near the western end there is a projection of high ground forming a kind of bay which opens on the west, and it is in the angle of this bay that the subrecent concrete is found. In the Gora Dongar, north of Andhou, a broad open valley is formed by a dome of Jurassic rocks, the eastern side of which is bounded by an escarpment of limestone rising towards the north. Near the summit the continuity of this escarpment is broken, and we find a narrow recess of which the mouth faces west. It is on the two flanks of this recess that the concrete occurs, occupying nearly the highest level in the neighbourhood, which, from the figures given on the Trigonometrical Survey map, must be some 560 feet above the level of the Ran. In the glens of Bela these deposits lie, as noted, at a high level. On the northern flanks of the Habo Hills the principal part lies on the southern slope of an outlying scarp, and reaches a height of 300 feet above the Ran. In

<sup>1</sup> Mem. Geol. Surv. India, vol. ix. pt. i. (1872) p. 85.

<sup>2</sup> The spelling of the names is in all cases that found on the Trigonometrical Survey Maps; but the local pronunciation, as given by Mr. Wynne's names, is often very different, unaccented *a* being pronounced as a short *u*, and *d*, *l*, and *r* being often interchangeable.

<sup>3</sup> The Kala Dongar Hills run along the northern half of Patcham, and the Gora Dongar Hills along the southern half.

the three localities south of the same hills the occurrence is very instructive. Here a long east-and-west valley is bounded on the north side by gently sloping surfaces, and on the other or south side by a long and very uniform escarpment. This, however, is broken at one place where the pass over the summit crosses, and shows a kind of notch in the outline, which is the only spot where the subrecent concrete occurs. It here reaches its highest elevation, being not more than 100 feet below the summit of the escarpment, and therefore about 700 feet above the level of the Ran. Towards the east the valley closes in, and we reach the watershed below some high hills. It is on the west side of this watershed that the greater part of these deposits of concrete occurs, while there is very little on the east (see fig. 10 in Mr. Wynne's memoir). On the south side of the Jhurio Hills there is a fairly continuous encircling scarp which faces north. The main drainage of the southern slopes of the inner hills escapes through a gorge in this scarp, which at one time was fairly broad, but is now nearly choked up by the concrete, while within the scarp we find the concrete spreading out as a thick white mantle over a square mile of the slopes beyond. Notwithstanding this, the outer slopes of the scarp, up to within a few hundred yards of the gorge, are quite bare, the solid rocks being everywhere visible. At Bhujia Hill the deposit is found in a semicircular valley which opens on the south. Between Ler and Jadura there is a long east-and-west valley, opening to the east, and this is almost entirely bare; but at one place a basaltic dyke crosses the valley like a wall, and on the west side of it the concrete is piled up in places to its summit. A similar phenomenon may be seen in the valley north-west of Godpur. Where the Mandvi road crosses the Charwar range, it traverses in one place a valley whose streams run west, and in this valley we find the concrete on the north side resting against the Jurassic prominences as seen near the Mandvi road. Farther east the locality Khedoi, where Mr. Wynne records this concrete, is situated in a semicircle eroded back from the general line of the trap-escarpment.

In structure these deposits are very uniform. Leaving out of consideration for the present the large stones derived from the nearest solid rocks, which they sometimes contain, they consist of fine particles very slightly agglutinated, so that a blow of the hammer shatters them to dust. Some southern varieties, however, are tougher, and are used for building, while on reaching the extreme north-east in Bela we find them scarcely consolidated at all. They are for the most part obliquely laminated, and in this case the slope of the laminae in the part of the deposit nearest to the solid rock is in the direction of that rock.

In composition the majority are mostly white sand, cemented only with calcareous matter. In the more southerly exposures there are calcareous particles also, but I have not seen any that are truly oolitic. The complete rounding of the particles gives the rock that appearance, especially in the deposit near Kotae, but on examination they appear to be organic fragments, and there are white specks

which consist of little-worn miliolines. These organisms belong, of course, to the deposit itself; but the concrete is in the habit of enclosing what it finds on the spot. Thus at Bhujia Hill it is full of the fragments of trap that have fallen from the summit; on the Kas scarp it encloses the little *Buliminus* which is now living in the district, and in Bela it is said to enclose human bones, though it is not stated definitely that the deposit there was undisturbed.

Such are the facts with which we have to deal in attempting to discover the origin of these curious deposits. Their constant association with hills, and their occurrence in the glens, might suggest at first that they are a rainwash, more or less transported by rapidly descending water, on account of their lamination. But this seems impossible. In some cases, no doubt, the solid rocks might yield the sand, but it would be ferruginous, not white, and such sandstone-rocks would yield very little calcareous matter. But in other cases there is no sand in the neighbourhood at all. Thus, in the Gora Dongar all the hills are of limestone, and the deposits are at the very summit. The same may be said of the deposit in the Jhurio Hills and in Bela, while the miliolines at Kotae cannot possibly be of local derivation. Moreover, the deposits lie on a great variety of rocks, and yet have an uniform character. We may therefore dismiss this explanation.

Another alternative is that they are marine deposits. This would involve a depression in quite recent times of 700 feet or more, and would in no way account for their peculiar local distribution, nor for their lamination. One might also expect marine shells when delicate *Bulimini* and tiny miliolines have been preserved. But greater than all other difficulties is that of their loose porous character. So far as my experience goes, no deposits that have been laid down in water are of similar character. The water invariably aids the particles in packing together at their closest, and with such materials as these they would form a solid rock.<sup>1</sup>

There remains, so far as I can see, but one other alternative, and that is that they are æolian in origin, and this will, I think, be found to account for all their peculiarities. It would need, however, a strong wind to raise sand up to 700 feet in one place and 560 feet in another, and carry the miliolines from the nearest sea. We must therefore enquire whether there are such winds in Cutch.

The Meteorological Office in Simla publishes every day a series of observations showing, amongst other things, the average rate per hour for the last 24 hours, and the direction of the wind at 8 A.M. We cannot gather from this what was the direction of the wind at other times, for if the direction has changed the time of the change is not recorded; but by assuming that the direction at 8 A.M. is the same as that for 12 hours before and 12 hours after, we may arrive

<sup>1</sup> Mr. Wynne (*op. cit.* p. 103) speaks of a small patch of littoral concrete full of shell-casts on the northern side of Patcham, about 20 feet above the Ran; but he does not classify this with the 'subrecent concrete,' which he says is unfossiliferous.

at a rough estimate of the average direction and speed. Taking the year 1895, and treating the records in this way, it appears that the air travels at Bhuj, in the various directions, at an average rate of  $10\frac{1}{2}$  miles per hour for the whole year. But at the end of this time, the air is not found to have returned upon itself. According to the records, a particle of air which travelled constantly with the wind would find itself at the end of the year 66,000 miles to the east and 9600 miles to the north of its initial position. These figures, of course, are merely indicative of general results, the meaning being that there is, on the whole, a constant passage of air in one direction, from a little to the south of west, at a rate of  $7\frac{2}{3}$  miles per hour.

We shall form, however, a better idea of the action and power of the wind by examining the records in detail. There were, in the first place, only 40 occasions in the year when there was any east in the wind at all, and the total velocity of such winds was only  $12\frac{1}{2}$  per cent. of that of the westerly winds. Again, for the greater part of the year the winds are not excessive, but out of the 140 days between April 25th and September 11th, no less than 90 days' gales are recorded, 7 of which are specially recorded as dust-storms. If now we confine ourselves to these dates of gale we find that the average velocity was 20 miles per hour, and the average direction about  $20^\circ$  south of west. The velocity exceeded in six cases 30 miles per hour. This is an average for 24 hours, and, as gales do not continue to have a constant velocity for so long, there must have been not infrequent times when the wind was moving at 40 miles per hour. The complete records for other years I have not been able to consult, but there is no reason to believe that 1895 had a maximum of wind, nor are we sure that the present winds as a whole are equal in intensity to those of some period of the past. We have, therefore, good reason to believe that there is adequate force available to do the work required.

Moreover, similar work is now being done, as witness the dust-storms for which Cutch is famous. As, however, the gales blow from the west, it is important to know what happens in that direction, and on consulting the Meteorological Reports above quoted we find that there were no fewer than 55 dust-storms recorded at Karachi during 1895, mostly under westerly winds, and in the other stations next north and north-east of Cutch 53 dust-storms and 53 dust-hazes, which latter may be taken to mean the transport of the finer particles of dust. It is obvious, therefore, that the passage of fine sand, etc., across the country is a widespread phenomenon.

We have evidence also that the sand thus carried travels with great velocity, for, as shown on p. 456 of the 2nd edition (1893) of Blanford & Medlicott's 'Geology of India,' there are in Sind two types of sandhills—one lying transverse to the prevailing winds and the other parallel to them, the direction here being about  $30^\circ$  south of west. Now it is only necessary to study the drifting of snow to see that, while comparatively gentle winds make transverse drift, the snow that is borne along tumultuously by the wind lies, when

the wind drops, in long straggling lines parallel to the course it has taken. These longitudinal sand-dunes, therefore, indicate a great velocity of wind in the desert north of the Ran, so that we are not surprised to learn that some of them, even without the aid of any inclined plane of solid rock below, are able to attain a height of 400 to 500 feet. That the same phenomena are found in Cutch itself may be gathered from the fact that in speaking of the sand-dunes along the southern coast Mr. Wynne says that they have a bearing of about  $20^{\circ}$  south of west,<sup>1</sup> which is exactly the average direction, as seen above, of the strongest winds. From personal observation I can only say that at Mandvi, after the close of the monsoon season, when the sea had calmed down enough for steamers to call, the wind was constantly blinding with sand and the pier was all buried in a dune. That large areas of Cutch are now covered with still drifting sand is pointed out by Mr. Wynne.<sup>2</sup>

The cause assigned being thus found adequate for the work, we must next enquire how far it explains the special phenomena noted above. As it was the distribution of the deposits that suggested the cause, this must be taken first. Now all the localities may be described as spots where a wind coming from the west or south would be stopped by an obstacle, or where a shelter-spot exists in a long scarp. Thus in the Kala Dongar the wind would be stopped by a projecting high land, below Roha Hill by a watershed, below Bhujia Hill by the hill itself, between Ler and Jadura, and also N.W. of Godpur, by projecting dykes, and on the Mandvi road by the Jurassic escarpments. On the other hand shelter-spots occur above Andhou on the Gora Dongar, on the flanks of Habo Hills, on the Kas scarp, on the south side of the Jhurio Hills, and at Khedoi on the trap-escarpment. In some other places, as along the north side of the Katrod Hills, and apparently at Baukha, the deposit makes no feature on the surface, being level with the ground, and thus probably fills originally existing hollows. To this latter category must also be assigned the various glens in which the deposits less abundantly occur.

It is thus seen that the horizontal distribution is exactly what it ought to be. In the vertical direction, where the deposits occur at high levels inland the main valleys are also high, so that there is not a great difference of level; but in the case of the Gora Dongar, where the deposits are 560 feet above the neighbouring Ran, there is a gradual rocky slope all the way, leading up to the hollow where they lie. In the case of the Kas scarp the west wind would be hemmed in by lofty hills into a gradually narrowing valley, so that its force would be greatly increased.

The lamination may at first sight seem a difficulty in the way of the proposed explanation, but it is not so. The principal dust-bearing gales are in the hot season, and these will leave a deposit of sand or calcareous dust upon any preexisting surface. Then the succeeding rains, which are not often so heavy in Cutch as to wash

<sup>1</sup> Mem. Geol. Surv. India, vol. ix. pt. i. (1872) p. 82.

<sup>2</sup> *Ibid.* p. 12.

such deposits away, will cement the particles together at once, as they do the flood-deposits along the riversides. Thus each lamina will represent a season's work. That the laminae should dip towards the rock on which the concrete rests, on the side nearest to the rock, is what we should expect in a wind-blown deposit. For when sand is blown against an obstacle it is thrown back again and the wind has to pass away on either side, so that in such places we always find an intervening valley between the mound and the obstacle, the surface of the mound thus sloping towards the obstacle.

The loose porous character of the deposits, as already pointed out, is against their aqueous origin, but is what we should expect in an æolian formation, only so far subjected to water that it has been rained upon. The uniformity of general character over a wide area, independently of the rock below, is thus fully accounted for. The more calcareous composition of the southern deposits is due to the fact that the materials here are mostly derived from the sea (hence the milioline also), while farther north the dust is reinforced by the breaking-up of the Jurassic sandstones. The enclosure of the local rocks and of the local *Buliminus* is quite natural, the dust finding its way into the interstices of whatever was lying on the ground.<sup>1</sup>

## (2) The Associated Boulder Beds.

These are not mentioned by Mr. Wynne, unless he refers to them in the passage quoted above, when he writes of the concrete that it is 'sometimes conglomeratic' (*op. cit.* p. 81). As no æolian deposit can be in itself conglomeratic, these boulder-beds require explanation.

I will first describe the three localities where I have observed these beds. The first is in the banks of a river running out from the Habo Hills at Fulae near Kotae, where the subrecent concrete has been above recorded. Here we find the following section (see fig. 1).

The bed of the river and about 4 to 6 feet of the vertical sides are composed of Oxfordian shales dipping at a very high angle. Their surface, except for the river-erosion, is nearly flat, and immediately on the top lies a 5-foot bed of rounded and subangular stones, from the size of a quarto book downwards, embedded in a fine loamy material without any stratification. The boulders lie irregularly jumbled together, with a tendency, however, for the long axes to lie horizontally, so that the deposit has very much the aspect of a boulder-clay. Over this comes 7 to 8 feet of false-bedded concrete, and then follows another boulder-bed 5 to 12 feet thick up to the top of the cliff, in which the boulders are smaller, about the usual size of coals in a scuttle. All the boulders, so far as observed, can be matched in the neighbouring hills. The stratification is approximately horizontal; but the boulders only commence some way down stream, away from the outer slopes of the hills

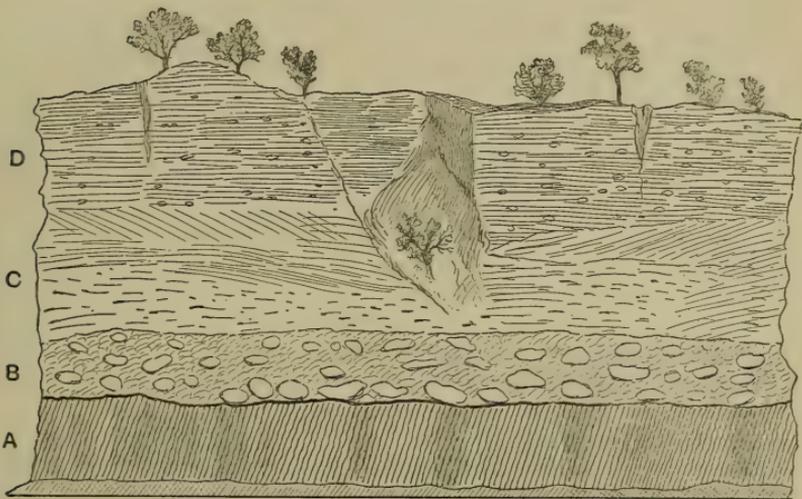
<sup>1</sup> If this be the true origin of the calcareous surface-deposits of Cutch, it is probably also the origin of the foraminiferous rock of Porbandar, which too is local and is backed by a range of felsite-hills on the north and east.

and below the spot where the *Miliola*-bearing concrete is seen resting directly on the Jurassic rocks.

The second locality is on the south side of the Jhurio Hills, in the concrete-filled gorge and beyond. The description of these deposits would be practically a repetition of the last—only the thicknesses are somewhat greater, and the bed-rock is not reached in the stream-bottom, where the boulders are seen in the sides.

The third locality is a more remarkable one, namely, that on the north side of the Kala Dongar in Patcham. It was here that the boulder-beds were first noticed and called loudly for some explanation. At this spot there are marked on the map of the Trigonometrical Survey two long projecting elevations running out at right angles from the Jurassic escarpment, where it is coated with the

Fig. 1.—Section on stream west of Kotae.



A = Oxfordian.  
B = Boulder-bed.

C = False-bedded concrete.  
D = Smaller-boulder-bed.

subrecent concrete. These no doubt were originally one, the end having been eroded along the dividing watercourse. Their length is  $\frac{9}{10}$  mile, the united breadth  $\frac{1}{2}$  mile, and their elevation (not marked on the map) is perhaps 100 to 150 feet above the plain. They have the general aspect of the tip-heaps of a cyclopean railway-embankment in course of construction. As seen weathered on the surface they are covered with large fragments of rock from  $\frac{1}{2}$  cwt. downwards, more or less rounded, but not scratched, and all to be apparently matched in the neighbouring Jurassic hills. Where a section is seen the matrix is rubbly, more or less tufaceous, and tough enough to form a cliff. At the base of the valley laterite is found, and the long mounds appear to rest upon it.

In the first two localities the stratification in alternate boulder- and non-boulder-bearing beds may be without discussion assigned to the action of the streams when they were depositing and not eroding, but in all three cases the difficulty is to account for the carriage of the large stones and their promiscuous heaping together. The principal agents that have been supposed to possess sufficient transporting power are ice, torrents, and sea-waves. In a place where the present range of temperature is between  $70^{\circ}$  and  $120^{\circ}$ , it is scarcely feasible to call in the aid of ice, and certainly sea-waves are out of the question. In the first two localities, where the boulder-beds fill up the bottom of valleys at the end of gorges leading out from lofty domes, the bottom beds may be fairly ascribed to the force of the water, with or without further aid; but those which overlie the soft concrete could scarcely, one would think, be borne along in so rapid a torrent that they could not even be sorted, without that torrent eroding the surface below.

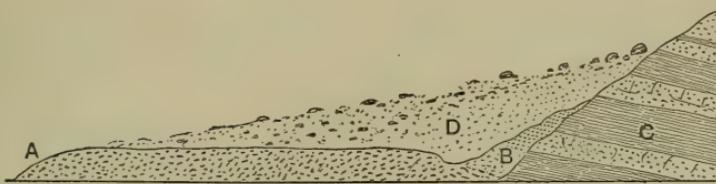
For the third locality, however, there seems no possibility of calling in the aid of a torrent, as there is no gathering-ground for the water. The whole history of the deposit must at the outside be confined within an area of  $1\frac{3}{4}$  square miles on which no longer line than  $2\frac{1}{2}$  miles can be drawn, with a maximum difference of elevation of 1150 feet. But the mounds point in the direction of the scarp only  $1\frac{1}{4}$  miles distant and whose highest point is only 640 feet above their surface, and for three-quarters of this distance the boulders occur. Nor do they fill up a valley, but form mounds on a flat surface. The only area whence the water could be obtained to form a torrent would thus be the slopes of the hills opposite the mounds, with an average fall of only 320 feet. This appears to me quite inadequate to produce a torrent sufficient to carry large stones over a nearly level surface for  $\frac{9}{10}$  mile. If we take the longer oblique line and greater height the difficulty is found to be not lessened but increased.

In the 29th volume (1873) of the Journal of this Society, p. 493, Dr. W. T. Blanford describes similar deposits on a far larger scale in Persia. Here there are boulder-ridges extending for 5 to 10 miles from the foot of the hills, with a fall of their upper surface in that distance of 1000 to 2000 feet. He says that the large fragments are commonest near places where small streams issue from the higher ranges, but the mounds increase in quantity towards the north and east, where the rainfall is less. I thought that this last fact would have led the author to enunciate the theory which I am about to expound, but he argues only that there must have been a greater rainfall in past times, and that lakes were thus produced—without saying how even then these boulders could have been transported for 5 to 10 miles with so little fall.

In Cutch these boulder-beds occur only where there are deposits of æolian origin, and in Persia they are most abundant where there is less rain and therefore presumably more dry sand to be blown about, so that some connexion between the two is suggested. It appears to me that, if we suppose that at one time there was more

blown sand present, so as to make a greater slope, the weathered blocks which fell on it from the hills would, under the influence of the rains saturating the sand below, slip gently forward along the slope, supported by the underlying sand, till they reached their farthest destination without sinking to the bottom. Thus the æolian deposits have served as the carrier (see fig. 2).

Fig. 2.—*Boulder-beds in the north of Patcham.*



A = Boulder-beds.

B = Subrecent concrete.

C = Jurassic rocks.

D = Hypothetical former extension of concrete with boulders.

This explanation is analogous to that made use of by Sir Wyville Thomson to account for the forward motion of the stone-river in the Falkland Islands,<sup>1</sup> and, if it be a true one, it is possible that it may in some cases account for deposits of loose blocks which have been referred to glacial action. There will always be antagonism between this process and the running away of the water in definite channels, and at last, when the slope of the æolian deposits became too low, the growth of the mounds would cease and the streams would begin to sensibly denude the deposits, and even cut channels in the bed-rock. It might be thought that all along the rain would wash the sand away and let the boulders drop, but we see that as a matter of fact it does not; besides which, the boulder itself protects the sand below it, as in the case of earth-pillars, and what is washed away above or below will be replaced by the next dust-storm.

### (3) Infratrappean Grits.

These deposits, lying as they do below the traps, cannot in strictness be called superficial, but it will be seen that they were probably of that character—that is, deposited on the land before the traps were poured on the top of them. This is what Mr. Wynne says of them:—‘These form a peculiar, soft, loosely granular, and obscurely stratified group of earthy and sandy rocks, largely composed of trappean materials . . . [they] are frequently associated with the base of the stratified traps, but they also occur in separate patches over the country, and sometimes at a considerable distance from them. They are clearly beneath the trap in some localities; in others they fill up hollows in the Jurassic beds, the planes of stratification not

<sup>1</sup> ‘Nature,’ vol. xv. (1876) p. 359.

being conformable even to the surfaces of the hollows which they occupy.<sup>1</sup>

In the detailed description, however, I can find only eight places where they are recorded, namely, west of Bhachau, Bhujia Hill, two places north of Katrod, Rhojla Hill, 'Khirgreea,' Rampur, and Lakhapur. The letter *d* by which they are indicated is also marked on the map at Sanosra and west of Mundhan. Of these, one of the localities obviously represents, by the description, some fault-rock only; that at Lakhapur and west of Mundhan is related to an intrusive mass of igneous rock which the deposits do not underlie, but merely abut against, so that they may possibly belong to the subrecent concrete. Of the deposit at Rampur, it is stated that 'it may have been the basal portion of the trap series.' It is not connected with the trap of the neighbourhood, and consists of 'scoriaceous lumps of trap mixed with sand, etc.,' so that this also may be an old variety of subrecent concrete. Of the other deposit north of Katrod, we read that beneath the trap is 'a hard bed of black ferruginous grit;' it therefore contains no trap-fragments, and may perhaps be dismissed as doubtful. There remain, therefore, five spots where peculiar deposits are actually found below the traps, with a sixth at Artara, unrecorded by Mr. Wynne, and in no case are they large enough to map.<sup>2</sup>

These six may also be grouped together, for those at Artara and at Sanosra are of the same character, and those at Khirgreea and Rhojla Hills are described as similar to that at Bhujia Hill. There are thus, with that west of Bhachau, three types of such deposits.

I have thought it necessary to thus analyse the evidence on account of the statement that they are 'largely composed of trappean materials,' which is difficult to understand if they are *infra-* and therefore presumably pre-trappean.

We will first examine the deposits on Bhujia Hill. The following are the only two sentences in Mr. Wynne's memoir which give us his description of them:—'To the eastward from beneath the highest summits, the basalt is underlaid by, and intercalated with, a rapidly increasing mass of soft, ? ashy, sandy rock of greenish-yellow colour, passing in places into a hard siliceous trappoid sandstone of coarse texture, containing fragments of woody plants. . . . From Bhoojia to the conical sandstone-hill on which Soorul temple stands and near the latter, the subtrappean grits are occasionally seen; the trappean blotches and interstitial portions weathered out into little cavities on the surface of the rock, which sometimes occupies pockets or wide fissure-like spaces in the underlying Jurassic beds.'<sup>3</sup> With this description I am in perfect agreement, but the accompanying map and section do not correspond to it, and I am at a loss to understand

<sup>1</sup> Mem. Geol. Surv. India, vol. ix. pt. i. (1872) p. 56.

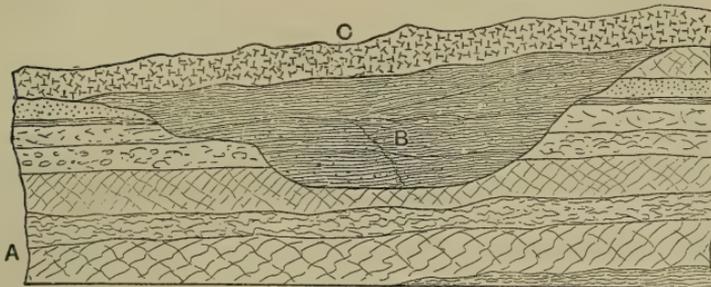
<sup>2</sup> On Mr. Wynne's map there is marked a considerable expanse of *infra-trappean* rocks in the neighbourhood of Bhachau, but there is evidently something wrong here. A distinct unexplained colour is inserted, and the details do not correspond with the text. Moreover, the deposits are not overlain by the traps.

<sup>3</sup> *Op. cit.* p. 168.

them. It will be seen that, beyond calling some of the rocks 'ashy' and 'trappoid' and speaking of 'trappean blotches,' the author speaks of nothing but grits. It is true that in some parts they are so much and so irregularly discoloured, apparently by infiltration, that they then bear a superficial resemblance to some rocks of volcanic origin, but their essentially gritty nature is unaltered.

The best exposure is on the northern slope of the hill, where the section shown in fig. 3 is seen. Here the bulk of the hill is com-

Fig. 3.—*Infratrappean grits at Bhujia Hill.*



A = Jurassic rocks.  
B = Infratrappean grits.

C = Trap.

posed of the Jurassic sandstones, which on the western side rise up and meet the capping of basalt. East of this junction there comes in rapidly a series of thick beds of very porous character, all of which are laminated, but not conformably to the base on which they lie. Their porous character gives them a very 'ashy' appearance—that is, the appearance of fine débris deposited in the open air; but they are almost entirely composed of sand-grains lying in a loose matrix of finer dust, and are so like some of the samples of subrecent concrete that without labels they can scarcely be distinguished in hand-specimens. The laminae run up to and meet the basalt above, and as we pass eastward the deposit becomes thinner till the basalt and Jurassic sandstones come together again. The other patches referred to as lying in the open hollows are generally darker and more compact, but they are still sandy. The isolation of this and similar deposits at Khirgrea and Rhojla; its occurrence in a shelter-spot on an old Jurassic hill; its porous character and sandy composition, all point to an æolian origin, representing as they do the same conditions as those represented by the subrecent concrete.

The second type of deposit at Sanosra, due south of Bhuj, and at Artara, between the Jurassic rocks and the trap, is simply a collection of stones derived from the rocks below, cemented by finer material, and lying in hollows over which the trap passes: that is to say, it is the surface-débris of the land on which the lava was poured out.

The section west of Bhachau, which appears to show a third type, I have not seen, as at the place where alone I was able, from lack of more time, to examine the trap, it was lying directly on the Jurassic rocks, showing, as pointed out by Mr. Wynne, the very local character of the subtrappean group. I therefore copy here the description in the memoir (p. 136) of the beds referred with a query to this group, as taken from Mr. Fedden's note-book :—

	Feet.
7. Brecciated and conglomeratic bed, lower part almost wholly of pink lava? .....	3
6. Yellow sandstone ... ..	2
5. Conglomeratic and concretionary bed of pale lavender and pink lava?, with large pebbles of hornstone, fragments of yellow clay, and fine sandstone .....	1-4
4. Hard, yellow and pinkish, gritty sandstone .....	5'

It will be seen from this description that the only ingredients which could not be derived from the Jurassic rocks are the fragments of 'pale lavender and pink lava?' I think it is very doubtful whether these are really volcanic fragments. Even Mr. Fedden queries them, and as the large area south of Bhachau, mapped as trap, is now seen in the cuttings of the new road to be entirely lateritic, it is more probable that the fragments here noted are also of that character. Perhaps, however, it comes to the same thing if laterite is derived from trap, in which case the basalt of Bhachau must be one of the later flows. The stratification also of these deposits indicates the agency of water, so that we may perhaps sum up as follows :—

The subtrappean rocks are all superficial deposits on the pre-trappean land-surface, those at Artara and Sanosra being the ordinary results of weathering: those at Bhachau, the washing-down of similar debris onto a lower, water-covered level; and those of Bhujia Hill, etc., æolian drift.

Taking this last in connexion with the subrecent concrete, we have thus a record of the constancy of the meteorological conditions in Cutch, from recent times as far back as the Cretaceous epoch.

#### (4) The Laterite.

The deposits hitherto dealt with are on a small scale and more or less peculiar to Cutch, but those which remain to be discussed are widely distributed in this part of India.

The various deposits which in different parts of India have gone by the name of laterite are, with exceptions, superficial in origin. As, however, the term has been so widely applied that the only definition which will cover all the varieties is that it is a very ferruginous rock of peculiar character, it follows that the rocks included under this definition may be of many origins and of many ages. All the laterites of Cutch are classed and mapped by Mr. Wynne as 'sub-Nummulitic,' so that they stand, with those of

the Nerbudda valley near Surat, as the only laterites which lie below well-defined marine deposits.

That there are lateritic beds below and associated with the Nummulitic Series in Cutch admits of no dispute; but those whose age can thus be proved all lie on the south side of the trap-escarpment and rest immediately on the trap itself, where there can be little doubt that the lower red earthy varieties are the products of decomposition *in situ*. It is with an entirely distinct area that I am concerned, where the laterite is separated from the trap by miles of intervening Jurassic rocks and Ran, and is overlain by nothing but alluvium. That these also are sub-Nummulitic depends on the assumption that all the lateritic deposits in a province as large as Cutch must necessarily be of the same age—an assumption which does not appear to me to be warranted.

The superficial group of laterite is found only on the southern and western margins of the Ran islands and along the northern border (and eastern also according to Mr. Wynne) of Wagir. In the course of this range it is found lying on various members of the Jurassic series. In the north of Patcham it lies on the oldest, in the north of Wagir on the youngest, and on intervening members at other places.

This distribution indicates, I think, a later age than the Nummulitic rocks, for these latter rest upon the decomposition-products of the trap, which do not require long to form, and they nowhere extend to the Jurassic rocks, as they surely must have done, if these had been already denuded to any great extent. Whereas, before these laterites were produced, not only must the lowest Jurassics have been exposed by denudation, but the general contour of the country must have been not far different from what it is at present. The only indication of age that I can quote is that they underlie the boulder-beds in Patcham.

The laterite here is a sort of gravelly deposit, the pieces being of fantastic shapes with a crinkly surface. They are dark red or black in colour, and consist of concretionary and stringy ferruginous matter, more or less closely sprinkled with sand-grains. The several pieces often interosculate into a vacuous spongy mass, in which case the rock so closely resembles some of the higher members of the Jurassic series as to be undistinguishable in hand-specimens. In certain well-defined spots, the surface of the ground is covered with small, irregularly-shaped, and obviously detrital agates, sometimes white and sometimes tinged yellow and red. These ferruginous beds are frequently seen to overlies well-stratified, soft, white sandstones and earthy beds, which are tinged with pink and purple by the infiltration from the laterite, as seen by the stalactitic form of the coloured parts (see fig. 1, p. 69 of Mr. Wynne's memoir).

Deposits of this kind are mostly found at levels relatively low, as compared with the surrounding Jurassics, and they seem to be limited to a level lower than about 120 feet above the Ran. They are only found inland at spots which would become lakes if the water-level were restored to that height.

From the preceding observations we may safely conclude that

- (i) This laterite and its associates were formed in water.
- (ii) They are not the result of the decomposition of any rock *in situ*.
- (iii) They are detrital in origin.
- (iv) They were formed at a time when the surface of the country was not very different from what it is at the present day, but when the water-level was 120 feet or more higher than now.

As to the source of the detritus, the materials of the sandstones, etc., might easily be procured from the higher Jurassic rocks, and the iron of the laterite itself could be found abundantly in the same beds or in the lower Jurassics—though possibly not in a state suited for solution. But we cannot derive the agates thence, and agates and iron probably came together. Agates are abundant in certain of the lower flows of trap, and to such rocks we must look for the source of the laterite. Now, as the ‘stratified traps’ are flows without pipes, and in the Jurassic area to the north of them there are several pipes without flows, it has been natural to connect the one with the other; and if the southern traps were emitted from these pipes, there must have been flows also to the north. Here, however, is a sharp anticlinal visibly bringing in the higher Jurassics, so that the relics of such flows would now be hidden beneath the Ran; and it is from the degradation of these flows that we may best seek the source of the laterites. This would account for their occurrence on the north side, but not on the south side of the inner Ran.

In the absence of any organic remains, it is impossible to say whether they are marine or lacustrine deposits. Their resemblance to the higher Jurassic rocks which have associated plant-beds points to the latter, in which case we may call in the aid of vegetation, as suggested by McGee and by Mallet; but as there are other deposits which have a similar distribution, and yet contain remains of apparently marine shells, and as moreover a depression is easier to imagine than a barrier, the former becomes at least equally probable.

#### (5) The Alluvium and Ran.

The area marked as alluvium on Mr. Wynne’s map is a very large one. It occupies no less than 800 square miles. A large portion of it, however, lies along the southern margin of the province, overlying fossiliferous Tertiary rocks, and it is to this portion that I think Mr. Wynne’s description must especially apply, when he says that ‘it is the result of the degradation of the local rocks, consisting largely of materials derived from the Tertiary beds, frequently mingled with travelled fragments brought by rivers from the hills.’ On this part of the alluvial area I have nothing to say, but of those parts which are in relation to the Jurassic rocks the above is scarcely a suitable description. In these I have found no evidence that the materials are specially of local origin or of Tertiary derivation, and no travelled fragments have been any-

where seen by me. The history, in fact, of these portions must be somewhat exceptional and instructive.

The alluvium comes into relation with the Jurassic rocks (except in the lateritic and a few other, possibly marine, patches of similar age, which have contributed no recognizable elements to it) in the broad flat area which joins the mainland of Cutch, north of Bhachau, to Wagir, continues round the western and northern sides of that district and unites it to Bela, skirts the south-western sides of the islands of Kharir and Patcham, and forms patches here and there along the northern coast of Cutch proper. With the deposits of this area must be classed about 650 square miles of lower-lying land, still occasionally flooded, known as the Bani, which lies in the middle of the area between the mainland and Patcham; and the deposits on the floor of the Ran, which may be divided into the inner Ran, south of the islands, and the outer or Great Ran, north of them. All these areas pass insensibly into each other, being merely distinguished by the relative heights of an undulating surface above the general level of the sea.

In the area mapped as alluvium there are parts which become muddy in the rains, and these pass gradually into Ran; but a larger portion is sandy soil, which soon becomes dry, including vast tracts where the sand is all loose and where no amount of rain can remain for an hour on the surface.

The characteristic deposit of the Bani is a very fine micaceous silt, and the surface is dotted over with groups of trees which stand round the margins of artificial tanks, or near the wells which are known to be abundant here. The surface of the Ran, in the wet season, is everywhere covered with the slimiest of muds, on which the camels can scarce maintain a foothold; but this is probably underlain by a firmer, perhaps sandier deposit, as below the first two or three inches the ground is firm and may be easily traversed while covered with water.

Before attempting the history of this strange area, attention must be drawn to the further features which may help to elucidate it. One of the most important of these is the aspect of the Ran where the alluvial deposits are absent. It has been shown long ago by Dr. Blanford<sup>1</sup> that both the Ran and the sandy desert on the north of it may be reasonably concluded to have been formerly occupied by the sea, and the latter to have been since more or less choked by blown sand. Mr. Wynne<sup>2</sup> quotes the numerous statements that have been made that the Ran was navigable and provided with various ports within the period covered by native traditions, though, in describing the Kharir cliffs (p. 106), he appears to be doubtful of the geological evidences. In one place in Patcham (*op. cit.* p. 27) he quotes a deposit with 'marine shells nearly 20 feet above the Runn' as 'traces of this old sea'; but elsewhere he states that these 'shells' are casts and may be 'very new Tertiary.' They are therefore no evidence

<sup>1</sup> Journ. Asiat. Soc. Bengal, vol. xlv. pt. ii. (1876) p. 86.

<sup>2</sup> Mem. Geol. Surv. India, vol. ix. pt. i. (1872) p. 26.

that before the sea left in comparatively recent times it stood 20 feet higher than the present surface of the Ran.

Standing by the edge of the Great Ran, on the northern shore of Patcham, Kharir, or Bela, one might fancy oneself looking over flats which have just been deserted by the tide. Save for the absence of the scraps of sea-wrack and the greater firmness of the mud, there is little to distinguish the appearance from that which might be seen along the coast of Brittany and Normandy between St. Malo and Mont St.-Michel. Here, too, are the clean-swept foreshore, the low cliffs on its landward margin,<sup>1</sup> the broken tumbled masses on the slopes, and the frowning scarps above, all recalling the aspect, though wilder in type, of the Undercliff of the Isle of Wight, where the lie of the strata also is the same as it is here. But, since the formation of the laterites and other minor deposits, there is no evidence that the sea has stood at a higher level than when it washed the low cliffs that now edge the Ran.

Why then has the sea departed, as it were yesterday, and left its bed to be dried up by the sun? Two explanations are possible: either the sea has been dammed out of the area by deposits on its surface, or the land has relatively risen. If the former were the sole explanation, the level of the borders of the Ran would still be uniform. But, according to the figures on the Trigonometrical Survey maps, it would require a depression of about 30 feet to bring the sea-water to the edge of the inner Ran along the northern shores of the mainland, whereas on the edge of the eastern side of Kharir it would require no more than 5 or 6 feet. The land therefore must have risen unequally, which is not an improbable counterpoise to the depression that has taken place over the Sindree basin.

But that deposits also have taken place and that the peculiarities of the Ran result from these will, I think, appear probable from what follows:—In the first place the Ran proper is extraordinarily level; this may be seen from the figures on the Trigonometrical Survey map, where, over wide areas, we find 1, 3, 5, 4, 8, 11, 12 feet, showing a difference of very few feet, and I have myself ridden over 10 miles of it in the rainy season with water on it almost all the way of never greater depth than the knees of the coolies. Yet, beneath the lofty scarps of Patcham and Kharir with their broken undercliff, the shores are swept quite clean, and the débris must have been carried away when these shores were in the making, and when the small cliffs, sometimes 30 feet in height, were being worn away. Now, in such a shallow sea as the Ran would be if the water returned no waves or currents could originate, nor would the harbours, of which tradition tells, be restored, and I conclude that in former times the bottom must have been deeper and have been since filled up.

<sup>1</sup> I do not specially quote in this connexion the curiously worn cliff figured by Mr. Wynne as 'sea-cliff,' because it happens to be composed of irregularly hardened sandstone which even inland weathers into similar fantastic shapes, as near Mundhan.

Again, the Ran is traversed by no rivers; some of those from the northern side of the mainland reach its edge, and the projecting higher alluvial land in their neighbourhood may be taken to represent their deltas. But the great majority begin and end without reaching it. At the lower end they break up into constantly subdividing branches, which dwindle away to nothing. In this latter case all the water which runs even during the heaviest rains is absorbed by the porous soil, and sinks in before it can reach the Ran; in the former case the quantity and velocity of the water are too great for this to be entirely effected, and the remaining water spreads out in a broad sheet on the surface, and so helps to flood the Ran. In the higher parts of the Bani, and in the alluvial area west of Wagir, there are a number of short nullahs, which begin and end in the middle of a flat surface, and sometimes follow each other in a broken line. They indicate the course of underground streams, the roofs of which have fallen in and exposed them in places. Such an underground course must be due to the original valley being filled in with loose and porous material, into which the water sinks. This it may be actually seen to do with great rapidity. I have known 4 inches of rain to fall in the course of a night, and the rivers to be torrential in the morning, but before evening to be all dry again; and one can watch the water sinking in on the bottom of their beds.

The nature and origin of these deposits can also, I think, be determined. With regard to the Bani, as it is separated both from the mainland (except at the two extremities) and from Patcham by an area of Ran, it can hardly be 'a bank formed . . . by the discharge of the Cutch streams,' while the fine micaceous silt of which it is composed could scarcely be obtained from thence. Its composition and the power which it has of retaining water indicate rather that it is a relic of the sea-bottom, corresponding perhaps to a higher level of the submerged bed-rocks. The highest part of the alluvial area between Wagir and the mainland lies in the direct line of an anticlinal which passes from one area to the other, and is doubtless continuous. This may have originated the higher level here.

With these two exceptions, the whole of the features may be put down to the wind and rain. The importance of the former may be argued from the wide sheets of loose sand that lie to the west of Wagir and on the south-western edges of the islands. These are comparatively scarce on the margin of the mainland, and entirely absent along the northern island-coasts: that is, these sands occur where the prevailing strong winds will be stopped and are lacking on the lee of high grounds. Moreover, the rivers that reach the Ran on the north side of the mainland (with one exception where there is higher Tertiary ground to the west) are deflected to the west by the accumulation of sand, etc., on the east; hence the distribution of this sand may be assigned to the wind. Nevertheless, much of the fine dust that is carried by the gales must fall *en route* and beyond the lee of the hills. Here, however, it will be covered by water during the rains, and the finer particles will come

to the surface and form the mud, but the ground as a whole will be fairly firm.

The amount of deposit from rivers must be comparatively, if not very, small. What they bring down must for the most part be left behind when the water sinks in, and then be distributed by the wind. It is only when the rainfall is very heavy, 2 or more inches in 24 hours, that it can escape on to the more impervious Ran, and in this case it will make a comparatively small part of what has fallen there directly from the clouds, for the depth of water there is so immediately sensitive to the fall of rain that it cannot depend for its principal supply on remote sources. The only material that the rivers succeed in bringing directly to the Ran will be of the finest mud, and it will be uniformly spread.

From these causes I believe that the whole depression of the Ran has become shallower, just as the Sindree basin to the east has become more contracted, and in course of time all the surface will become 'alluvial' soil. There are no satisfactory means of ascertaining whether such a diminution of the Ran is now actually in progress, the older maps being only approximate. Nevertheless all comparisons tend in that direction. Thus the western end of the Bani is marked on the old maps as surrounded by Ran, but as joining the mainland by a wide area now under cultivation in the new. The northern edge of the Bani is also separated by Ran from Patcham in the old maps, but I found little or no mud there after 4 inches of rain, while the Ran on the south side was under water. Mr. Wynne mentions places where the Ran is very soft, as between Patcham and Kharir; but it is reported as perfectly passable now. Mr. Wynne also goes out of his way to correct the statement that Bela is joined by alluvium to Wagir; and though no doubt in the dry season, when both are barren, it may be difficult to distinguish alluvium from Ran, I can scarcely think he could have done this, if so many trees had then found root in it as are now to be seen growing in the area. But on the lee of the hills there is certainly no change—the cliffs of Kharir are to-day exactly as he drew them.

It will be seen from the above that the main geological agent in Cutch is now, and for long ages past has been, the wind. The heat of the sun expands the surface-rocks, the rain disintegrates them; but the wind denudes, cleaning them in one place and covering them in another. If this be so, we can scarcely admit with Mr. Wynne that 'the question of how the alluvial plains of India were formed is not cleared up by anything observed in Cutch'; but we may adopt, with a slight modification, another statement of his, that to whatever causes the great plains of Sind and the Ran are due the coast-plains of Western India may also be ascribed. These, indeed, with their wide distribution of thick unstratified deposits of fine soil over areas inaccessible to rivers, and their abundance of kunkur gathered from disseminated calcareous particles, seemed to bespeak an æolian origin, even before a visit to Cutch rendered the activity of the wind in this quarter of the globe an observable fact. Doubtless much of the material is brought down in the first instance

by the Indus and other rivers, but from the neighbourhood of their mouths this has been blown about in an easterly and northerly direction, and has thus afforded a constantly renewed source of fresh fertility.

#### DISCUSSION.

Dr. W. T. BLANFORD expressed his satisfaction that some of the peculiar formations of Western India had been examined by an English geologist of experience. Indian geologists appreciated the value of independent criticism. Taking the deposits, which varied greatly in geological age, in the order in which they had been treated by the Author, the speaker said that his own knowledge of the subrecent concrete, the Miliolite of Dr. Carter, was small, but the fact that the rock was said to be so calcareous that it was in many places burnt into lime was difficult to reconcile with a purely æolian origin. The deposits described by the Author as boulder-beds doubtless belonged to the subaerial accumulations so enormously developed in Central Asia, Cutch being on the edge of the great dry region in which disintegration is in excess of transporting power, and the rainfall only suffices to carry detritus, including boulders, to a lower level, not to wash it down to the sea. With the so-called quartzite-reefs the speaker was unacquainted. The infratrappean grits were possibly part of a similar formation occurring at the base of the Deccan traps throughout the Nerbudda valley and elsewhere, and known as Lameta Beds. These often contained small rolled quartz-pebbles. The laterites of Cutch were principally of Eocene age, but it was very probable that lateritic deposits of more recent origin also occurred. Some of the peculiarities of the rock were that the two principal types—that supposed to be due, in part at least, to alteration of other rocks, and that which was unquestionably of detrital origin—were remarkably similar, and that the rock is easily reconsolidated from the detritus of an earlier laterite. The Ran must formerly have been much deeper, and according to tradition was navigable; but as late as the time of Alexander the Great the Indus flowed into the western part, and silt must have been deposited with great rapidity. Even now silt-laden water from the sea is driven up the channels on both sides of Cutch in the south-west monsoon, and from this and other causes deposits take place constantly. The high elevation of the Ran alluvium near the land-area of Cutch may be due to rainwash.

Mr. E. A. MARTIN regretted that he could not quite understand how the quartzite-reefs could have been formed in the manner suggested. It seemed to him that if this pseudo-stratified rock were formed by the action of the prevalent south-westerly winds, there would not be that thinning-out arrangement on the north-east and east which the diagram appeared to show. If, however, the occasional winds from the opposite direction were also to be taken into account, the force of the theory was more apparent, and then the prevalence of one wind more than another would be shown by the north-easterly trend of the apices of the beds where the dovetailing took place.

Mr. LAMPLUGH was glad that the Author had called attention to the phenomena of dry erosion, as he had touched the fringe of an important subject which had not yet received its due recognition from the geologists of this country. Over vast areas in various parts of the world the surface-drainage was at present insufficient to remove the detritus brought down the slopes by atmospheric agencies, and the waste-material consequently accumulated around the hills and partially buried them. The speaker had been greatly impressed by these phenomena in Arizona, where, as Dr. Blanford had just remarked with respect to another region, the rocky ground often stood out like islands above the vast spreads of loose material.

Mr. VAUGHAN CORNISH said that the power of the winds in the locality dealt with in Mr. Blake's paper was undoubtedly adequate to carry sand to the situations described; and that, with regard to the calcareous nature of the subrecent concrete which Dr. Blanford regarded as a difficulty, the blown sand of Hale in Cornwall might be cited in support of the Author's views. This was largely composed of shell-fragments, and he had observed that it was more mobile under the action of wind than the ordinary quartz-sand of the sea-shore. Referring to the boulder-beds, he said that the travel of boulders presented some curious features, which he was at present examining. For example, a large boulder travelled badly on fine sand because the sand was readily displaced, and the boulder sank. Conversely, little pebbles travelled with difficulty over a bed of boulders because they were caught in the hollows, and with difficulty surmounted the humps of the rough surface. The best condition for the transport of large boulders, and of blocks or slabs of stone, appeared to be when the bed was composed of pebbles large enough to form a hard floor, but not so large as to allow the boulder to catch in the pits of the surface. It seemed, therefore, that to every size of boulder there should correspond a particular size of pebbles over which the boulder could be transported with the minimum effort.

The AUTHOR, in replying, remarked that the infratrappean grits were, in his view, of entirely local origin and not to be compared, except in point of time, with any deposits elsewhere; while the presence of a single quartz-pebble in them would be destructive of his account of their origin. He admitted that there were laterites in Cutch of Eocene age. Those examined by him, however, which were far more widely spread, gave no indication of age, but were certainly neither derived from the rocks on which they rested nor produced by the reconstruction of such as were so derived. He very much doubted the usual statement that water was driven on to the Ran from the Indus-mouth by the monsoon. He had ridden over part of it towards the end of an exceptionally rainy season, and there was less water on it than the rain that had fallen. Moreover, the strongest winds in Cutch blow in the hot season, but the Ran is not flooded till the rain has fallen. He agreed with Mr. Lamplugh that the study of the phenomena of denudation by aerial agencies in the tropics was a new experience for an English geologist.

19. COAL: *a NEW EXPLANATION of its FORMATION; or the PHENOMENA of a NEW FOSSIL PLANT considered with reference to the ORIGIN, COMPOSITION, and FORMATION of COAL-BEDS.* By W. S. GRESLEY, Esq., F.G.S. (Read February 24th, 1897.)

[Abstract.]

THE Author argues that the brilliant black laminæ in coal and materials similar to those that form these laminæ, which are found in earthy coals, shales, and clays, point to the former existence of an aquatic plant, having the general shape of the modern *Platycerium alcicorne*, which grew in place. He believes that much coal was formed by this aquatic 'coal-plant,' which grew amongst the mechanical sediments and the débris of the terrestrial vegetation that accumulated on the floors of sheets of water.<sup>1</sup>

#### DISCUSSION.

Mr. MARR spoke.

<sup>1</sup> [Specimens, and a series of large diagrams in illustration of his paper, were exhibited by the Author when the paper was read. By an unfortunate oversight, the mention of this exhibit was omitted in the Proceedings, p. xciii. —ED.]

20. *On the NATURE and ORIGIN of the RAUENTHAL SERPENTINE.*  
By MISS CATHERINE A. RAISIN, B.Sc. (Communicated by  
Prof. T. G. BONNEY, D.Sc., LL.D., F.R.S., V.P.G.S. Read  
February 24th, 1897.)

## [PLATES XVI. &amp; XVII.]

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## INTRODUCTION.

THE general origin of the rock serpentine as a metamorphosed peridotite is now usually admitted since the investigations, which have become classic, of Profs. Tschermak, Sandberger, Bonney, and other later observers. An exception is made, however, for certain masses by some geologists. One of the most interesting of these is that described as the Rauenthal serpentine. The hypothesis which was put forward by Weigand in 1875<sup>1</sup> was that this did not originate from a peridotite, that it is indeed a metamorphosed rock, but is the result of the metamorphosis of part of a gneiss. The investigation of the genesis of this rock thus has a bearing on an important general petrological question. Exception was taken to the conclusions of Herr Weigand by Prof. Bonney from the study of microscopic slices.<sup>2</sup> In consequence of this, on my return journey from Switzerland in 1895, I turned aside to visit the Rauenthal, and brought back a few specimens, with the idea that they might be useful in the further examination of the question which I hoped that Prof. Bonney intended to make. As, however, it was not possible for him to visit the locality himself for some time, he asked me to continue the investigation, which I did in the summer of 1896, spending about a fortnight in the district. From the numerous specimens then collected, many slides have been prepared, the inferences from which seem entirely to corroborate the views formed on the spot. I have been able fortunately to submit to Prof. Bonney the specimens and slides, and he kindly allows me to state that he agrees with the main conclusions from them as here put forward. For all the help of various kinds given to me by him in this investigation, and for the facilities most generously afforded for examining his numerous specimens of serpentines from other localities, I would here offer my best thanks.

<sup>1</sup> Jahrb. d. k.-k. Geol. Reichsanstalt, vol. xxv. (1875) p. 183; or Tschermak, Min. & Petr. Mitth. 1875.

<sup>2</sup> Geol. Mag. 1887, p. 65.

## I. INVESTIGATION IN THE FIELD.

The outcrop of the Rauenthal serpentine is marked on the French map published in 1837<sup>1</sup> as a somewhat lenticular patch rather more than 1200 metres from S.W. to N.E. by 200 metres from N.W. to S.E., occurring between 'granulitic gneiss' below and 'granulite' above. A small tributary streamlet<sup>2</sup> seemed to be fed by springs near the upper limit of the serpentine, to fall over a steep rocky bed westward in a course roughly determined by the northern boundary of the outcrop, although cutting through one corner, then to continue to the north and north-west into the Rauenthal stream. The steep hillside is often covered with grass or a close growth of ferns or flowers, and much of it is richly wooded. Fortunately several paths, and, still better, the road leading beyond the Schaafhaus, give easy access to the area which had to be examined.

## (1) Relation of the Gneiss.

In the description given by Herr Weigand he speaks of a passage from the gneiss into serpentine. Therefore I first examined, as far as possible, the adjacent parts of the former rock. From the side of the path near the lower course of the above-mentioned streamlet, and from a quarry close by, I took several specimens, one being a well-marked hornblendic band, but the outcrop here by the path is small, and distant  $\frac{1}{4}$  mile, or perhaps more, from the serpentine.<sup>3</sup> The gneiss is well exhibited on the north of the stream along the road (marked *a*, Pl. XVI.) cut by it in small cliffs at intervals. This rock is foliated and banded; it sometimes has layers resembling a reddish granitoid rock, and others a foliated diorite; it is usually micaceous, and often has bands especially rich in biotite. The general dip here and in other masses is to the west of N. or to N.W., often at a considerable angle ( $45^{\circ}$  to  $60^{\circ}$ ). The gneiss, of perfectly normal type, is seen in a large mass at about 240 feet<sup>4</sup> north of the stream, and in a small mass, apparently *in situ*, about 40 feet north of the stream, or 120 feet north of the serpentine. The actual junction south of the stream is obscured, but a sloping cliff of muddy talus extending about 80 feet seems to be full of fragments, some of slickensided schistose rock, such as often results from disturbance along a junction. Serpentine forms next a mass of tumbled big blocks, and then occurs as fragments in the earthy bank for about 470 feet. Beyond this the gneiss apparently extends

<sup>1</sup> Published by the Dépôt de la Guerre: scale  $\frac{1}{80,000}$ . This map is rather later in date than that of Köchlin-Schlumberger to which Weigand refers.

<sup>2</sup> Marked with more accuracy on the German contour-map of the district, not coloured geologically (scale  $\frac{1}{25,000}$ ). This is the streamlet along which scattered blocks can be traced, as described by Weigand.

<sup>3</sup> At this distance, or farther from the serpentine, some of the rock is a hornblende-schist or foliated diorite.

<sup>4</sup> All measurements are very rough calculations, made from pacing the distances.

until we reach the granite rather north of the next tributary streamlet.

Here, then, was the first result which I had not anticipated. No clean continuous sections were found, showing a passage from gneiss to serpentine, nor even from gneiss to an almost pure amphibolite, and the gneiss seemed to be everywhere of normal type. Herr Weigand states in regard to this rock that the hornblende 'gradually gains the upper hand, and thus the rock passes through amphibole-gneiss to a pure hornblende-rock, which, however, retains the stratified aspect of the gneiss.'<sup>1</sup> Whatever changes have occurred in the local exposures (and it would have been perhaps a help if Herr Weigand had given a more detailed description of the parts which he examined in the field), it is difficult to see where the sections can have been which showed the passage stated.<sup>2</sup> As just previously recorded, in the gneiss almost adjacent to the serpentine (along the strike of the foliation) hornblende can hardly be found, all the dark layers which have been cut for the microscope proving to be micaceous; and although the mineral occurs in the valley below<sup>3</sup> and in an occasional band on the lower slopes, this seems but slender proof of a gradual passage to an almost pure amphibolite.

## (2) The Serpentine and its Relation to the Amphibolite.

The crags on the grassy and tree-covered slope consist mainly of serpentine *in situ*, and these were next examined.<sup>4</sup> They generally face steeply towards the west or valley-side, and are often large masses extending 40 or 80 or even 150 feet in length, and to a height of 20 feet or more. Among them examples are soon noticed of the amphibolite and of various minerals associated with the serpentine, such as may have been found in blocks by the brook and roadstones in the valley. The chief rock is serpentine, often including, as described by Herr Weigand, a peculiar chlorite. That mineral is definitely orientated, the rock is generally platy, and its appearance on transverse and parallel surfaces is in marked contrast. On the former it looks dull, of a rather varied dark green colour, with slightly marked lines along the edges of the planes rich in chlorite. If these are exposed in step-like fashion, or if the rock be broken parallel with them, the chlorite gives a silvery glitter to the

<sup>1</sup> 'Diese letztere [Hornblende] gewinnt nach und nach die Oberhand und führt so das Gestein durch Amphibolgneiss in reinen Hornblendefels über, der aber die Schichtung des Gneisses beibehält.' *Op. cit.* p. 197.

<sup>2</sup> The road has been made somewhat recently, I believe, and doubtless changes have occurred in the sections exposed. But along the smaller (and, I should think, older) path above (marked  $\beta$ ) gneiss is seen, in small outcrops towards its southern end, and in bosses north of the stream, and these are of the same normal type.

<sup>3</sup> This would be rather distant, as previously stated, unless more crags occur which I failed to see, because they were hidden by the trees on the lower slopes of the hill, and even these would not be close at hand.

<sup>4</sup> One or generally several specimens were taken from each mass. I believe that I examined every crag, but I certainly left no important section untouched.

surface. In the serpentine, enstatite-crystals are sometimes seen on the cross-fracture planes, where the chlorite is not visible. This platy serpentine rich in chlorite can be recognized in many crags (see Pl. XVI). In a second form of the rock the chlorite-flakes are much smaller, more crowded, and not orientated. A third variety is massive, dark rich greenish, not platy, without chlorite, but containing well-developed enstatite or bronzite. Fourthly, the serpentine may be mottled with greenish patches, or a similar material may form streaks and laminæ sometimes about  $\frac{1}{8}$  inch thick; these patches and layers are somewhat indefinite in outline.

Lastly, the peculiar amphibolite occurs in places. Where typically developed it is a beautiful mass of glittering, silvery, pale-greenish crystal-flakes, orientated so as to produce an appearance of foliation. Examples of it are found in at least five of the serpentine-crags. It often forms layers an inch or two in thickness embedded in normal serpentine, and the two rocks are clearly distinguishable in the crags, although the boundary is not always sharply defined, a certain indentation or mixing being visible on close examination.

*Olivine-serpentine and 'amphibolite' (Raumenthal) in thin section.*



The darker-spotted parts represent the distinctly green portions of the slice, which are composed of olivine-serpentine. The paler areas represent the 'amphibolite,' which is colourless. ( $\times 2\frac{1}{2}$ )

Thus the amphibolite-bands occur not along the limit of the serpentine, but included in it (see Pl. XVI). Again, the loose blocks in the valley show the amphibolite and serpentine in similar relations. Another mode of association, however, is exhibited in certain loose boulders, and in one crag near to and south of the streamlet.

Here angular and irregular patches of serpentine and amphibolite are intermingled, giving the appearance of a breccia.

This occurrence of hornblendic bands and patches presumably represents the passage of the amphibolite into the serpentine described by Weigand. In these separate bands or streaks, as also in the chlorite-bearing serpentine, a parallelism and orientation of the minerals is usually found, and Herr Weigand speaks of this as if only one cause could bring it about. He states that the serpentine 'lies in the amphibolite and in the strike of the gneiss; it is thus a metamorphosed banded complex of hornblende-rock.'<sup>1</sup> As will be seen from my description, the fact is rather that the amphibolite lies in the serpentine. A parallelism, however, with the foliation of the gneiss could be explained on the theory of the igneous nature of the serpentine and amphibolite. If a magma were intruded into a mass of gneiss, the intrusion would be likely to follow the structure-planes of that rock and to show a general parallelism with them.

### (3) General Character of the Gneiss.

Finally, we must notice one general difficulty. The gneiss near the Rauenthal, as I have stated, is exposed, and exhibits a normal character over a large area. Occasionally (I should say rarely) it has bands rich in hornblende or composed of that mineral. In these, the hornblende, as Weigand describes it, is the dark greenish variety usually found in the gneiss. The rock shows the usual alternations of layers: quartz and felspar, biotite and felspar, or quartz, felspar and mica. Yet, on Weigand's hypothesis, the gneiss becomes in one isolated locality a mass of almost pure hornblende. Nowhere else in the neighbourhood is this representation found.<sup>2</sup> The only evidence for it here consists, first, in a comparatively few isolated layers of the peculiar pale amphibolite (and no hypothesis is put forward to explain the supposed bleaching and modification of the dark mineral of the gneiss), and secondly, in a mass of serpentine into which the hornblende-rock is supposed to be changed. Of the latter alteration we may at least say that it is neither usual nor easily explained. Even if there were a passage, of which I can see no evidence, this general difficulty should have been discussed.

On Herr Weigand's measurements, the serpentine-outcrop is 30 paces broad,<sup>3</sup> and the occurrence of hornblendic bands a few inches in thickness would not afford much material for so massive a development.

<sup>1</sup> 'Er liegt im Amphibolit und im Streichen des Gneisses; er ist also ein umgewandelter Schichtencomplex von Hornblendefels.' (*Op. cit.* p. 203.)

<sup>2</sup> As Prof. Bonney points out, a large mass of either pure hornblende or pure pyroxene is certainly very rare. (*Geol. Mag.* 1887, p. 66.)

<sup>3</sup> 'Die grösste Breite des Serpentinanstehenden ist ungefähr 30 Schritte' (*op. cit.* p. 197). My own very rough measurements up the steep, covered, boulder-strewn slope gave the outcrop as about 260 yards broad. This agrees better with the map, but would increase the difficulty discussed above.

## (4) Relation to the Granite.

I traced the serpentine upward, passing off it in many places until satisfied that I was on the granite and that no serpentine occurred higher up, since fallen blocks were not to be seen. The two rocks approach most closely along the upper course of the streamlet already noticed, especially below the road ( $\delta$ ) and above the little path ( $\gamma$ ). Clambering here for a few paces at several spots over ground covered with soil and plants, I passed in each case from the serpentine to fragments and blocks, mostly moss-covered, consisting of granite, but I found no actual junction.

## II. MICROSCOPIC DETAILS.

In the slides of rocks from the Rauenthal certain distinct minerals can be identified. For very many details about these we may briefly recapitulate the descriptions given in previous articles by Herr Weigand<sup>1</sup> and by Prof. Bonney.<sup>2</sup>

## (1) Chlorite.

The shining folia visible macroscopically exhibit water-clear sections which extinguish straight, and are identified as chlorite often enclosing extruded iron oxide. In addition, they sometimes contain spindle-shaped crystals of another mineral\*,<sup>3</sup> probably aggregates of perofskite, or perhaps in some cases an impure sphene. The chlorite is associated either with the ordinary serpentine or with the amphibolite (Pl. XVII. figs. 4, 6). At places it shows in polarized light transverse bands like strain-shadows, so that it imitates the twinning of felspar, and has almost a microcline appearance.<sup>4</sup>

## (2) Hornblende.

Clearly-marked hornblende occurs within the serpentine, in longitudinal sections with rectilinear structure and in transverse sections with lattice-work, both often showing partial alteration, as described by the above-named authors<sup>5</sup> (Pl. XVII. fig. 2). There would be no difference of opinion that such crystals are undergoing serpentinization, and that these serpentinized parts retain the characteristic indication of hornblende-cleavages. The transverse serpentinized bars may be somewhat sinuous and fringed, but the longitudinal planes extend as straight boundaries to the kernels of

<sup>1</sup> 'Die Serpentine der Vogesen,' Jahrb. d. k.-k. Geol. Reichsanstalt, vol. xxv. (1875) p. 197.

<sup>2</sup> 'Note on Specimens of the Rauenthal Serpentine,' Geol. Mag 1887, pp. 65-70.

<sup>3</sup> The \* indicates a mineral not mentioned in Weigand's description.

<sup>4</sup> I found in another slide a twinning somewhat resembling the above in a mineral which I believe to be pyroxenic, probably enstatite. Cf. T. G. Bonney, Geol. Mag. 1887, pp. 239, 240.

<sup>5</sup> *Id. ibid.*; also J. J. H. Teall, 'British Petrography,' 1888, p. 111.

hornblende. Although the original hornblende-crystal has in the process of change become ragged and often irregularly replaced at the exterior by the mineral serpentine or actinolite, yet in a few cases a definite external form can be traced. An idiomorphic character would not have been generally acquired in the original crystallization of hornblende any more than in other hornblendic peridotites or in the amphibolite of this area. The pale hornblende which forms the last-named rock consists of crystals often bounded by straight sides (generally prism-faces) and exhibiting perfect cleavages, but with ragged ends (Pl. XVII. figs. 4 & 5). Most of the mineral is fresh, but occasionally it is broken up into an aggregate partly serpentinous, partly actinolic, which begins in tooth-like projections penetrating into the hornblende.

### (3) Enstatite.\*

This mineral can be identified by various characters. It exhibits close parallel structure, with straight extinction, appears streaked at least partially with serpentine, and includes, along the structure-planes, minute tubular enclosures, or some clustered brownish crystals, probably perofskite. The enstatite is undergoing serpentinization and is similar in its characters to that which Weigand describes as forming the major part of the Starckenbach mass, which, partly from this fact, he infers to have an origin different from that of the Rauenthal rock.

### (4) Augite.\*

Augite occurs in one slide, although it is in a layer of amphibolite, and thus, according to Weigand's hypothesis, not within an original peridotite. The augite is colourless, fresh-looking, with well-developed cleavages seen both in transverse and in longitudinal sections. The crystals are partly idiomorphic (with planes 110, 101, 011) and are enclosed within the hornblende.

### (5) Iron Oxide.

Secondary minerals occur, one of the most important of which is iron oxide, commonly associated, as Weigand describes, with the chlorite, and often in the form of hæmatite. Other minute grains of iron oxide will be noticed shortly as occurring in the serpentine.

### (6) Perofskite.\*

In connexion with the serpentinized enstatite, small crystals occur (about .025 mm. or less in diameter), sometimes in definite cubes or octahedra, but usually clustered. The mineral is clear, colourless, with a high refraction and rough-looking surface, and it has whitish or silvery lustre by reflected light. It apparently is perofskite.

The mineral within the chlorite (as mentioned above) has very

similar characters. In the enstatite and in some of the hornblende, gummy-brown granular aggregates are clustered along the cleavage-planes, and perhaps cause a filmy appearance over intervening parts. This also is not unlike perovskite, possibly a second form of that mineral or a stage in its development, but it is in grains too minute to be tested. The serpentinized hornblende in one slide encloses small rhomboidal nets, which might be clusters of a similar mineral, but have rather the appearance of skeleton crystals.

### (7) Rutile.\*

In one slide of serpentine (from a loose specimen) many of the rounded kernels within the network exhibit acicular brownish crystals. They are long, but too slender to be examined in detail. Their colour and form suggest a dark impure rutile, and geniculate twins, although not common, occur. The needles are developed usually towards the border of the kernel and point in a more or less radial direction. The late Prof. Carvell Lewis, as will be seen from his forthcoming work on the Genesis and Matrix of the Diamond, identified rutile in serpentinized olivine.

### (8) Serpentine.

The mineral serpentine in these slides shows varietal forms. It may consist of tubular or fibrous elements, sometimes parallel in bundles, sometimes in a matted mass. This serpentine is greenish, gives yellowish polarization-colours, and extinguishes parallel to the direction of the fibres, which thus are probably chrysotile. Secondly, the serpentine may show the lattice-work or the somewhat rectangular network surrounding angular kernels as described by Weigand and others.<sup>1</sup> Thirdly, it exhibits kernels of less regular form which, although they sometimes have rectilinear boundaries, are generally rather more rounded. Several differences between the last two cases are often recognizable. These are for the most part best seen with high powers in ordinary light by the use of a diaphragm. The parts with angular network are paler in colour; the net gives an effect of higher refractive power than the mesh, appearing like a green rim bordering a colourless area. With crossed nicols, the rim gives low colours and extinguishes nearly or quite parallel, while the enclosed parallelogram is faintly or not at all doubly refracting. The part with rounded grains is greener, the kernels are paler, more highly refracting and prominent than the intervening bands; where they have a greener tint we may sometimes be looking at a band cut parallel to its plane. In either case the nucleus has no effect on polarized light, but the borders give the usual low colours of serpentine.

Thus, as was pointed out by Prof. Bonney, there are two type-

<sup>1</sup> This form of serpentine results from the alteration of hornblende, transverse sections of that mineral showing a lattice-structure, and longitudinal sections exhibiting the prism-cleavages crossed roughly at right angles by less regular lines.

forms of the serpentine, differing in several characteristics. Whether the fibrous part is connected always with one or the other form is difficult to decide, but it seems certainly in some cases related to the more irregular part, since it can be traced originating either as patches or as a fringe beginning to extend into the kernels. A fourth form of serpentine with close parallel structure has been noticed as the result of change in enstatite.<sup>1</sup>

Although these observations thus agree with many of the details given by Herr Weigand, yet some additions to his list are required, and the presence of enstatite especially has an important bearing, as it is distinctly a mineral associated with peridotites or allied rocks.<sup>2</sup>

### III. CONTROVERSIAL QUESTIONS.

The characters must now be considered in which, according to Weigand, the Rauenthal serpentine is unlike the other masses, and by reason of which, according to the same authority, a different origin must be attributed to it.

#### (1) Accessory Minerals.

It is stated that 'the accessory minerals so characteristic of olivine-serpentine here are wholly wanting.'<sup>3</sup> It is true that picotite does not appear to be present, but it is absent from other serpentines, and other accessories characteristic of peridotites (perofskite, rutile, enstatite) are found here.

#### (2) Iron Oxide.

A second important distinction is stated to be that, 'for one thing, strings of iron are entirely wanting, and in consequence differently coloured zones.'<sup>3</sup> The serpentine in many parts has a rather uniform greenish tint, contains only minute specks of ferrite scattered within the kernels, or aggregated in minutely granular strings along the

<sup>1</sup> A kind of spherulitic serpentine also occurs within certain veins which cross the amphibolite. In one of these, a very pale greenish or yellowish isotropic ground exhibits, with polarized light, scattered stars which consist of fibres, evidently serpentine or chrysotile. A vein in another slide shows, in polarized light, a diaper-like pattern with black crosses similar to that of spherulitic rhyolites. At other parts wedge-shaped crystallites grow in tufts from the sides of the vein. I noticed a slight development of a similar structure in a serpentine from the Lizard.

<sup>2</sup> The views of Herr Weigand as to the Rauenthal serpentine are quoted by Mr. Teall ('Brit. Petrogr.' 1888, pp. 110-112). We find it stated, however, in another place, in connexion with Sandberger's results, that 'one or more of the minerals, chromite, picotite, pleonaste, chrome-diopside, enstatite, and pyrope, are found in the typical peridotites. The occurrence of any of these minerals in a serpentine is therefore strong evidence that it has been produced by the alteration of an olivine-rock.' (*Op. cit.* p. 108.)

<sup>3</sup> B. Weigand, *op. cit.* p. 201:—'Ferner fehlen hier im Hornblendeserpentin gänzlich die für den Olivinserpentin so charakteristischen accessorischen Mineralien. . . . Einmal fehlen hier gänzlich Erzschnüre und damit verschieden gefärbte Zonen.'

intervening bands, as indicated by Prof. Bonney.<sup>1</sup> Thus, even apart from the chlorite, iron oxide is not entirely absent<sup>2</sup>; but it is true that the strongly marked black or brownish network of many serpentines is not here visible.

I fail to see, however, that this fact leads to any other inference than that the original olivine was not a ferriferous variety. It would seem that the original magma was one rather poor in iron, for the colourless hornblende probably owes its peculiarity to a want of the ferruginous constituent.<sup>3</sup> Much of the iron oxide which is present in the serpentine seems to be associated with the peculiar chlorite. In certain specimens, however, the olivine-serpentine is more ferruginous, with grains of magnetite (?) and so much scattered minute opacite that it gives a bluish tinge to parts of the slide; but here no chlorite is exhibited.

### (3) Microscopic Structure of the Serpentine.

(1) After the accurate description of the serpentinization of hornblende, Herr Weigand goes on to state that 'the same arrangement is found everywhere in the serpentine,'<sup>4</sup> and that it 'follows without doubt that . . . a serpentine . . . in great masses . . . has originated from amphibolite.'<sup>5</sup> It was shown by Prof. Bonney that the serpentine had not so universal and uniform a character, and that the major part of it can be distinguished from the serpentinized crystals of hornblende.<sup>6</sup> We cannot ignore the differences which certainly exist, which Weigand himself to a certain extent recognizes from his words the 'larger rounded parts.'<sup>7</sup> This phrase alone suggests two differences; others have now been added; and the true explanation seems to be that the part with 'larger rounded' kernels is the result of the serpentinization of an olivine-mass (Pl. XVII. figs. 2, 6). In fact the hornblende occurs as an accessory in an original peridotite, just as that mineral is found in parts of the Lizard serpentine.

(2) We are told that this Rauenthal serpentine does not exhibit the 'irregular network' which is characteristic of olivine-serpentines.<sup>8</sup> Here there is a network—it is only therefore a question of

<sup>1</sup> Geol. Mag. 1887, p. 68.

<sup>2</sup> Indeed this appears to be acknowledged, although the statements do not seem perfectly clear:—'Die Analyse zeigt also in Übereinstimmung mit der mikroskopischen Untersuchung eine grosse Menge Eisen.' (B. Weigand, *op. cit.* p. 200.)

<sup>3</sup> The analysis of the amphibolite given by Weigand includes  $\text{Fe}_2\text{O}_3$  4.649,  $\text{FeO}$  2.107, but the analysis was obtained, we are told, from material which included some serpentine.

<sup>4</sup> 'Zeigt sich dieselbe gitter- und fensterformige Structur über das ganze Gesichtsfeld verbreitet' (*op. cit.* p. 198); ' . . . man im Serpentine selbst mittelst des polarisirten Lichtes den Chrysotil in derselben Anordnung überall wiederfindet wie in der Hornblende . . . ' (*op. cit.* p. 200).

<sup>5</sup> 'Geht unzweifelhaft hervor, dass . . . wir also hier einen in grossen Massen auftretenden Serpentin haben, der aus Amphibolit entstanden ist' (*op. cit.* pp. 200–201).

<sup>6</sup> Geol. Mag. 1887, p. 68.

<sup>7</sup> *Op. cit.* p. 197: 'grössere rundliche Partien.'

<sup>8</sup> B. Weigand, *op. cit.* p. 201.

the regularity in its arrangement. If there be any difference in this respect from other serpentines, there is a far greater difference between it and the changed hornblende.<sup>1</sup> Moreover, in the olivine of various rocks there is a marked difference in the amount of internal structure which it exhibits. While in many crystals no cleavage and only irregular cracks are seen, in others straight parallel lines of cleavage are well developed. Perhaps no better examples of the latter character can be found than in certain eulysites.<sup>2</sup> If, however, we examine for comparison other serpentines, we find in many that bands equally straight form the network; and the structure of the strings in the Rauenthal rock was stated by Prof. Bonney to 'agree perfectly with those in a normal serpentine.'<sup>3</sup>

(3) In the mode of development of the chrysotile, Herr Weigand sees evidence of the hornblendic origin of the rock. The fibrous aggregates, however, in some of these slides have not a regular arrangement, but form a matted mass. Again in other rocks, parallel sets of fibres can be found beginning to develop from olivine. Thus the fibrous serpentine may in some cases have originated by alteration of hornblende, but there seems no evidence that this derivation is a necessity; on the contrary, a development from olivine can sometimes be traced.

#### (4) Specific Gravity and Hardness.

I have tested four specimens of the Rauenthal serpentine, and have found in them a specific gravity varying between 2.53 and 2.62. These results differ little from those given by the Bonhomme (an admitted olivine-serpentine),<sup>4</sup> or by similar rock elsewhere.<sup>5</sup> A specimen of the amphibolite (chosen to include as little foreign admixture as possible) gave a specific gravity of 2.828.

Herr Weigand further states that the serpentine of the Rauenthal is distinguished by its greater softness (*op. cit.* p. 197). I find that the degree of hardness in certain type-specimens is nearly 4.0, while that given by the 'olivine-serpentine' (Bonhomme) is only about 3.0.

<sup>1</sup> The serpentine-bands in the network of an olivine-serpentine seem broader than those along the cleavages in hornblende. Further, in those slides which are cut across the structure-planes of the rock, a fair proportion of the recognizable hornblende-crystals show the lattice-structure. But if there be any marked regularity in the serpentine, the parallelepipeds mentioned by Weigand are mostly rectangular.

<sup>2</sup> It becomes a question whether the mode of origin of such a rock may not be related to the more perfect cleavage of the mineral. If we could connect the cause of this structure with the flow of the original magma of the eulysite (a character which seems indicated in the rock), this might have an interesting significance in connexion with structures in the Rauenthal serpentine.

<sup>3</sup> *Geol. Mag.* 1887, p. 68.

<sup>4</sup> Herr Weigand gives 2.713 for the freshest rock and 2.609 for one more decomposed (*op. cit.* p. 189). I obtained, for 3 specimens, 2.671, 2.622, and 2.52 respectively; but the rock is so variable that differences are easily explained.

<sup>5</sup> For Lizard serpentines, see *Quart. Journ. Geol. Soc.* vol. xlvii. (1891) p. 466. Sp. gr. from 2.545 to 2.77 for 8 specimens; one other had a sp. gr. of 2.85.

## (5) Presence of Chlorite.

One striking characteristic, macroscopic and microscopic, in the serpentine is the presence of the 'silvery scales,' or the peculiar chlorite which is stated to be one of the essential points of distinction. It depends, however, on the explanation to be given of the formation of this chlorite whether it can be used as an argument for the origin of the rock from an amphibolite. It was not at first easy to come to a conclusion on this point, and the question is partly connected with the relation of the rocks in chemical composition.

In the supposed chemical change of a hornblende-rock to serpentine, Weigand points out that there would be a decrease of silica, a proportional increase of magnesia, and the loss of most of the lime and alumina. For the latter changes he offers two suggestions: the first, that these constituent substances induced the formation of the chlorite; the second, that possibly layers might occur of poorly aluminous hornblende.<sup>1</sup> Of the latter suggestion it is only necessary to say that it would be as easy to demand a belief in layers of completely non-aluminous olivine, which would grant the whole contention. The former suggestion seems necessary to Herr Weigand's hypothesis, and demands the acceptance of his view that the chlorite is a new formation. But all that can be established on this point is that the extrusion of iron oxide and the general affinities of the mineral suggest its being in a secondary or modified condition. The sharp contours, however, and the general parallelism of the flakes, to both of which facts Weigand refers as evidence,<sup>2</sup> are surely no arguments for his view. If the chlorite were developed in the alteration of hornblende to serpentine (using up the spare alumina and possibly lime),<sup>3</sup> it would be likely to occur interlocking with the serpentine, of an irregular form, and with a less uniform arrangement, as is usually the case in secondary minerals. Further, we find the chlorite sharply limited at its junction with a hornblende-crystal, or completely embedded in an enstatite, as if it represented an original constituent of the rock; in other words, it seems to be the modification of a mineral with a definite form. Although I had considered in the field the question of its development, and even had tried to trace a connexion with more than one occurrence of a mica, I owe to Prof. Bonney the suggestion of what I believe to be the correct view, reconciling seemingly conflicting appearances—that the chlorite probably is the result of change of a mica akin to biotite; if so, the original rock must have been related to a mica-peridotite. If the mica, as is probable, was a somewhat ferruginous variety, then, where it is deficient, the presence of a more ferruginous olivine may be explained. If

<sup>1</sup> *Op. cit.* p. 202.

<sup>2</sup> *Ibid.*

<sup>3</sup> Herr Weigand notices the difficulty of the lime, and makes the significant remark that if not found in true chlorite in such large proportions it is not unusual in the mica group (*op. cit.* p. 200).

the magma there was poor in the lime,<sup>1</sup> alumina, and alkali necessary to form mica, the iron may have been used up in the composition of the olivine.

If, however, anyone maintains that the evidence just given for an original mica is not conclusive, difficulties still remain in Weigand's hypothesis. First, patches of the chlorite occur in the Rauenthal rock in parts where no hornblende can be traced, or flakes are isolated within olivine-serpentine (Pl. XVII. fig. 3). Secondly, in rock from other localities there is serpentinized hornblende, but no indication of chlorite. Thirdly, the chlorite occurs in Rauenthal specimens embedded among completely fresh hornblende, and thus apparently not associated with its serpentinization. Fourthly, so far from the presence of the chlorite differentiating, as we are told, this serpentine from serpentines which have originated from olivine-rocks, the mineral in question is found in the latter, as Prof. Bonney has pointed out,<sup>2</sup> and as will be described shortly in several examples.

Finally, specimens were found from Bonhomme, and afterwards from the Rauenthal, in which a transition from mica to a pale chlorite could be traced; and, as will be shown later, the structure of the platy serpentine would agree with this origin of the chlorite.

#### (6) Chemical Changes.

If the chlorite be thus a modification of an original mica, the process for the formation of the serpentine from a hornblende-rock would be quite inexplicable. The alumina (and possibly other constituents of the supposed hornblende), if not used in the formation of the chlorite, would have, as Weigand suggests, no place. In addition to this, however, the difficulty in the supposed chemical changes of the disappearance of silica or accession of magnesia is not touched. Thus, if we assume the quantity of the most persistent substance, alumina, to be represented by unity, and take the amounts of the other components as ratios to that in the amphibolite and in the bulk serpentine<sup>3</sup> respectively, we find how very different is the composition of the supposed original rock and of that into which it is stated to change. Thus

the silica would be 27.305 : 1 instead of 6.898 : 1 ;  
 the magnesia ,, 26.623 : 1 ,, 3.902 : 1.<sup>4</sup>

<sup>1</sup> Since it was shown that the chlorite contained lime, then the original mica should have been a variety which included that constituent. The amount of lime, however, in the bulk analysis is slightly greater than would be explained by the quantity in the chlorite. The presence of perovskite might partly account for this.

<sup>2</sup> Quart. Journ. Geol. Soc. vol. xlvii. (1891) p. 466.

<sup>3</sup> That this serpentine represents a normal average specimen may be seen by combining the analyses of the chlorite and of dissolved serpentine on the estimate that the chlorite forms roughly about  $\frac{1}{4}$  or  $\frac{1}{5}$  of the bulk of the rock, when a composition is obtained very near that of the bulk analysis.

<sup>4</sup> Or compare the calculation given by Prof. Bonney, Geol. Mag. 1887, p. 67, and note.

Although it may not be possible to show the fate of the surplus silica,<sup>1</sup> this does not offer much difficulty if only a small amount of hornblende has been really transformed. In all cases of serpentinization such a change takes place, but is not evident microscopically; and in the case of sundry hemithrenes, where there is distinct evidence of serpentine having formed from malacolite, no visible silica can be detected.

We conclude then, in regard to the Rauenthal rock, that serpentinization occurs of occasional hornblende-crystals, and of some enstatite, but that the greater part is to be attributed to the serpentinization of an olivine-rock, and that the probable origin of the chlorite is a modification of a mica.

### (7) Structural Characters.

The structural characteristics of the mass suggest some further explanations. With regard to the amphibolite, Herr Weigand has described its peculiar foliated appearance. If the hypothesis put forward by him could not be accepted, there yet seemed a possibility that the rock might represent parts of the adjacent gneiss in contact with an igneous mass and modified by it. Indeed, my first examination of the locality suggested the possibility that one rock might have been included and partially melted down by an intruding magma, as has been proved to be the case in parts of Cornwall<sup>2</sup>; but the idea was clearly negatived by further evidence in the field and afterwards by that obtained by the microscope.

The amphibolite of the Rauenthal (with a foliated appearance) forms actual streaks or layers (sometimes a few inches thick) within the serpentine. Under the microscope these are seen to consist chiefly of characteristic and unaltered hornblende. But at parts of the serpentine itself the thin dull-greenish streaks ( $\frac{1}{8}$  inch thick) previously mentioned are composed of similar hornblende, which, however, is partially serpentinized. The chlorite-flakes usually form thin layers, which help to give a platy habit to the rock—one of its distinctive characteristics (Pl. XVII. fig. 6). All these structures, so far as my observations went, have a general parallelism.<sup>3</sup>

In the different layers, however, streaks of other composition occur; thus, in an amphibolite-band, we find strings of serpentine or occasional chlorite, sometimes in fair abundance (see fig. on p. 249 & Pl. XVII. fig. 4). And the various minerals are not confined to special layers. Chlorite occurs, as Weigand states, scattered without orientation; the serpentine sometimes has a patchy look, and is dark green mottled with pale green—owing to an irregular mixing of serpentinized hornblende. As already stated, enstatite can be

<sup>1</sup> Is it possible that the brownish, somewhat amorphous-looking substance, found at places, could be opaline in its nature?

<sup>2</sup> Quart. Journ. Geol. Soc. vol. xlvii. (1891) p. 471.

<sup>3</sup> This seems to be in a direction roughly parallel with the boundary of the outcropping serpentine; but the observations on this point were taken in bad weather, and must be further tested for confirmation.

recognized in the serpentine, and augite occurs in one part of the amphibolite.

There seems only one possible explanation—since the hypothesis of a modified gneiss is not alone improbable from *a priori* reasons, but also is contradicted by field evidence and by microscopic structure—namely, that the serpentine has been derived from a peridotite, *i. e.* from an igneous rock. The interlamination of the amphibolite, its boundary ‘not sharply marked off’ (as was described by Weigand), the ill-defined hornblendic patches and streaks, all point to gradations from the peridotite to the amphibolite. Similar variability also is shown in the amount and arrangement of the chlorite, and in the distribution of enstatite. Thus the evidence suggests that the original magma was somewhat variable (as often is the case, especially in magmas of a basic character),<sup>1</sup> and that the rock formed from it was sometimes an olivine-enstatite rock (saxonite), sometimes a hornblende-peridotite, or a mica-peridotite, or even a hornblende.

The parallelism of the structures has, however, to be explained, and it may be due to the same cause which has developed in many igneous rocks and complexes a fluidal banding or orientation. The mica-flakes would then lie in the direction of the flow, causing a platiness, possibly afterwards further developed by contraction, and the hornblende-crystals would exhibit a similar orientation. The arrangement of the chlorite, and the related platy structure of the rock, would be very difficult to explain on Weigand’s hypothesis as to the origin of that mineral. It is impossible to appeal to pressure as a cause; the whole rock, as shown in both the serpentine and the amphibolite, evidently is generally unmodified by any such mechanical force.

At places, rather ill-defined large patches of serpentine and of amphibolite are found, as if a brecciation had occurred, and the distinction between the two rocks here and at other places is macroscopically so evident that it suggests the possibility of magmas somewhat different in age. The gradations and intermixing, however, make it probable that this distinction originated by differentiation of a single magma, but whether at a comparatively late epoch after the intrusion had commenced, or whether earlier, it does not seem possible to prove. Only at the greater depths, separation by specific gravity on Soret’s principle might have acted, causing the less dense part of the magma, which solidified as amphibolite, to separate from the heavier part; and the fragmental appearance just mentioned might then be due to a kind of flow-brecciation. This pseudo-breccia is found in one or two crags towards the north-western border of the serpentine massif. In this direction the amphibolite appears to be more developed, not because it is due to metamorphosis of the gneiss (since serpentized hornblendic patches and streaks occur, almost to the

<sup>1</sup> Cf. J. W. Judd, Quart. Journ. Geol. Soc. vol. xli. (1885) pp. 358, 390, where a peridotite is shown to pass gradually into a picrite or other minor varieties, and even into gabbro or dolerite.

opposite border of the outcrop), but possibly because it formed here the lighter upper part of the mass, like a kind of scum.

Thus I believe that the structural and mineralogical characters of the Rauenthal serpentine can all be explained by the intrusion of an original peridotite-magma<sup>1</sup> somewhat variable in its composition, and that they do not require the hypothesis of an origin different from that which has been proved for most serpentines.

#### IV. COMPARISON WITH OTHER SERPENTINES FROM THE VOSGES.

In order to test more fully the views set forth above, I have made a study of other serpentines, both from the Vosges and from more distant localities. So far as concerns the former, before comparing them with the Rauenthal serpentine, we must add certain types of rock and certain mineral constituents to those described by Herr Weigand; and some corrections must be made in the proportions which he assigns to the constituents.

1. Thus there is far more variation in each mass than he has observed, and at the same time far more similarity between those which he has taken as different masses. The Starkenbach and Bonhomme serpentines are described as originating from separate magmas,<sup>2</sup> but parts of the two rocks are almost identical. The Starkenbach mass is stated to be a bronzite-serpentine having olivine sometimes up to as much as 25 per cent.<sup>3</sup> While one of my specimens agrees fairly well with this description, the proportions estimated by rough calculation in the slices of three others seem to give—in two of them, about 80 per cent. and 90 per cent. of olivine respectively, in another about 50 per cent. of augite. The Bonhomme mass is described as an olivine-serpentine, and therefore distinct from that of Starkenbach. As we have just seen, parts of the latter, however, are formed mainly of olivine, and it is acknowledged that in the former variations exist. Weigand speaks of 'only a few small flakes of hornblende' being accessory<sup>4</sup> (besides picotite, modified 'garnets,' noble serpentine, and iron oxide), but this hardly describes parts of the rock which include about 60 per cent. of augite and hornblende.

2. The most important point, however, is the distinct resemblance of the Starkenbach and the Bonhomme masses to the Rauenthal rock, since both these are admitted by Weigand to be derived from forms of peridotite,—the first from a bronzite, and the second from an olivine-rock.<sup>5</sup>

(i) Thus one slice from Starkenbach is from a rock completely serpentized, evidently formed from two minerals—enstatite and olivine. The enstatite has the appearance described by Weigand,<sup>6</sup> but the major part of the slide consists of serpentine undoubtedly

<sup>1</sup> The absence of intrusive 'dykes or branching veins' seems to be in harmony with the 'usual habit of peridotites and serpentines.' See T. G. Bonney, *Quart. Journ. Geol. Soc.* vol. lii. (1896) p. 29.

<sup>2</sup> B. Weigand, *op. cit.* p. 196.

<sup>3</sup> *Ibid.* p. 194.

<sup>4</sup> *Ibid.* p. 191.

<sup>5</sup> *Ibid.* pp. 191, 196.

<sup>6</sup> *Ibid.* p. 193.

having the meshwork-structure of a mass developed from olivine, and, except in the presence of rather more magnetite than occurs in most but not in all of the Rauenthal rock, this has a similarity, we might say an identity, with the parts of that serpentine which may be claimed as showing an olivine structure. In many kernels of the original mineral a border occurs, of slender rutile-rods with a radial arrangement as I have described it above in a Rauenthal serpentine (p. 253). In another slice from Starkenbach we can trace all stages in the alteration. In the completely altered rock, strings of serpentine, often straight, not seldom form a rudely rectangular network or even occasionally cross at angles of nearly  $120^\circ$ . In other words, it has the characters of most of the Rauenthal serpentine, but here is associated with distinct remains of olivine. Serpentinized enstatite and picotite occur, as described; a colourless hornblende and a white augite are also present.

(ii) The strongest resemblance, however, can be found in parts of the mass which is claimed by Herr Weigand as an olivine-serpentine—that at Bonhomme. This rock shows much variation, includes sometimes the patches described as modified garnets,<sup>1</sup> sometimes picotite in exceptional abundance, sometimes serpentinized enstatite or clustered augite or hornblende. Most of the serpentine has been derived from olivine, but at parts well-cleaved crystals of hornblende more or less serpentinized occur, which, like the chlorite or the hornblende within the Rauenthal rock, are ‘grouped in layers’ or ‘scattered quite irregularly.’ One slice which consists mainly of olivine (some kernels still remaining unchanged), but includes several crystals of partially altered hornblende, seems to give a perfect representation of what parts of the Rauenthal rock should have been at an earlier stage (Pl. XVII. fig. 1).

This mass it was which first furnished evidence, conclusive in my opinion, of the origin of the peculiar chlorite already discussed. Glittering silvery flakes occur on certain specimens,<sup>2</sup> and microscopic investigation proved their identity with the chlorite; but in the same slide the mineral could be traced associated with, and evidently developed from, a variety of mica. This is pale brownish, with pleochroism from almost colourless to that tint, and resembles the form of phlogopite seen in the Kimberley peridotite.<sup>3</sup> A specimen from among tumbled blocks, which are almost *in situ* by the road just south of the col, has mica occurring in larger flakes, also large enstatite-crystals, and a bright green apparently chloritic mineral. The specimen is practically identical with a rock from Portsoy.<sup>4</sup>

<sup>1</sup> B. Weigand, *op. cit.* p. 190. The interesting structure of these must be left for future investigation, since it has no direct bearing on the question here under consideration.

<sup>2</sup> The chlorite is noticed by Delesse, who states that it differs from the variety formed from garnet in the Zöblitz rock, being less rich in iron: *Annales des Mines*, ser. 4, vol. xviii. (1850) p. 327.

<sup>3</sup> *Geol. Mag.* 1895, pp. 497, 498. This mica seems to undergo change to vaalite or to silvery spangles.

<sup>4</sup> For the loan of this and other slides from Portsoy I am indebted to Prof. Bonney.

Thus the most noticeable peculiarity in the Rauenthal serpentine may be connected with conditions characteristic of other peridotites.

Lastly, in both the Starckenbach and Bonhomme masses, a banding is well exhibited, being apparently the effect of a flow-structure similar to that which has developed some characters of the Rauenthal rock.

#### V. COMPARISON WITH SERPENTINES FROM OTHER LOCALITIES.

Other serpentines afford a valuable means of comparison on many points, and I have to thank Prof. Bonney for the opportunity of studying the large collection of slides of this rock made by him during so many years of his work.<sup>1</sup>

First, as to the accessory minerals: while in some of the Lizard rocks picotite is well developed, many of them do not contain it; and even in outcrops of the Vosges (as Herr Weigand shows) it is found at some parts, while absent at others of the same massif. It is thus by no means universal as a constituent. Further, the occurrence in the Rauenthal rock of perovskite and of rutile, similar in character to that in other serpentines, has now been shown.<sup>2</sup>

The iron oxide visible in the slides in most of the Rauenthal specimens is small in amount, and this fact is associated with the character of the serpentine next to be considered, but the chemical analyses prove that a fair quantity of iron oxide is present. Much of it is connected with the chlorite, although some occurs in minute form in the serpentine.

The meshwork-structure of serpentine, now so well known, is not always universal (even in the rocks of one area); although no doubt would be entertained as to their origin from peridotites. The valuable article of F. Becke on the Stubachthal has recently expressed this conclusion.<sup>3</sup> In the Rauenthal rock, however, a serpentinous network can be recognized generally, and, although it is usually somewhat regular in form, a similar rectangular net was traceable in the great majority of the slices from the Lizard rocks. No argument seemed more impressive than this likeness in the essential structure<sup>4</sup> shown throughout so large a collection of specimens,

<sup>1</sup> The collections of slides which I examined included 43 specimens from 18 localities at the Lizard; others from Portsoy, Zöblitz, the Rauenthal, the Harz, Aberdeenshire, and New Brunswick.

<sup>2</sup> It is interesting to recall the fact that the mica-peridotite dyke of Kentucky is described by J. S. Diller as composed 'essentially of biotite, serpentine, and perovskite,' with small amounts of secondary minerals: *Am. Journ. Sci. ser. 3*, vol. xliv. (1892) p. 287.

<sup>3</sup> 'A distinct serpentine occurs which is derived from a typical olivine-rock, and in which nevertheless the meshwork-structure is completely wanting in the changed parts,' *Olivinfels & Antigorit-Serpentin*, *Min. & Petr. Mitth.* 1894, p. 271.

Of the three types of serpentine enumerated by Mr. Teall ('*Brit. Petrogr.*' 1888, p. 115) the study of the Rauenthal rock seems to take away one chief example of the second, and the work of Herr Becke to lead to an important subtraction from the third.

<sup>4</sup> A likeness which was previously indicated by Prof. Bonney, *Geol. Mag.* 1887, p. 68.

since it may be presumed that no one would maintain a hornblende origin for the Lizard serpentine.<sup>1</sup>

A colourless hornblende is characteristic of various masses of serpentine. At places (as, for example, Portsoy), a peculiar amphibolite occurs which shows an almost exact similarity in microscopic structure to that of the Rauenthal; and in rocks from Portsoy and the Lizard the appearance of hornblende undergoing serpentinization is exactly represented. The garnetiferous serpentine from Zöblitz also may be closely compared in the character of the serpentinized hornblende, except that in one slide I found that the amount is far greater than is usual in the Rauenthal serpentine; but in others the hornblende-serpentine formed the smaller part of the rock, and the account given by Lemberg<sup>2</sup> describes the serpentine as originating from an olivine-rock containing some hornblende and garnets or their chlorite-pseudomorphs. Thus, in the first two characteristics, it may be compared with that of the Rauenthal.

The characteristic chlorite is not peculiar to the Rauenthal serpentine, for it was identified by Prof. Bonney in slices from the Lizard. Even there it suggested a possible bleaching of biotite.<sup>3</sup> On examining these slices, I at once recognized the mineral as similar to that in the Rauenthal mass. It is represented also at Portsoy.

Mica has generally been described, occurring in serpentines or peridotites, as akin to phlogopite, and this seems to be the nature of the mineral from which the chlorite originated in the Rauenthal rock. Thus an interesting comparison may be made with the few and rare mica-peridotites which have been described.<sup>4</sup>

The chemical composition of the Rauenthal and of other serpentines shows so great a resemblance that it would be difficult to suppose that they had originated by alteration of two totally different rocks. One of the Lizard serpentines most closely related seems to be that from near Cadgwith, of dark or black colour. The microscope-slide also shows marked similarity, and exhibits chlorite as well as some hornblende. It may be convenient to place side by side the analyses of the two rocks, and of two others, which are interesting for comparison:—

<sup>1</sup> Residual olivine has been described at several localities, such as Coverack, Carn Sparnack, south of Kennacka, and others on the western coast.

<sup>2</sup> Zeitschr. d. Deutsch. geol. Gesellsch. vol. xxvii. (1875) p. 531.

<sup>3</sup> Quart. Journ. Geol. Soc. vol. xlvii. (1891) pp. 473, 474. Cf. slices from near Cadgwith, Porthalla, and other places.

<sup>4</sup> The clustered chlorite in some specimens apparently has a similarity to the occurrence of mica in the mica-peridotite from Kentucky described by J. S. Diller, where the mica 'occurs in round or oblong patches.' It is, however, more abundant than it would have been in the Rauenthal rock and 'forms the groundwork.' Within the scales is scattered some serpentine. 'The biotite is occasionally altered to chlorite,' Am. Journ. Sci. ser. 3, vol. xlv. (1892) p. 287. The similar dyke near Ithaca, N.Y., is described by J. F. Kemp as occurring with 'the characteristic reddish biotite of the peridotites,' Am. Journ. Sci. ser. 3, vol. xlii. (1891) p. 411. Cf. also a dyke in Central New York, *ibid.* vol. xliii. (1892) pp. 322-327, C. H. Smyth Jr.; and the De Witt dyke, *ibid.* vol. xlix. (1895) p. 458, N. H. Darton & J. F. Kemp.

- A : The Rauenthal serpentine ; the bulk analysis given by Herr Weigand.<sup>1</sup>  
 B : The matrix of the dark serpentine from near Cadgwith.<sup>2</sup>  
 C : Dark oil-green serpentine from Porthalla.<sup>3</sup>  
 D : A mica-peridotite from Kentucky, described by J. S. Diller.<sup>4</sup> In this the high percentage of lime and alumina, and the low proportion of magnesia, can be accounted for by the large quantity of mica present.

	A.	B.	C.	D.
SiO <sub>2</sub> .....	36.944	38.50	37.15	33.84
TiO <sub>2</sub> .....	.....	.....	.....	3.78
Al <sub>2</sub> O <sub>3</sub> .....	1.353	1.02	5.60	5.88
Cr <sub>2</sub> O <sub>3</sub> .....	.....	.....	.....	0.18
Fe <sub>2</sub> O <sub>3</sub> .....	6.868	4.66	1.10	7.04
FeO .....	9.563	3.31	8.80	5.16
MnO .....	.....	.....	.....	0.16
NiO .....	.....	0.59	.....	0.10
CoO .....	.....	.....	.....	trace
CaO .....	1.393	1.97	0.10	9.46
BaO .....	.....	.....	.....	0.06
MgO .....	36.022	36.40	32.80	22.96
K <sub>2</sub> O .....	.....	.....	} 0.29	2.04
Na <sub>2</sub> O .....	.....	.....		0.33
H <sub>2</sub> O .....	13.089	12.35	} 13.70 } 0.46	7.50
P <sub>2</sub> O <sub>5</sub> .....	.....	.....		.....
Cl .....	.....	.....	.....	0.05
F .....	.....	.....	.....	?
CO <sub>2</sub> .....	.....	.....	.....	0.43
FeS <sub>2</sub> .....	.....	0.41	.....	.....
Insol. in HCl .....	.....	1.37	.....	.....
Total.....	.....	100.58	100.00	99.86
Specific gravities.....	.....	2.587	2.56	.....

The significance of the occurrence of bastite as a point of likeness is so obvious that it need only be mentioned.

The variation in many masses is an important means of correlation, since it is from this character, or rather from the overlooking of it, that some difficulties in interpretation have arisen.<sup>5</sup>

The structural characteristics afford a means of comparison with other serpentines. For instance, in the Lizard rocks, the occurrence of a structure both on the eastern and the western coast, which resembles a slight foliation, has been noticed, and occasionally there is also banding, especially at Porthalla.<sup>6</sup>

<sup>1</sup> *Op. cit.* p. 199.

<sup>2</sup> Quart. Journ. Geol. Soc. vol. xlvii. (1891) p. 466. Analysis v., by Mr. Hudleston.

<sup>3</sup> *Ibid.*, analysis vii., by Mr. Collins.

<sup>4</sup> Am. Journ. Sci. ser. 3, vol. xlv. (1892) p. 288.

<sup>5</sup> The variability of Lizard serpentines is well shown by the tabular summary, Quart. Journ. Geol. Soc. vol. xlvii. (1891) p. 467.

<sup>6</sup> Quart. Journ. Geol. Soc. vol. xlvii. (1891) pp. 470, 472, 474. See also note on lherzolite written in 1876, quoted on p. 475. A banded specimen which I brought from Bonhomme is practically identical with that from Porthalla which is represented in pl. xvi.

A similar structure (fluxional or banded) has been observed in other holocrystalline igneous rocks, as in the diorites of Guernsey (Quart. Journ. Geol. Soc.

Thus a serpentine such as may be found at the Lizard exhibits marked likenesses to that of the Rauenthal. The bastite is similar, the accessory hornblende, the chlorite (although more common in the Rauenthal), the general network of the serpentine, the variability in the composition, and the occasional banding at the Lizard. It may perhaps be said that in the Rauenthal rock the olivine is a less ferruginous variety, and the mica richer in iron more common. But, with such marked likenesses, how could a different origin for the two masses be at all probable?

## VI. SUMMARY.

The views of Herr Weigand on the Rauenthal serpentine are briefly as follows:—

That a passage can be traced, from the dark hornblendic bands of the gneiss (by increase and modification of the hornblende) to the pale greenish amphibolite, and from the amphibolite (by a process of alteration) to the serpentine.

That the chemical changes in the latter process can be explained, if we assume that chlorite is formed mainly from certain constituents of the hornblende.

That by microscopic examination a hornblendic structure is shown throughout the serpentine.

Therefore, that the serpentine here is the result of change, not of an igneous peridotite, as in neighbouring localities, but of part of the gneissic series.

The evidence opposed to this conclusion may be shortly stated:—

(I) That in the field we can trace no passage from gneiss to the peculiar amphibolite.

That no consideration is given by Herr Weigand to the general difficulty which would be involved by a peculiar and local modification of the gneiss such as is to be found nowhere else in the neighbourhood.

(II) That the chemical changes of amphibolite to serpentine as exhibited in his analyses cannot be fully explained; and that the chlorite seems more probably derived from an original mica.

(III) That on microscopic examination the hornblendic structure in the serpentine is seen to be limited to certain isolated crystals or crystalline layers or patches of original hornblende, and that the greater part of the serpentine appears to be derived from olivine. That enstatite, a constituent of peridotites, occurs here. That some iron oxide, minute rutile, and perovskite are also present.

(IV) That apparent gradations in the rock are connected with the different arrangements of hornblende, chlorite and enstatite. That this variation (of which the amphibolite may form an extreme case)

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vol. xlviii. 1892, p. 135) and the gabbros at the Lizard (*ibid.* vol. xlvii. 1891, pp. 484-490). Cf. 'Brit. Petrogr.,' J. J. H. Teall, pl. xliii. fig. 2. See also Report on Rocks of St. Paul's Island, Renard, *Chall. Exped. Narrative*, vol. ii. App. B, fig. 2, pp. 7, 14.

seems to be due to differentiation of an original magma, in which fluxion-structures were developed.

(V) Neighbouring serpentines in the Vosges are found to exhibit closer likeness one to another, greater variation in each mass, and more marked resemblance to that of the Rauenthal (in mineralogical composition and structure) than are described by Herr Weigand. Thus it seems impossible to maintain that the Rauenthal serpentine is distinct in its origin from these adjacent masses. Yet they are claimed by him as derived from peridotites (olivine- or enstatite-rock).

(VI) By comparison with serpentines from many other localities beyond the Vosges, such a likeness is found that it does not seem possible to attribute a different origin to the Rauenthal mass. As Prof. Bonney has said, possibly 'the white hornblende is rather exceptionally abundant'<sup>1</sup> and '(as sometimes occurs elsewhere) a peculiar variety of chlorite is locally developed.'<sup>2</sup> Otherwise, the Rauenthal rock resembles in structure, in chemical composition, in mineral constitution, and even in the variations of its minerals, certain serpentines from Cornwall, Scotland, and the Continent.

Thus the serpentine of the Rauenthal would be but one of the varied forms in which that rock occurs in the neighbourhood of the Bressoir. It seems to have developed there from a not very pure or an ill-mixed magma, which was sometimes an olivine-rock (a dunite), sometimes either an olivine-enstatite rock (saxonite) or an augite-olivine or a hornblende-olivine, or, as I believe, a mica-peridotite. These variations may extend over fairly large areas or may be closely associated as thin, probably fluxional bands, within the same mass. As, then, I cannot admit the Rauenthal serpentine to be anything but an altered peridotite, I should not expect that serpentines in other gneissic regions<sup>3</sup> were unusual in their origin.

#### EXPLANATION OF PLATES.

##### PLATE XVI. (MAP).

The serpentine-bosses are marked diagrammatically, but the patches give a rough idea of the relative size of the different crags. The boundary of the outcrop cannot be traced with exactness, but indications are given by fragments of rock and by the contour of the ground; thus the curving line at the south-west is drawn roughly along the direction where a rather sudden steepening in the slope seemed to imply a change of rock. The minerals (chlorite, enstatite, hornblende) are indicated in the serpentine at places on the plan, as examples of the variation in its composition; but no attempt has been made to show exhaustively where these minerals occur.

The blocks and fragments of rocks are intended only to show general position.

Paths and roads are mapped from examination of the area by the Author.

<sup>1</sup> Not without parallels for comparison: for example, Zöblitz, Portsoy.

<sup>2</sup> Geol. Mag. 1887, p. 69.

<sup>3</sup> B. Weigand, *op. cit.* p. 203 'Es steht mit Sicherheit zu erwarten, dass Serpentine ähnlicher Entstehung sich in Gneissgebieten in Menge finden werden.'

## PLATE XVII.

All the figures are  $\times 20$ . Figs. 2-6 are of Rauenthal serpentine.

- Fig. 1. A slice from the Bonhomme serpentine (which is admitted to be an olivine-serpentine), to illustrate the similarity to the Rauenthal rock. The drawing shows accessory hornblende-crystals, serpentinized, among olivine-serpentine as in fig. 2 from the Rauenthal. The chief differences are, in the Bonhomme rock, the presence of picotite (represented together with opacite by dark spots in the drawing) and the occurrence of some residual unchanged olivine.
- Fig. 2. Crystals of accessory hornblende, serpentinized, but still exhibiting characteristic cleavage, within a mass of olivine-serpentine. Iron oxide, with amount and arrangement as usual, occurs in the slide. Serpentinized enstatite and chlorite are also present, but are not shown in the drawing. (The darker tint of this figure, as compared with fig. 1, is due to the slice of the rock being much thicker.)
- Fig. 3. Chlorite accompanying and enclosed within olivine-serpentine, associated with partly-changed hornblende. Some of the chlorite is in a transitional condition, evidently forming from mica. Crystalline grains of iron oxide are present.
- Fig. 4. 'Amphibolite' consisting of hornblende, mostly unaltered, sometimes in idiomorphic crystals, associated with well-developed chlorite. (Band in Rauenthal serpentine.)
- Fig. 5. Interstreaking of greenish olivine-serpentine and colourless well-cleaved hornblende ('amphibolite'). Iron oxide is present. Structure probably fluxional.
- Fig. 6. Olivine-serpentine, with the usual meshwork-structure. Many of the fine dots over the grains represent minute granules of ferrite, probably hæmatite; and a few larger patches of opacite and ferrite are shown in the drawing. Chlorite occurs in parallel or orientated flakes, but no hornblende is associated with it.

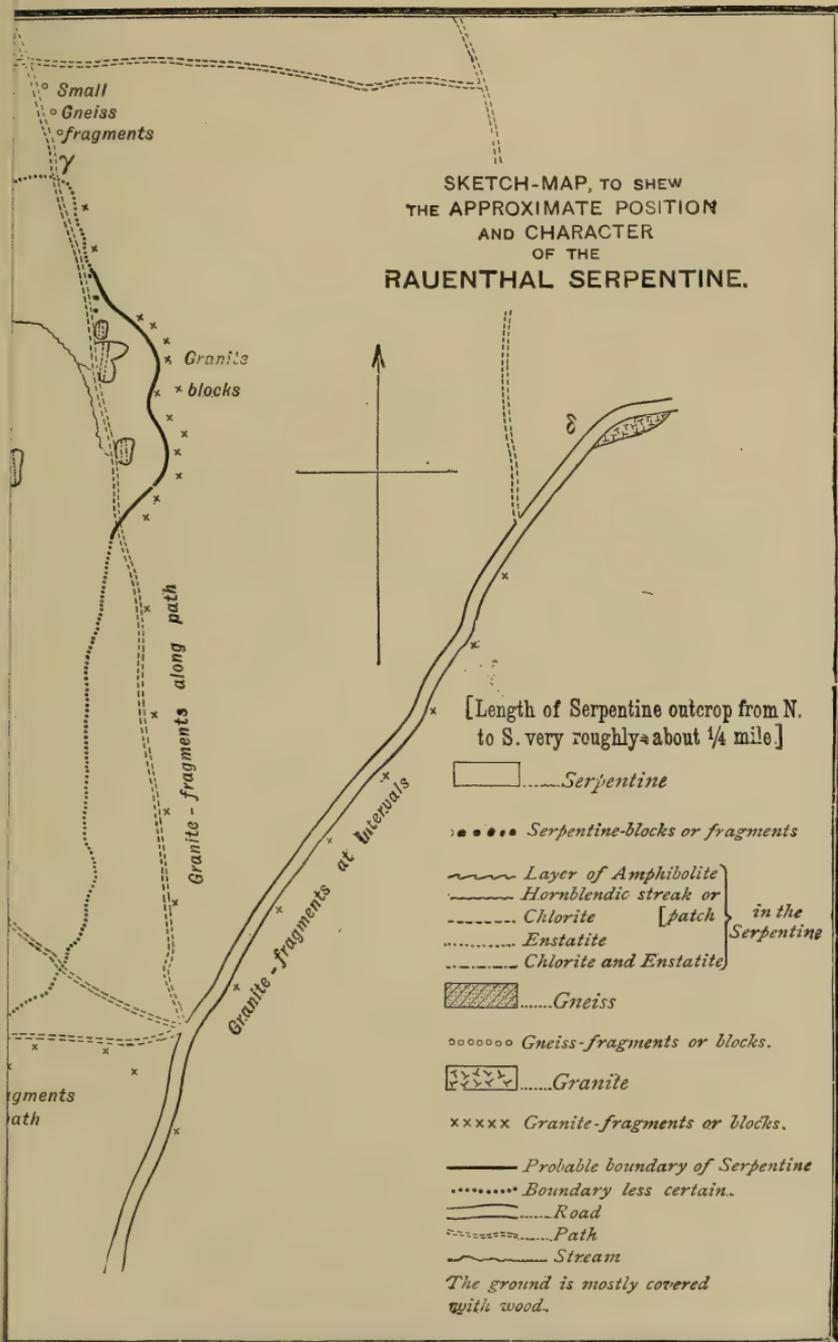
## DISCUSSION.

Prof. JUDD called attention to the fact that the relations of the serpentine of the Rauenthal to the adjacent granites and gneisses, as described by the Author of the paper, are strikingly like those of the peridotites and serpentines of North Carolina and Georgia to the granites and gneisses of that area.

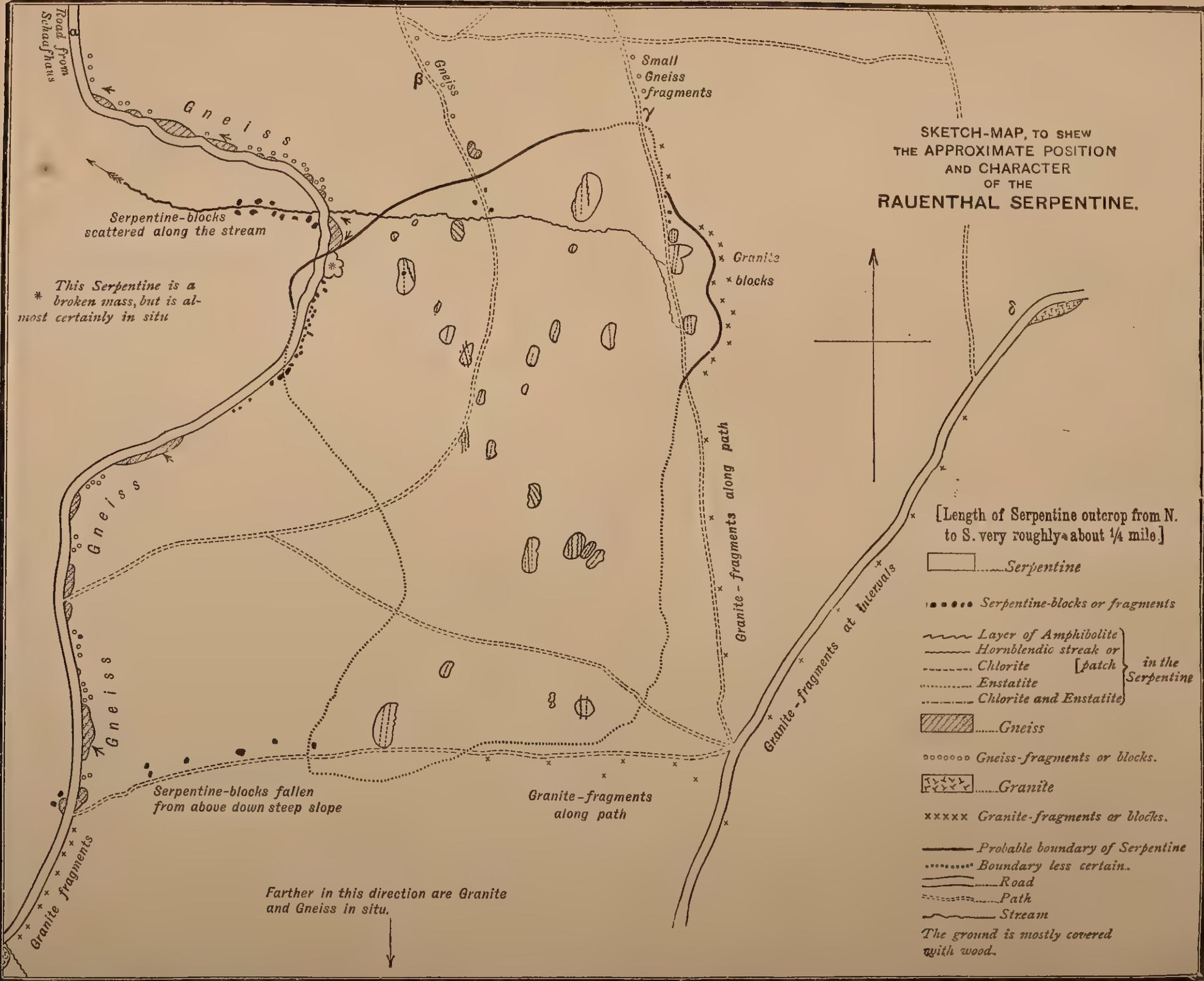
Mr. RUTLEY said that the rocks included within the area described would unquestionably yield serpentines varying considerably in character. One of these rocks was stated to be amphibolite, and, although the nature of rocks bearing this name is open to question, he thought that in certain cases amphibolites were eruptive rocks. When the hornblende of an amphibolite was converted into serpentine, it would be interesting to know what became of the other constituents. He appreciated the straightforward way in which only actual exposures were represented on the map, and believed that the paper, when printed in full, would be a valuable addition to the literature relating to serpentines and their origin.

Prof. BONNEY stated that the mode in which the serpentine occurred corresponded with what could be seen in several localities. The question of the connexion of the foliation of the serpentine with pressure had always been present to the mind of the Authoress, but no connexion had been proved. He agreed with Mr. Rutley that amphibolite was generally an igneous rock. There was a difficulty in accounting for the missing silica; but the fact of the change of certain pyroxenes into serpentine was indubitable. This rock, however, had originated from a peridotite.

SKETCH-MAP, TO SHEW  
THE APPROXIMATE POSITION  
AND CHARACTER  
OF THE  
RAUENTHAL SERPENTINE.









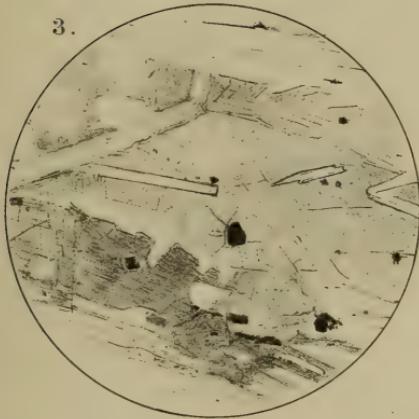
1.



2.



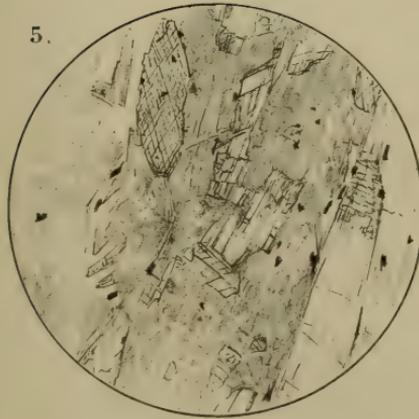
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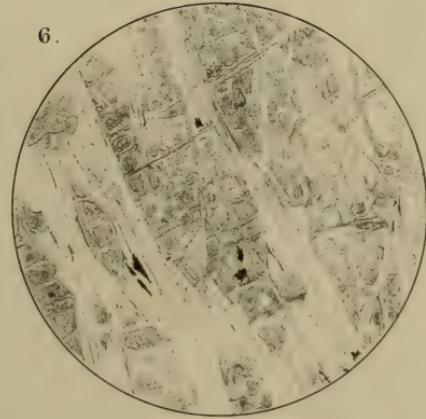
4.



5.



6.





21. *The RED ROCKS near BUNMAHON on the COAST of Co. WATERFORD.*  
By F. R. COWPER REED, Esq., M.A., F.G.S. (Read March 10th,  
1897.)

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## I. INTRODUCTION.

THERE are a few patches of red sandstone, shale, and conglomerate on the coast of Co. Waterford whose age has been the subject of much divergence of opinion, owing to the obscurity of their stratigraphical relations and isolated positions. A recent visit which I paid to these parts enabled me to collect evidence which seems to my mind to settle their age conclusively.

The earliest description of these rocks with which I am acquainted was published by Mr. J. Hodgson Holdsworth<sup>1</sup> in 1833. He maintained the view that they were of the same age as the 'great conglomerate-formation' of the Monovoulagh or Comeragh Mountains, which he rightly ascribed to the Old Red Sandstone. He pointed out also the fact that they rest unconformably on the 'Silurian' rocks.

The next mention of these beds is by Mr. T. Weaver<sup>2</sup> in 1835, when he described a gradual passage from the greenstone rocks into the red sandstone 'through the medium of a compound conglomerate' of greenstone with red sandstone-fragments and of red sandstone with greenstone-fragments. Thus he apparently favoured the view of their 'Silurian' age.

Mr. J. Beete Jukes<sup>3</sup> in 1852 put forward the view that these patches were blocks of Old Red Sandstone let into the 'Silurian' rocks of the coast by complicated faults.

In 1860 Messrs. W. B. Brownrigg and Theo. Cooke,<sup>4</sup> in a brief description of the coast, accepted the view that these patches are faulted masses of Old Red Sandstone.

In the Geological Survey memoir of this district<sup>5</sup> Mr. G. V. Du Noyer rejected the idea of the Old Red Sandstone age of these red sandstones and conglomerates, and maintained that there are two

<sup>1</sup> 'On the Geology of the District of the Knockmahon Mines in the County of Waterford,' Journ. Geol. Soc. Dublin, vol. i. (1833) p. 85.

<sup>2</sup> 'On the Geological Relations of the South of Ireland,' Trans. Geol. Soc. Lond. ser. 2, vol. v. pt. i. (1837) p. 14.

<sup>3</sup> 'Sketch of the Geology of the County of Waterford,' Journ. Geol. Soc. Dublin, vol. v. (1852) p. 147.

<sup>4</sup> Journ. Geol. Soc. Dublin, vol. ix. (1860) p. 8.

<sup>5</sup> Explan. Sheets 167, 168, 178, and 179, Geol. Surv. Ireland (1865), p. 10.

groups of these beds 'clearly interstratified with the Lower Silurian' rocks and folded with them.

Mr. Kinahan,<sup>1</sup> however, in 1878, pointed out that they lay unconformably on the 'Cambro-Silurian' rocks, and ascribed them with some hesitation to the 'Lower Carboniferous' (= Old Red Sandstone).

The same writer in 1887<sup>2</sup> speaks of these red beds as lying on or partly in the Ordovician, and says that they 'must be either of Silurian or Devonian age, probably the latter—that is, small outliers of the Comeragh conglomerates.' In 1889 he writes<sup>3</sup> of the Knockmahon conglomerate lying unconformably on the Ordovician, but observes that farther west the red beds appear as isolated masses in the Ordovician.

Sir Archibald Geikie, in his Presidential Address to the Geological Society<sup>4</sup> in 1891, hesitated to express a decided opinion, but seemed to incline to the view that they were not of Lower Silurian age.

## II. GENERAL STRUCTURE OF THE DISTRICT.

If we first glance at the characters and distribution of the undoubted Lower Silurian and Old Red Sandstone rocks, and at the general structure of the district, we shall be in a better position to attack the problem.

The Lower Silurian (Ordovician) is represented in this part of Ireland by a great assemblage of igneous rocks, together with sedimentary beds comprising black, grey, greenish, and buff slates and mudstones, and a few thin limestones. The igneous rocks largely preponderate, and consist of contemporaneous lavas, ashes, and agglomerates pierced by intrusive sheets, dykes, and irregular masses, and occasionally by breccia-filled 'pipes,' belonging to several more or less distinct periods of irruption.

The sedimentary members of this system nowhere assume in this district the character of red sandstones, etc., if we except for the moment these disputed patches on the coast.<sup>5</sup> *Primâ facie*, therefore, we might well hesitate to include these isolated masses in the Ordovician. If they be really interbedded with the Ordovician Series, we might reasonably expect that deposits possessing such well-marked and distinctive characters and so great a thickness would give indications of their presence elsewhere, especially as the Ordovician strata of the district seem to be repeated by a series of folds; but such is not the case, for nowhere else in the county do we meet with red rocks which can be ascribed by anyone to any formation but the Old Red Sandstone.

The Old Red Sandstone of the county itself rests everywhere

<sup>1</sup> 'Geology of Ireland,' 1878, p. 28.

<sup>2</sup> Sci. Proc. Roy. Dubl. Soc. vol. v. (1887) p. 611.

<sup>3</sup> *Ibid.* vol. vi. (1889) p. 283.

<sup>4</sup> Quart. Journ. Geol. Soc. vol. xlvii. (1891) *Proc.* p. 158.

<sup>5</sup> Red conglomerates of a similar character are said to appear in the Lower Silurian (Ordovician) slates of Tagoat, Co. Wexford, but their relations have not been clearly described, and I have been unable to visit the spot.

unconformably on the older rocks. Its basal portion varies in character, but is always either a breccia of fragments of the underlying Ordovician rocks, as at Dunmore,<sup>1</sup> or a series of conglomerates consisting of rounded or subangular pebbles of variously-coloured grits and white vein-quartz.

In the eastern corner of the county the sea-cliffs from Knockaveelish Head round to Brownstown Head are formed of red sandstone and conglomerates with the basal breccia about 200 feet thick, near Dunmore. The total thickness of the beds here is about 400 feet. In this district the strata are almost horizontal, the dip being at Dunmore only 5° S. Along the coast to Brownstown Head the dip is to the south-east at an average angle of 10°. On the south-eastern shore of Rinnashark Harbour the dip is to the north-west at about the same angle, so that an anticlinal axis occurs here, and seems to be in some way connected with the existence of the promontory of Brownstown Head, as is more plainly the case with the Kerry headlands.

The boundary of the beds then sweeps northward from this point past Passage, to the north side of the river Suir, then bends round westward, crosses the river again, and, with a mean dip of 30° N., they strike west as a narrow band which expands and rises into the Comeragh Mountains. These mountains consist in the main of a broad arch of the Old Red Sandstone beds, dipping steeply to the north and south, and resting on the upturned edges of the Lower Palæozoic rocks.<sup>2</sup> On the southern side of this anticlinal the Old Red dips suddenly and steeply at angles of from 60° to 70° beneath the valley of Dungarvan and Lismore, reaching the coast at Ballyvoyle Head, where a fine section of the tilted beds is exposed and their unconformable junction with the older rocks plainly seen. Details of this section are given by Sir R. Griffith<sup>3</sup> in his paper on 'The Order of Succession of the Strata of the South of Ireland.' The beds are here about 2250 feet thick, and the basal portion consists of 'alternations of reddish grey and red conglomerates, reddish grey compact sandstone and dark red slate, the conglomerate predominating.' A good diagrammatic sketch of this section is given in the Survey Memoir already quoted.<sup>4</sup>

The thickness of the beds in the Comeragh Mountains is about 3200 feet. Towards the north, south, and east, they are thus seen to become attenuated. Sir R. Griffith also notes (*op. cit.*) that conglomerate forms the base of the Old Red in these mountains, and in the Cahirconree and Slievemish Mountains of the Dingle peninsula of Kerry, and also in the Galtees and Slievenaman Mountains of Limerick and Tipperary. Thus the presence of conglomerates at the base seems a feature of the Old Red of the South of Ireland. This point was emphasized by Mr. John Kelly in 1856,<sup>5</sup> and by Prof. Hull

<sup>1</sup> Explan. Sheets 167, etc. Geol. Surv. Irel. (1865) p. 13.

<sup>2</sup> J. Beete Jukes, Journ. Geol. Soc. Dublin, vol. v. (1852) p. 147.

<sup>3</sup> Journ. Geol. Soc. Dublin, vol. iii. (1845) p. 150.

<sup>4</sup> Explan. Sheets 167, etc. p. 60, fig. 7.

<sup>5</sup> J. Kelly, Journ. Geol. Soc. Dublin, vol. vii. (1856) p. 115.

in 1879.<sup>1</sup> The former says that in all parts of Ireland the two prominent characteristics of the formation are (1) the presence of a thick basal conglomerate of quartz, jasper, and other pebbles, and (2) its unconformity to the inferior rock.

The basal breccia above mentioned as occurring at Dunmore is a local phenomenon, and is found again in the county only along a strip of country about 6 miles in length, extending from the northern base of the Reeks of Glenpatrick to the glen of the Coolnamuck stream (Geol. Surv. Mem.).

From this rapid survey of the distribution and characters of the indisputable Old Red Sandstone of the district, we see that it forms an incomplete elliptical ring round an irregularly oval area of Lower Palæozoic rocks. Remembering the steep dips of the Old Red Sandstone off this central area to the north and south, and its lesser dips to the east and west, we recognize that we have to do with the remains of a denuded elongated dome. The incompleteness of the ring on the south between Ballyvoyle Head and Brownstown Head is due mainly to the fact that the southern limb of the dome is now concealed by the waters of the sea, as Jukes<sup>2</sup> long ago pointed out; but supposing this ring is as irregular on this side as on the northern, and the trend of the beds as variable, owing to minor folds and disturbances, we might not unreasonably expect to find some traces of it along the present line of coast. Such indeed I believe to be the case, and I hold that the patches of red rocks at Bunmahon and in the neighbourhood are fragments of this distorted and dislocated ring. Jukes (*op. cit.*) originally held this view, but subsequently abandoned it, and in the Survey Memoir, together with Du Noyer, put forward the opinion that the red rocks here were of 'Lower Silurian' age, as already stated.

### III. MODE OF OCCURRENCE AND RELATIONS OF THE RED ROCKS OF BUNMAHON AND NEIGHBOURHOOD.

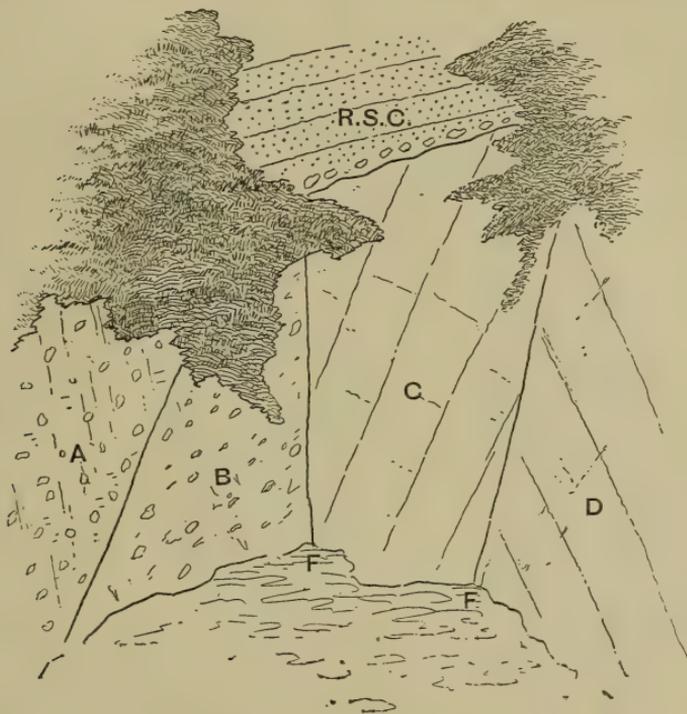
The most westerly exposure of these disputed red rocks occurs in the bay of Ballydouane West, immediately east of Killelton Bay and stream, and, so far as I know, has not been noticed previously by any writer on these rocks. Immediately to the east of the steep zigzag path, winding down the cliffs to the beach in this bay, is seen a rib of red shaly sandstone halfway up the cliff-face. The relations of it to the other rocks are obscured by the ground being partly overgrown and by several landslips, but a careful investigation of the lines of junction shows that the red sandstone dips into the cliff in a north-westerly direction, and rests unconformably upon the igneous rocks which form the lower part of the cliffs. There is also a thin layer of coarse angular breccia at the base of the red sandstone, composed of fragments of the underlying felsites, diabases,

<sup>1</sup> Quart. Journ. Geol. Soc. vol. xxxv. (1879) p. 719.

<sup>2</sup> Journ. Geol. Soc. Dublin, vol. v. (1852) p. 147.

etc. (see fig. 1). Not only do none of these igneous rocks penetrate the red beds, but they show signs that they were tilted, faulted, and crushed along certain planes, as well as eroded before the sandstone was deposited on their edges. A more complete example of unconformity it would be hard to find. A sheet of a very conspicuous felspar-porphry, with large pink felspar-crystals, is seen high up in the cliffs some 20 or 30 yards west of the red rib, and seems to run directly towards the latter. A grass-covered steep slope hides the actual junction, but a line of fault is certainly suggested by the abrupt termination of the felspar-porphry within

Fig. 1.—Section in cliff at E. end of Ballydouane West Bay.



[Height of section = about 40 feet.]

A = Dark greenish, coarse, cleaved ash.

B = Whitish felsite, fine ash, and breccia filling old neck.

C = Greenish-grey dolerite.

D = Crushed dark green diabase.

R.S.C. = Red sandstones with basal conglomerate of diabases, dolerites, etc., resting unconformably upon the eroded edges of C.

F F = Faults.

a few yards of the red beds. There is no evidence of the basal layer of the red sandstone being a friction-breccia, since the sandstones and fragments in the breccias show no signs of crushing or shattering. There is moreover no sign of alteration or disturbance of

these beds by the intrusion of any igneous rock. The sandstone is quite similar in lithological characters to many beds in the undoubted Old Red Sandstone around Waterford; and the basal breccia may be compared with that of Dunmore.

The vertical line of junction of the red beds with the igneous rocks on the east is obscure, for the adjacent rocks are stained red by the washing down of the shaly material; small slips also have taken place which are now grass-grown, and a spring here breaks out. There is, however, everything to suggest a fault on this side too, by the position and characters of the igneous rocks seen beyond this talus and grass.

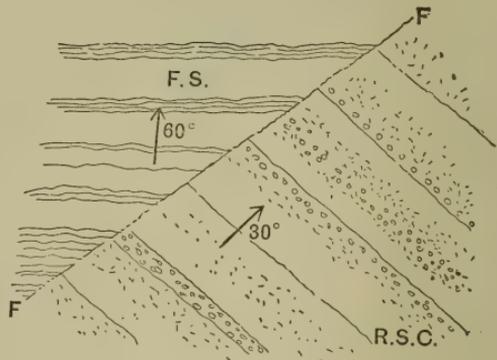
The next patch is in the large Ballydouane Bay, and is the one described with more or less minuteness by all the writers on these red rocks of the coast. Beginning at the western corner of the bay, west of the road leading down to the beach, we find the low cliffs—not more than 40 feet high at this point—composed of a curious banded rock (ophiolite of Kinahan), much resembling serpentine in appearance, but containing fossils, dipping most distinctly  $60^{\circ}$  N.N.W.—that is, into the face of the cliff. On the east, separated from these banded rocks by

a grass-grown talus slope, a few yards wide, we find red and yellow sandstones with thin but frequent bands of fine conglomerate, made up of white quartz and other pebbles, dipping  $30^{\circ}$  N.E. These form the low cliffs. On the foreshore we see these sandstones ending abruptly against the serpentinous bedded rocks along a line of fault which most clearly shows the two rocks in contact (see plan, fig. 2). Thus the western boundary of the red beds of Bally-

douane Bay is a line of fault. An isolated pyramidal mass of the red sandstones and conglomerates stands in front of the cliffs at this point, a few yards west of the gap occupied by the stream and road. This mass shows the beds dipping N.E. at  $45^{\circ}$ .

There is thus absolutely no evidence here that the red rocks are interbedded with the neighbouring strata, and I cannot understand the succession of beds which is tabulated in the Survey Memoir as occurring on the western side of Ballydouane Bay. Certainly

Fig. 2.—Ground-plan of foreshore, W. side of Ballydouane Bay.



F.S. = Fossiliferous banded 'ophiolite,' dipping N.N.W. at  $60^{\circ}$ .

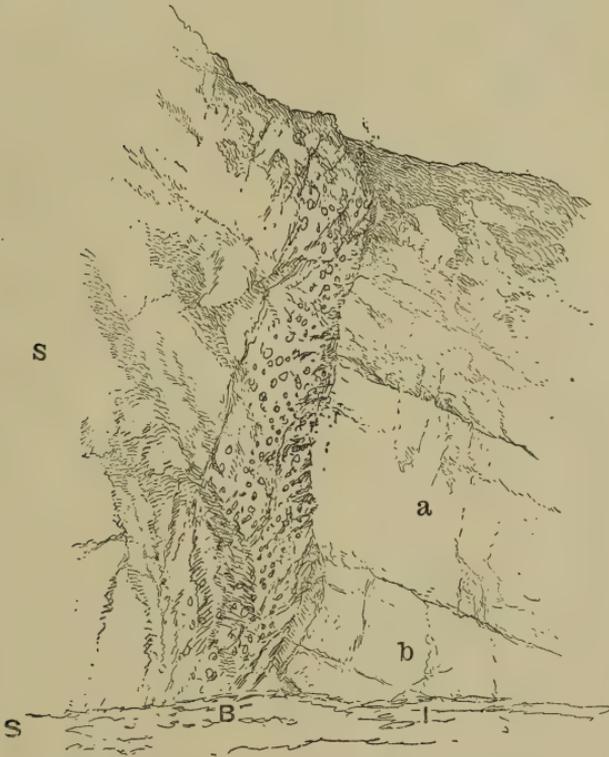
R.S.C. = Red sandstones with thin bands of fine quartz-conglomerates, dipping N.E. at  $30^{\circ}$ .

F = Fault.

what is now visible does not at all correspond to the description there given.

At the gap in the cliffs formed by the Ballydouane stream we find the same red sandstones and conglomerates composing both sides of the narrow valley, but the beds are here considerably shattered and disturbed for a distance of a few yards, and the cliffs are low, irregular, and confused by landslips. However, a dozen yards or so to the east of the stream-gap we meet with almost vertical beds of coarse quartz-conglomerates, which, as we follow

Fig. 3.—Section in cliff at N.E. corner of Ballydouane Bay.



S = Fine red sandstones in massive beds, dipping N.W. at  $80^{\circ}$ .

B = Coarse breccia of underlying igneous rocks (Ia, Ib, etc.) in red sandy matrix 20 feet in thickness, resting unconformably upon the edges of the igneous rocks I.

I a = Decomposed greyish dolerite; b = Dark greenish felsite, intrusive in a.

the cliffs eastward, are found to be underlain by finer conglomerates and subsidiary alternating beds of red sandstone from 2 to 8 feet thick. The conglomerates form the greater part of the beds, and are composed of subangular or angular pieces of white vein-quartz and liver-coloured quartzites. Some of the fragments in the coarser beds of conglomerate are as much as 8 inches long, and can scarcely be called pebbles, for they show little sign of rounding or

attrition. The finer conglomerates, however, have their materials more rolled, and resemble compacted fine shingle. This series of beds is from 70 to 80 feet thick, and is finely displayed in the lofty vertical cliffs at the head of the bay. The dip, which is vertical in the westernmost portion—*i. e.* the uppermost beds—becomes  $75^{\circ}$ – $80^{\circ}$  to the N.W. as we walk eastward and pass across the strike on to the lower beds. The line of cliffs here makes a large angle with the true strike of the beds.

Suddenly, at the north-eastern corner of the bay, the vertical cliffs of red sandstone cease, and their place is taken by a steep, grass-grown cliff formed of a succession of landslips and obscured by much talus. We at once suspect that this change is caused by the occurrence of rocks of a different character, and we have not far to look to find our suspicion confirmed. We find, firstly, that the lowest 20 feet of the red sandstone and conglomerate-series is composed of a very coarse breccia of fragments of felsites, greenstones, tuffs, etc., in a matrix of red sand; and then at the place where the character of the cliffs changes we find this breccia resting on the worn edges of the rocks which have supplied many of the fragments (see fig. 3, p. 275). The unconformity is most striking, and there is no room for questioning the complete discordance of the two sets of beds, and the wide interval of time that must have separated their periods of formation. The older rocks, including several intrusive masses, present their truncated and broken-up edges to the red series; none of the intrusions penetrate the latter, but end abruptly against the basal breccia. The section of the cliffs of this bay which is figured in the Survey Memoir (*op. cit.* p. 58, fig. 6) is very misleading, and contrary to the evidence now most clearly exposed along the coast. The arrangement and relations of the beds as now seen on the northern side of the bay are shown in fig. 4.

The inland extension of these red rocks I have not been able to trace with much accuracy, owing to the nature of the ground, but there are no superficial indications of their occurrence far inland in the townland of Ballydouane East. If we prolong eastward the line of fault marked A in fig. 9 (p. 284), we shall see that it must intersect the strike of the basal breccia so as to enclose a wedge-shaped block of red beds. A ridge of high ground runs inland from the central part of the bay in a north-easterly direction and gives indications that it is formed of the red sandstones and conglomerates. This ridge is cut across on the east by the north-and-south valley of the Cooneenacartan stream.

The cliffs of Ballydouane Bay from its north-eastern corner of grass-grown talus trend to the south-east, and until nearly halfway out to Poolatunish Point consist of similar steep, broken, grass-covered slopes, with the igneous rocks cropping out at their base and on the foreshore. At this halfway point, however, we see red sandstones, shales, and conglomerates again composing the cliffs and dipping to the south-east at  $60^{\circ}$  in a regular succession of beds. These rocks appear to be exactly similar to those above described in another portion of the bay, but are not so accessible. Their

Fig. 4.—*Dicynammatic section of cliffs on N. side of Ballydouane Bay.*

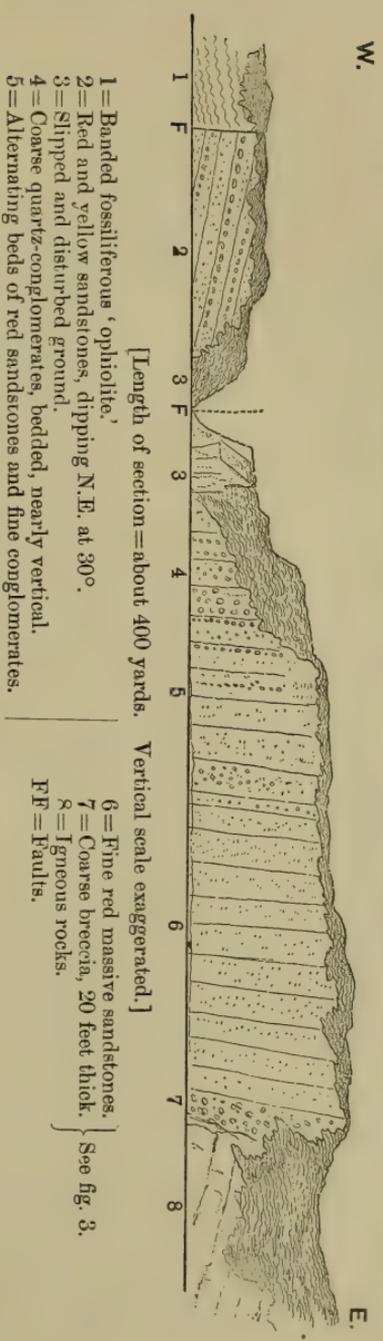
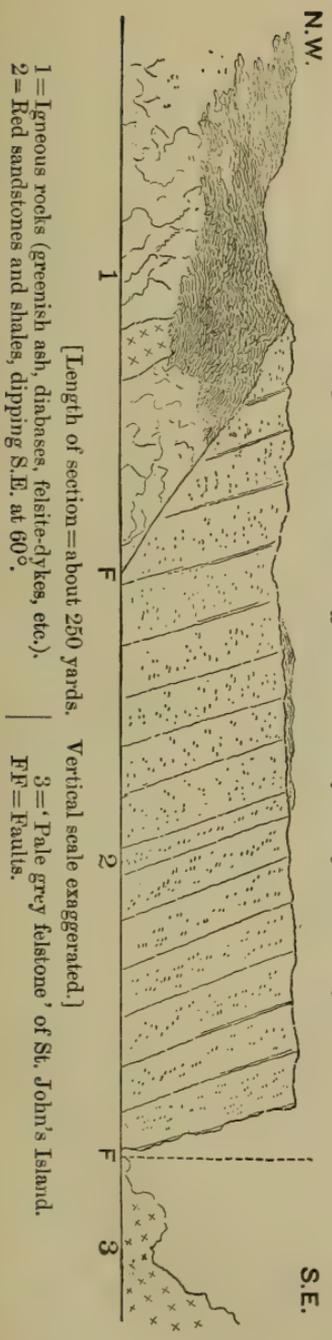


Fig. 5.—*Section in cliffs on E. side of Ballydouane Bay.*



junction with the talus-covered cliffs of the north-eastern angle of the bay is somewhat obscured high up by grass and rainwash, but it appears to be along a plane dipping about  $45^{\circ}$  S. Close to the level of the beach the older rocks which occur below this line of junction are crushed as along a fault-plane, which I take this to be (see fig. 5, p. 277). It does not appear to me to show the characters of a floor of deposition, like that to the north at the head of the bay described above.

The extreme point of the headland marked Poolatunish, and St. John's Island itself, are not composed of these red beds, but of some of the older igneous rocks—a 'pale grey felstone' according to the Survey. I was unable, however, to visit the base of the cliffs at this point, as it is inaccessible except by boat. Nevertheless, it was easy to satisfy myself from the top of the cliffs that the red beds are abruptly cut off by a fault at this point, and that a block of the complex and varied older igneous rocks of the coast is brought against them by this means.

Standing on the extremity of this headland of Poolatunish, and looking down into the small cove east of it, one can see the cliffs in its bend composed of the easterly extension of the southern mass of red beds of Ballydouane Bay, dipping south-east. They are sharply defined by faults from the igneous rocks, forming the promontories enclosing the cove. It may be that the fault in the eastern promontory is merely the continuation of that which cuts across the point of Poolatunish. At any rate the fault of the eastern promontory must run in a N.N.E. direction inland, as no red beds appear in the waterfall cove—Cooneenacartan—on the eastern side of this promontory. The red beds, however, were found inland in the townland of Ballynarrid and along the high road to Bunmahon (as far as the number '187' on the 6-inch map) east of the Cooneenacartan valley. This strip of red rocks appears, therefore, to be bounded both on the north and south by faults, the northern fault being that oblique one seen on the north-eastern side of Ballydouane Bay, and the southern fault that on Poolatunish headland.

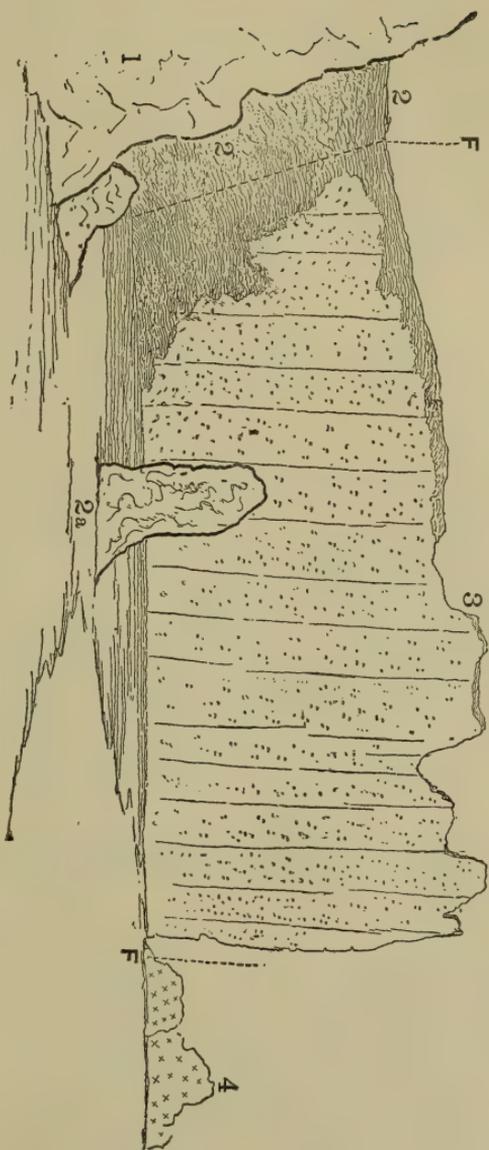
The next exposure of red beds is that of Bunmahon Head. They here form the headland known as Kennedy's Island, and this mass has been described by Mr. J. Hodgson Holdsworth.<sup>1</sup> The cliffs at this point are vertical, and rise to a height of about 120 feet; their edge exhibits in a striking manner the weathering into rectangular blocks, which is very characteristic of the Old Red Sandstone of Ireland<sup>2</sup> and elsewhere.

Viewed from the beach on the western side of the headland, the red beds are seen to form the whole wall of cliffs extending from the extreme point to the inner angle of the bay, where a steep grass slope exists. The red beds consist of the usual red sandstones, fine conglomerates, and shales, in alternating layers, and dip N.N.W. at an angle of  $80^{\circ}$  (see fig. 6). The above-mentioned grass slope at

<sup>1</sup> Journ. Geol. Soc. Dublin, vol. i. (1833) p. 85.

<sup>2</sup> Quart. Journ. Geol. Soc. vol. xxxv. (1879) p. 719.

Fig. 6.—Section of W. face of Kennedy's Island, Bunnahon Hea

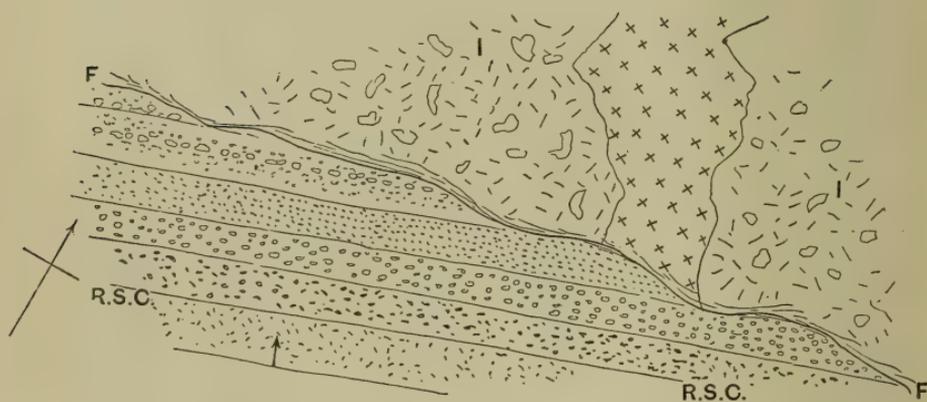


1 = Pink felsite and felsitic agglomerate occupying neck.  
 2 = Greenish ash, seen here and there on the grass slope.  
 2a = Greenish ash forming an isolated pillar on the beach.

3 = Red sandstones, shales, and fine conglomerates, dipping  
 N.N.W. at 80°.  
 4 = 'Epidiote felsite' forming reefs in the sea.  
 FF = Faults.

the inner angle of the bay hides the actual line of contact of the red beds with the neighbouring igneous rocks, but within a yard or so of the disappearance of the red beds we find a coarse so-called 'greenstone-ash' cropping out here and there. A great pillar of this ash stands out on the beach, some 20 or 30 yards from the foot of the slope, as an isolated mass right in the strike of the red beds of the cliff-wall of the headland, and thus it is evident that a line of fault separates them. A volcanic 'neck' filled with a felsitic agglomerate and a pink felsite runs up the cliffs almost vertically just on the west side of the grass slope, and cuts across the 'greenstone-ash' and a greenish felsite. There are no fragments of the red beds either in the 'greenstone-ash' or in the felsitic agglomerate of the neck, their absence indicating that both these igneous rocks are older than the red beds.

Fig. 7.—Ground-plan of foreshore on E. side of Kennedy's Island, Bunmahon Head.



- I = Greenish ash (crushed along line of fault), with intrusive dykes.  
 R.S.C. = Red sandstones and conglomerates, with thin red shaly bands.  
 F = Fault.

Passing round to the eastern side of Kennedy's Island and descending again to the beach by the zigzag path at the western corner of this eastern bay, we find here again the 'greenstone-ash' in the cliffs in contact with the red beds, and their line of junction may be most distinctly followed on the foreshore and over the reefs of rock, where successive beds of red sandstone and conglomerate are seen to end abruptly against the 'greenstone-ash' and igneous masses, which are somewhat crushed and shattered along the contact. This is most clearly another faulted junction, and the line of dislocation runs out to sea with a slightly sinuous course to the E.N.E. (see fig. 7). The red beds here, in the cliffs which form the eastern side of the headland, dip north-west at  $75^{\circ}$  to  $80^{\circ}$ . By the

side of the zigzag path down the cliffs they are of fine red sandstone and shale, while nearer the point thin bands of conglomerate come in, of varying degrees of coarseness, but mostly composed of small rounded pebbles. Thin layers of shale, 4 to 5 inches thick, occur in the conglomerates.

The larger pebbles of the conglomerates are subangular or angular in shape, and only the smaller ones are usually rounded; they consist of white and red vein-quartz, liver-coloured quartzite, and occasionally of felsites and other igneous rocks. The beds at the point are of coarser conglomerate; but the reefs and stacks off the point are composed of a felsitic rock—an 'epidotic felstone' according to the Survey Memoir—which is separated by a fault from the red beds, as at St. John's Island. Thus again in this locality we see the complete independence of the red beds and their sharp demarcation from the surrounding igneous rocks.

Passing along the coast and crossing the Bunmahon River we fail to find any trace of the red beds until we come to the little bay below the now deserted engine-house and ore-yard of the Knockmahon copper-mines. Here, on the top of the cliffs by the engine-house, the same type of conglomerate is found as at Kennedy's Island, but it is composed of rather larger pebbles and angular fragments. At the mouth of the shaft it is seen to dip to the north-west at about  $45^{\circ}$ , and is underlain by fine red sandstone resting unconformably at the top of the cliff upon an intrusive rock which forms all the lower portion of the cliff. The junction of the two is now inaccessible, and I was not able to determine whether it was a fault, but no basal breccia was visible, and I am inclined to think that a fault must exist. The ore-bearing lodes and quartz-veins in the igneous rocks are seen to end abruptly against the red sandstones and conglomerates. Mr. Hodgson Holdsworth (*op. cit.*) states that on the eastern side of Bunmahon Bay the conglomerate and 'red slate' underlie the rocks of the coast and run in a N.W.—S.E. direction, and that they are thought to disrupt or heave the principal lode. But in one shaft, at a depth of 10 fathoms, the same beds were pierced as those which are exposed on Kennedy's Island. Kinahan, however, says in his 'Geology of Ireland' (p. 28) that Mr. Hore, of the Bunmahon mines, proved that the red beds and conglomerates are of later age than the 'Cambro-Silurian' rocks of Knockmahon, and lie unconformably upon them, and that the lodes in the latter rocks are cut off by the conglomerates. What is now visible on the cliffs of Knockmahon corroborates this statement. The Geological Survey Memoir<sup>1</sup> also mentions the fact that both the Stage Lode at Knockmahon and the Trawnamoe Lode west of Bunmahon were lost when the red beds were reached.

<sup>1</sup> Explan. Sheets 167, 168, etc. p. 82.

## IV. SUMMARY OF THE EVIDENCE.

Summing up now the facts gathered from the above-described sections, the following points become evident:—

(1) The red beds either (*a*) rest unconformably on the edges of undoubted Lower Palæozoic rocks and are separated from them by a striking unconformity, or (*b*) are faulted against them. When the line of contact of the two sets of rocks is an unconformity, the basal layer of the red beds is frequently a breccia of variable thickness, composed of fragments of the underlying rocks. The absence or thinness of this basal breccia in some spots is of no importance, as a similar breccia at the base of the acknowledged Old Red Sandstone of the county occurs only at two widely separated localities—Dunmore and the base of the Comeraghs.

The strike and dip of the red beds are always widely divergent from those of the underlying rocks; and whereas the latter have suffered extensive disturbance and show much crushing, folding, and faulting in many places, the red beds are comparatively undisturbed, and certainly have not shared in the same movements.

The dykes, sheets, and other intrusive rocks penetrating the Lower Palæozoic strata of the coast have nowhere been found to pierce the red beds, but are abruptly truncated by them along a line of erosion.

When faulted junctions occur, the actual lines of dislocation are generally distinctly visible, and traceable on the ground or in the face of the cliffs.

(2) The patches of red rocks bear not only the closest resemblance to each other in lithological and structural characters, but also are precisely similar to certain of the undoubted Old Red Sandstone beds of the county. The mode of jointing and weathering exhibited by the rocks of these patches is also typical of the Old Red Sandstone.

(3) In no case is there indisputable evidence brought forward that these patches are really conformably interbedded with the Lower Palæozoic strata; and beds of similar lithological character are unknown in clear sections of these older rocks.

V. PROBABLE EXPLANATION OF THE MODE OF OCCURRENCE  
OF THE RED ROCKS.

There are no insurmountable or even grave difficulties to be overcome in attributing these red rocks to the Old Red Sandstone, or in accounting for the present isolated position of these patches. The post-Carboniferous folding threw the beds of this area into the well-known series of east-and-westerly trending folds, many of which are undoubtedly hidden beneath the sea off the southern coast, while others are cut across and partially denuded away—as at Dungarvan. Besides the large folds, the troughs of which now form valleys for several of the important rivers of this part of Ireland, there are other minor ones which have had comparatively little effect on the

features of the surface. Not all of these had their axes trending from east to west. Thus the Brownstown Head anticlinal and that of the Templetown district in Co. Wexford have an E.N.E. course. If we suppose a minor sharp fold, with a steeper northern limb, to have occurred in the Bunmahon district with this course and to have been dislocated by faults, and blocks of it to have been let down into the older beds, we shall be able to account for the occurrence of these patches.

Entering into details, we see first that this hypothetical anticline is cut across almost at right angles to its strike by the inlet of Ballydouane Bay. The next points to notice are the faults that have affected it. These may roughly be divided into two sets—one trending in a general W.S.W.-E.N.E. direction, and the other running transversely to them, with a downthrow to the east. In the accompanying sketch-maps (figs. 8 & 9) the first set are marked A, B, C, etc., and the transverse set *a*, *b*, *c*, etc.

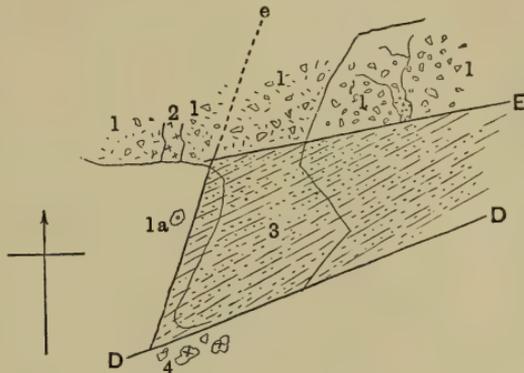
Fault A occurs on the north side of Ballydouane Bay, a short distance inland; its exact position is indeterminate, but its influence is plain, for it lets down on the south the steep northern limb of the anticline of Old Red Sandstone.

Fault B has a southerly hade of about  $45^\circ$ , and is seen in the cliffs on the east side of the bay. This is a reversed fault, as shown in fig. 10, p. 285.

Fault C, at St. John's Island, has a downthrow to the north, and thus, by faults B and C, a mass of Old Red Sandstone is troughed into the older rocks.

The small rib of red rocks in the bay of Ballydouane West has rather obscure relations, but it belongs to the northern limb of the anticline. On the north it is probably cut off by a continuation of fault A, shifted southward by the transverse fault *c* up the Ballydouane stream-valley. On the west it is seen to be cut off by a transverse fault *a*.

Fig. 8.—Sketch-map of Kennedy's Island, Bunmahon Head.



[Scale: 12 inches=1 mile.]

- 1=Greenish ash, diabase, etc. 1a=Pillar of greenish ash.  
 2=Felsitic neck. 3=Red sandstones, shales, and conglomerates.  
 4=Epidotic felstones. De, DE=Faults.

Fig. 9.—Sketch-map of the neighbourhood of Ballydouane.

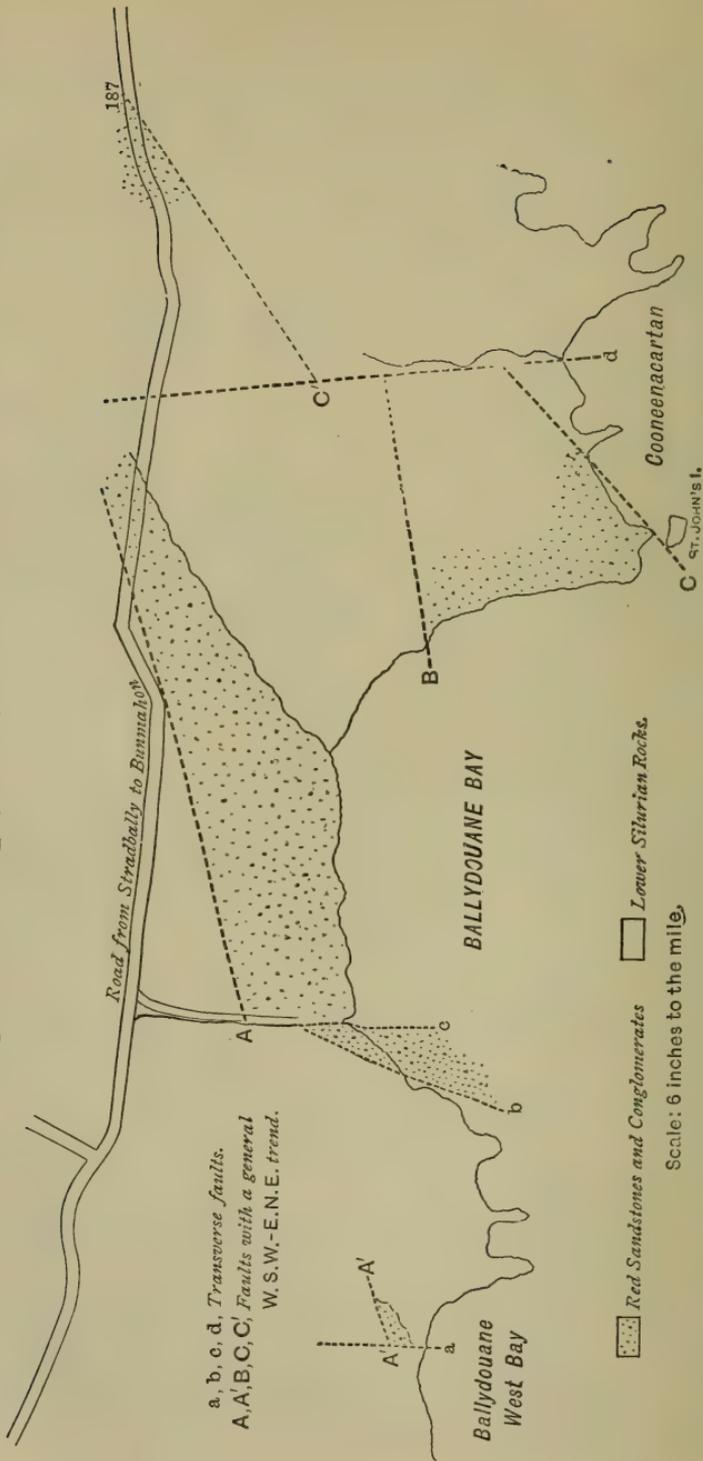
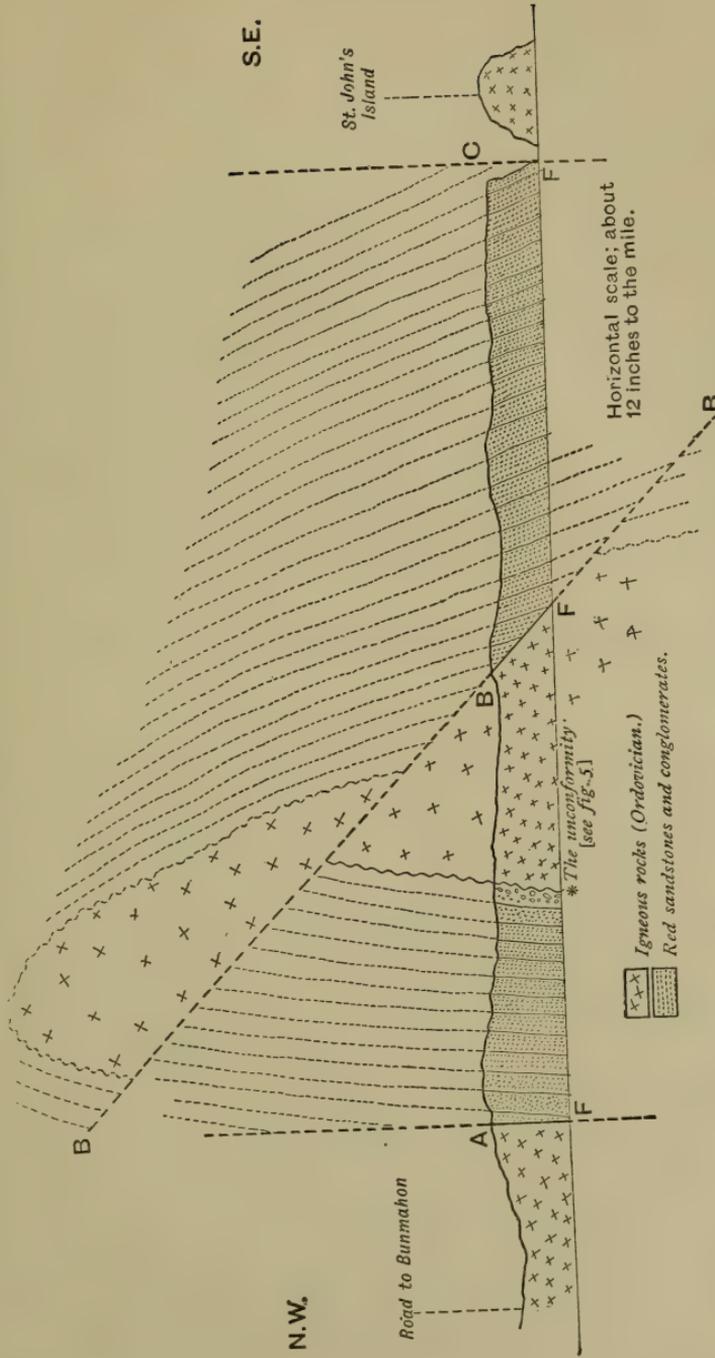


Fig. 10.—Diagram-section on E. side of Ballydouane Bay (to illustrate structure of broken anticline).



F = Faults A, B, C (B is a reversed fault) See fig. 9

A transverse fault *b* is well seen at the western corner of Ballydouane Bay, bringing the red sandstones against the 'ophiolite.' There may be more than the one transverse fault *c* at the mouth of the stream, but the beds are here confused by slips. A transverse fault is also supposed to run up the Cooneenacartan valley, shifting back the outcrop of the Poolatunish block of Old Red Sandstone to the road and townland of Ballynarrid.

The Bunmahon mass of red beds is cut off on the N.E. by a fault (E) running towards the E.N.E. from the angle of the bay. On the west it is cut off by a transverse fault (*e*), and on the south side one of the other set of faults (D) bounds it with a downthrow to the north, as at St. John's Island. Bunmahon Head is thus a triangular mass faulted on all sides (see fig. 8, p. 283). But it plainly belongs to the northern limb of the anticline. The Knockmahon mass must also be bounded by faults, but the positions of these are uncertain.

It is thus perfectly possible to account for the occurrence of the isolated masses of Old Red Sandstone by the faults traceable on the ground, nearly all of them being clearly exposed on the coast.

Any theory explaining them as strata interbedded with the Lower Palæozoic rocks is met by extraordinary difficulties; and I cannot see how these can be overcome in the face of the evidence of the sections.

In my opinion all the evidence points to these masses being faulted inliers of the Old Red Sandstone.

#### DISCUSSION.

The PRESIDENT remarked that the paper opened up many points of considerable importance with regard to the succession of these red rocks in the South of Ireland, South Wales, and Devon. This coast of Wexford and Waterford was separated from Pembrokehire by only 50 miles of sea, and the experience of the Author on the Pembrokehire coast had doubtless helped him to unravel the complicated structure of the Irish coast. Faults helped to explain this complexity—faults which took place at the end of the Carboniferous influencing all the rocks that had been deposited before that time. Earth-movements had caused so much compression and faulting as to throw beds out of the true succession into a false one. Here we had a slice of Old Red Sandstone brought into apparently conformable succession with much older beds. Such examples, but much more evident, were seen again and again on the Pembrokehire coast. The Author's lithological evidence was extremely convincing, and we had to use this in the absence of palæontological evidence.

Prof. HULL welcomed a paper such as the present on an Irish subject. He had, unfortunately for the present discussion, never had an opportunity of visiting the part of the coast of Waterford described by the Author, inasmuch as before his sojourn in Ireland, as Director of the Geological Survey, the district referred to had been surveyed by Du Noyer under the direction of the late Prof. Jukes. After having listened to the present paper, illustrated

as it was by clear diagrams and good specimens, he felt very much inclined to concur in the Author's views. The specimens of conglomerate considered by the Author to have been let down by faults, and to be discordantly superimposed on the Lower Silurian (or Ordovician) rocks, appeared to him to resemble the beds of the Upper Old Red Sandstone, rather than those of the Lower Silurian of that part of Ireland; and considering the whole case, as ably discussed by the Author, he was disposed to think that the latter's views had been made out.

Prof. HUGHES had examined some of the rocks described by the Author in the neighbourhood of Waterford, and so far as his own observations went they were quite in accord with those of the Author. He did not see how there could be much doubt as to his inferences, if the facts which he had recorded and supported by photographs, sections, and plans were admitted. The crushed-looking weathered character of the older rocks immediately below the conglomerate was precisely what we should expect to represent an ancient land-surface. The angular fragments of subaerial talus at the base, and the tough pebbles in a somewhat oxidized matrix of the overlying series, were exactly what must have resulted from the washing-down of the superficial deposits of a gradually submerged area. And all this, together with the evidence of great disturbances between the deposition of the two series, and the nature of the movements shown to have occurred since the deposition of the newer beds, agreed with what was known as to the relations of the Devonian to the pre-Devonian rocks, but not with the relations known to exist between the Silurian and Ordovician, or between any of the several members of the Ordovician.

Mr. W. W. WATTS pointed out that the determination of these rocks as Silurian had been made by Du Noyer, who, after examining the ground, came to the conclusion that Jukes was right in regarding them as belonging to this period. Similar, but thinner, red rocks occurring near Wexford, seen by the speaker and Mr. McHenry, were intercalated in the Silurian rocks in a district where true Old Red Sandstone was unknown. If the Author were right as to his facts, there could be no doubt as to the interpretation of them.

Mr. H. W. MONCKTON, Mr. J. E. MARR, Mr. W. WHITAKER, and Mr. W. V. BALL also spoke.

The AUTHOR thanked the Fellows for the manner in which they had received his paper. Referring to remarks made by the President and Mr. Watts, he wished to express his sense of the value of the work of the Geological Survey in that part of Ireland, though he differed from the Surveyors' conclusions about the age of these beds. The faults affecting the red rocks were in his opinion probably contemporaneous with the post-Carboniferous folding. With regard to the view expressed by Mr. Watts that the beds might be of Silurian age, he thought it highly improbable—firstly, because of their complete identity in character with the typical Old Red Sandstone of the county, and in their relations to the underlying rocks; and secondly, because of the complete absence of proof of the deposition

of any Silurian beds anywhere in the South-east of Ireland. In order to consider these beds to be of Silurian age, we should have to suppose, first, the folding, cleaving, and upheaval of the Ordovician rocks, then their great erosion, then their depression and the deposition of these red beds on their edges in Silurian times, then the faulting and tilting of these beds coupled with the upheaval of the area, then a long period of erosion to account for their complete removal from every other part of the area, then again depression in Upper Old Red Sandstone times. And in support of such views, there is not even the lithological similarity of the red rocks to Silurian beds, much less the occurrence of a Silurian fossil, or the evidence of the unconformable overlap upon them of the Upper Old Red Sandstone, which Prof. Hull has shown everywhere in the South of Ireland rests with a great unconformity upon all the older rocks, including the Silurian. There is, moreover, not another section in the area in which any similar beds occur, except those belonging to undoubted Old Red Sandstone.

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[No. 211 will be published on the 2nd of next August.]

[The Editor of the Quarterly Journal is directed to make it known to the Public, that the Authors alone are responsible for the facts and opinions contained in their respective Papers.]

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**Vol. LIII.**  
PART 3.

AUGUST 2nd, 1897.

**No. 211.**

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,, December .....	1-15
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22. NOTES on some VOLCANIC and other ROCKS, which occur near the BALUCHISTAN-AFGHAN FRONTIER, between CHAMAN and PERSIA. By Lieut.-Gen. C. A. McMAHON, V.P.G.S., and Capt. A. H. McMAHON, C.I.E., F.G.S. (Read March 24th, 1897.)

## [PLATES XVIII-XX.]

Part I.—THE BALUCHISTAN DESERT, SOUTH OF THE HELMAND RIVER.  
By Capt. A. H. McMAHON.

WHILE engaged, in the deserts south of the Helmand River, in the delimitation of the boundary between Afghanistan and Baluchistan, I made a small collection of such rock-specimens and fossils<sup>1</sup> as I thought were characteristic of the geology of the country. I regret to say that I am not myself a geologist, else my collection would have been perhaps a more methodical one, and would probably have been supplemented by notes on the positions and surroundings of the specimens collected, and on other points of geological interest. I say perhaps, because even if I had been the most learned of geologists I doubt whether political and other duties would have allowed me time to do more than I did. At any rate my collection would not have been a larger one, for the simple fact that, owing to long marches and want of water and food, our transport-camels were almost unfit for work, and the mortality among them rendered it a matter of difficulty for us to carry even the necessaries of life.

Turning now to the physical geography of the country, one finds in it various natural phenomena on a gigantic scale, the study of which I venture to think may throw light on similar phenomena seen elsewhere on a smaller scale. It is a country almost uninhabited by man, where man has left nature to do as she pleases undisturbed. If you look at the map (Pl. XVIII), you see high mountain-ranges fringing it on the east and south-east. These vary in height from 6000 to 8000 feet above the sea. West of them lies a vast wilderness of plains stretching away some 300 or 400 miles to the mountain-ranges along the Persian border which fringe them on the west. Rising like rocky islands out of the midst of this vast sea of plains are mountain-ranges upwards of 7000 feet high. The north of this tract is bounded by the Helmand River.

We will consider firstly the plains and their drainage-system, and then the mountains.

### The Plains.

We have first of all a wide level plain of alluvial soil which includes the whole of Shorawak, and then, spreading out from Nushki on the east to Chagai on the west, it stretches southward to

<sup>1</sup> These fossils have been made over to the British Museum (Natural History).

the foot of the Ras Koh and other mountains running south and west from Nushki. You see the Lora River coming out of the mountains and crossing the plain in the direction of the Lora Hamun, where it comes to an end. This river never reaches the Lora Hamun, except in flood-time, and then it makes the Hamun a broad lake of shallow water. This soon evaporates, and for the greater part of the year the Hamun is nothing but a vast sheet of dry, solid salt. It is evident that not only the Hamun, but all this plain, must once have been a great lake, thus accounting for the rich alluvial soil of which the plain is formed. North of this plain and stretching to the Helmand River lies the Registan sand-desert—a wide stretch of billows upon billows of sand with crests some 200 feet high. This

Fig. 1.—*View showing sand-dunes covering lower slopes of mountains and gradually overwhelming the higher spurs.*



[From a photograph.]

sand-desert, interspersed with level plains of black gravel, stretches from the Chagai and other mountains to the Helmand westward as far as the Persian border. In places this sand-desert is like unto a fairly calm sea, and the waves of sand are only of moderate height. In other places, especially along the north of the Koh-i-Sultan, Damodim, and Amir-Chah ranges, it resembles a wild stormy sea with great waves 100 or 200 feet high breaking against the sides of the mountains like the Atlantic surge on a rock-bound coast (see fig. 1). Here the sand-hills assume the proportions of sand-mountains. Many of the mountains themselves have become buried in sand and are no longer visible—others still tower with

their black crags above the sandy waste, but the sand banked some 1000 or 2000 feet above the level of their base foretells a similar fate in store for them.

The phenomena of sand-hills—their origin, formation, and prevailing shapes—are in themselves an interesting and difficult study, and it will be remembered that recently Mr. Vaughan Cornish read a valuable paper on the subject before the Royal Geographical Society, which, with the record of the discussion that followed, deserves the notice of geologists.<sup>1</sup> Suffice it here to note that some of the speakers on that occasion laid stress on the fact that, however devouring an element sand may be, water always has the upper hand, and that a small stream of water will always cut its way through sand. But in the country here described this principle does not hold good. If one looks at the map one sees that the drainage of the mountains from Chagai westward runs in the direction of the Helmand River, and farther west still it runs towards the God-i-Zirreh Lake. Little of that drainage ever reaches the Helmand River; none of it, so far as I can ascertain, reaches the God-i-Zirreh. In each case it is stopped by the sand. After rain, immense volumes of water must run down from the mountains in the numerous torrent-beds, but it is easy to see that this water never travels beyond the first few opposing lines of sand-hills. The God-i-Zirreh was at one time fed by flood-water from the Helmand, but it does not appear to have received any replenishment since 1880, that is 17 years ago, and it is now a lake of salt brine fringed by an ever-encroaching margin of solid salt. The great Helmand River farther north comes to a standstill in the lakes and swamps of Seistan.

### The Mountains.

The line traced on the map (Pl. XVIII) from north of Chaman to Nushki marks the course of a gigantic fault, or earthquake-crack, which was discovered when we came to carefully examine this country. It runs in a well-defined line of indentation, as well marked in places as a deep, broad railway-cutting. It starts at the edge of the plain north of Chaman and runs along the foot of the mountains to the point on the Chaman and Quetta railway-line where the earthquake of December, 1892, so curiously distorted the track, and shortened the distance between Chaman and Quetta by no less than  $2\frac{1}{2}$  feet, as described by Mr. C. L. Griesbach, now Director of the Geological Survey of India, in the May number of the Records of that Survey for 1893.<sup>2</sup>

From that point the fault runs on, gradually ascending diagonally the slopes of the Khwaja Amran range, until it crosses the crest of the main range near its highest peak, at an elevation of about 7000 feet. Descending again into the Spintizha Valley it thereafter ascends diagonally the slopes of a continuation of the Khwaja-

<sup>1</sup> Geogr. Journ. vol. ix. (1897) pp. 278–309.

<sup>2</sup> Vol. xxvi. pt. ii. pp. 57–61 with 3 plates.

Amran range. Cutting this in a similar manner, it descends to the Lora River, and, crossing that river, runs along the whole length of the base of the Sarlat range to Nushki. Beyond this point the duties connected with boundary-work prevented us from tracing it.

The length of this line, as surveyed by us, is no less than 120 miles. Along the whole course of it we found springs of water, and, both from the presence of water and from its forming a short cut across innumerable mountain-spurs, this fault-line is largely used by the natives as a thoroughfare. The old greybeards of the tribes living near it told us that on some three occasions during their lifetime, after severe earthquake-shocks, deep fissures had appeared along this line, and that similar accounts had been handed down to them by their fathers. After one of these earthquake-shocks the water-supply of the springs along the crack had, they said, been largely increased.

The rocks along the east of this fault-line appear to be sedimentary, and the mountains on the east are all of clay-slate. The rocks on the west are for the most part volcanic and igneous, but there are a few sedimentaries among them.

In the mountains on the Persian border we again come to shales and other sedimentary rocks. The Chagai, Koh-i-Sultan, and other mountains appear to be volcanic; some, like Damodim, retain their crater-form better than others. Lava, ash, and pumice abounded in all those localities where the mountains showed above the sand. The pumice was found lying about in large quantities, and it was abundantly sprinkled over the sand—whither it may have been blown by the wind.

Unfortunately, circumstances did not allow of a visit to the crater of Damodim. Natives told us that in the deep hollow at the top of that mountain there is some good soil which they are able to cultivate. All these volcanoes have no doubt long been inactive, but some 90 miles south-west of them lies the great Koh-i-Taftan, also known as the Koh-i-Chehaltan, 12,600 feet high, which is said to be still an active volcano.<sup>1</sup>

<sup>1</sup> [Since this paper was read the authors have been in personal communication with Capt. P. Molesworth Sykes, British Consul at Karman, now in England on leave, who climbed the mountain on Christmas Eve, 1893. After gradually ascending ravines in the foot-hills around the mountain, the exploring party arrived at the foot of the cone, at an elevation of 10,000 feet above the sea. Thence up to 11,000 feet the ground traversed consisted of boulders; but from 11,000 feet up to the top it was covered with fine volcanic ash, into which the foot sank deeply at every step. Throughout this portion of the ascent the smell of sulphur was unpleasantly strong. The summit consists of a plateau covering an area of about 400 square yards. On its northern and southern sides there are slight elevations, separated from each other by a narrow but shallow valley. The northern elevation forms the Sacrifice Hill, where goats are sacrificed by pilgrims; while the southern portion is called Madar Koh (Mother Hill). On the latter were, at the time of Capt. Sykes's visit, two apertures, some yards apart, each apparently 3 or 4 yards wide, which appeared to be connected with each other. From both of these dense white sulphurous smoke and flames were issuing. So strongly sulphurous and suffocating was the smoke that these holes could be approached only from the windward side, and even that was difficult, owing to the smoke and heat. Sulphur

The Koh-i-Sultan mountains deserve a few remarks, owing to the curious and grotesque shapes of their high peaks, which remind one irresistibly of Gothic cathedrals and churches. Here, too, we find a high natural pillar which, as seen at a distance from the plains below, looks like an artificial monolith on the crest-line of the range. On approaching it, we found that it was a huge natural pillar of stupendous size, made up of volcanic agglomerate. From the width of the base, which is over 100 yards in diameter, I calculate that its height must be over 800 feet. Deep fissures down its sides, caused no doubt by the action of rain, give it a fluted appearance from a distance. (See fig. 2, p. 294.)

So much for the general character of the country. In considering the present condition of its surface and the geological and other natural phenomena to be found there, it is advisable to note carefully the natural agents which are at work in that region with a force and activity unknown in most other countries. First of all, we have the agency of water, which is a more particularly destructive agent here precisely because this part of Baluchistan is one of the driest countries in the world. Rain comes but seldom, but when it comes it pours with great violence, and from the absence of vegetation or surface-soil, it rushes off the mountain-sides in huge torrents. The high-water marks in the dry torrent-beds and the large rounded boulders piled one upon another in those beds show with what volume and force those torrents come down.

Then we have the wind. I have never travelled in a country where strong winds are so frequent and continued. There is one wind alone which blows there with hurricane violence continuously

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and sal ammoniac were, however, extracted from the edge of one of these apertures.

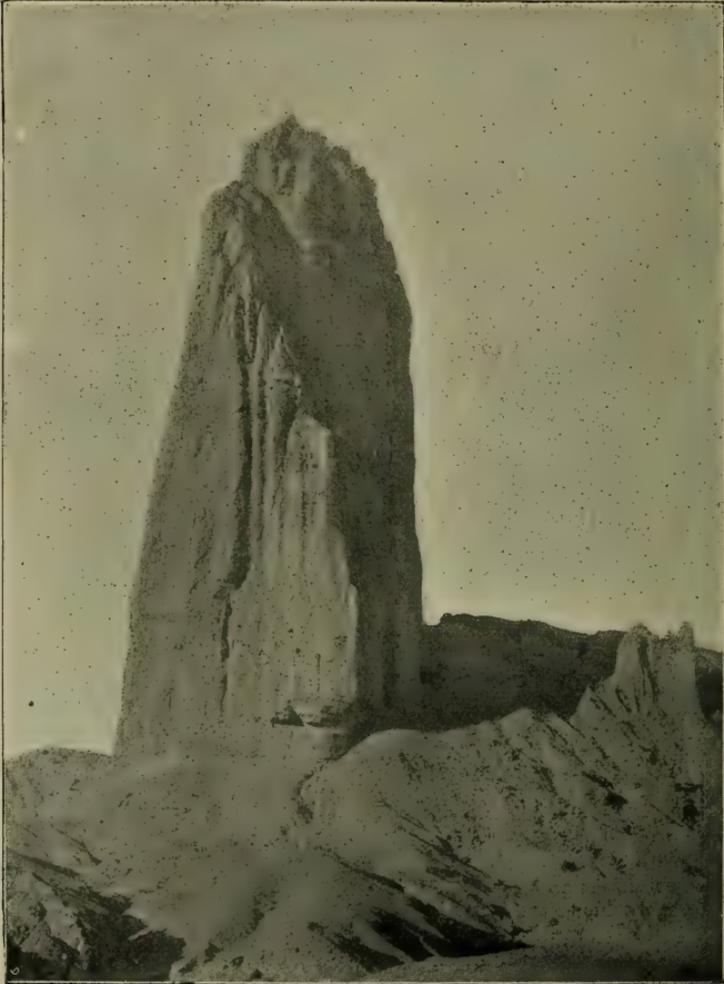
Capt. Sykes has paid several visits to the burning petroleum-springs at Baku, on the western shore of the Caspian Sea, and he is satisfied that the heat, smoke, and flames on the summit of the Koh-i-Taftan were not due to petroleum. There was no smell of petroleum, nor was the smoke dark and carbonaceous.

As the summit of the Koh-i-Taftan is still thickly covered with fine ash, this volcano must have been active during a recent geological period; but as no very fresh lava-streams appear to have been observed on the way up the mountain, it is not probable that the volcano has been active during the lifetime of the present generation. The authors infer from Captain Sykes's observations that the volcano is now in the solfataric stage of its existence. The flames seen were probably due to the emission of hydrogen sulphide ( $H_2S$ ), a very common and inflammable product of solfataric action.

Capt. Sykes brought home with him a specimen of lava found *in situ* on the Koh-i-Taftan, and this proves, on examination under the microscope, to be a vesicular hornblende-andesite. The hornblende belongs to the orthorhombic group, and is identical with the very peculiar red-brown and brilliantly dichroic variety of anthophyllite described in Part II. of this paper. It is very abundant in the Koh-i-Taftan slice. Augite is also sparsely present in it, but there is no olivine. Magnetite and ferrite also occur. The anthophyllite has strongly marked resorption-bands, and it is undoubtedly an original mineral. It is interesting to note that this peculiar mineral is a characteristic constituent of the lava of the Persian volcano Koh-i-Taftan as well as of some of the somewhat older lavas of Baluchistan described in this paper.—May 15th, 1897.]

for four months, from May to September, every year, and we found from sad experience that violent storms were not confined to that season alone. In considering this country we must neither overlook these strong winds, nor the effect which they have on the sand, nor

Fig. 2.—*The Neza-i-Sultan, a natural pillar of volcanic agglomerate.*



[From a photograph.]

the destructive effect which, combined with the sand, they have on everything else.

Last but not least, great extremes of heat and cold are the rule here, greater extremes perhaps than are found anywhere else in the world. The summer heat is terrific, while in the winter there is very severe cold; and not only is there a wide seasonal range of temperature,

but also a very wide diurnal range. Our solar radiation-thermometer would register 205° F. on cloudless days, while the nights in the sandy tracts were often bitterly cold. The diurnal variation must sometimes have been as much as 150° F. It is needless to point out how powerful an agent these wide variations of daily and annual temperature must be in the disintegration of the surface of the country. Nor is there cause for astonishment, if we think of the peculiar conditions of water, wind, and sand-action and of heat and cold obtaining in this country, that its surface should present curious and unusual features.

## Part II.—PETROLOGICAL NOTES *on the Rocks.*

By Lieut.-Gen. C. A. McMahan.

A NUMBER of rock-specimens collected by my son, Capt. A. H. McMahan, C.I.E., Boundary Commissioner, when engaged in the delineation of the boundary between Baluchistan and Afghanistan up to the borders of Persia, were made over to me for examination. Selected samples of these were sliced and studied under the microscope, and the results are embodied in the following pages.

### Andesites.

[The numbers are those of the slides in my own collection.]

No. 1424.	Augite-hornblende-andesite.	Sp. gr.=2.682
„ 1438.	„ „ „	„ 2.727
„ 1464.	Hornblende-andesite	„ 2.645
„ 1425.	„ „	„ 2.715
„ 1426.	„ „	„ 2.625
„ 1430.	Mica-andesite	„ 2.549
„ 1443.	„ „	„ 2.597
„ 1436.	Andesite	„ 2.645

The andesites enumerated above are in some respects very peculiar rocks, of a type not commonly met with. They vary in colour from grey to almost white. Many of them are very trachytic-looking, and some years ago would probably have been classed as trachytes. As, however, the felspar of which they are built up is a plagioclase, and not sanidine, they cannot be called by that name.

The specimens grouped together in the above list possess several features in common.

The first point to be noted is their low specific gravity, which averages 2.648. The mean specific gravity of quartzless andesites, according to text-books, ranges from 2.7 to 2.8; so that the average density of the rocks now described is somewhat low. The percentage of silica is evidently high, but I have not observed any free quartz in any of my slides.

The ordinary method of determining the specific gravity of a rock cannot be applied to these specimens, in consequence of their porosity. I boiled the samples for some time and allowed them to soak in water from 24 to 48 hours before weighing them in fresh unboiled

water, but the specific gravity even after these precautions had been taken was in almost every case too low. The specimens doubtless contained hidden vesicles filled with air, or gas, which the water failed to reach. The specific gravities given above were obtained by the use of a specific-gravity bottle. The rock was reduced to powder and boiled, and the weighing was done with the aid of a chemical balance.

The low specific gravities obtained are, I think, innate and characteristic of these rocks. In one case the low density is due to the alteration of the feldspars, which in this sample were mere pseudomorphs. Fragments of them were isolated, and their specific gravity determined with the aid of a heavy liquid and a Westphal's balance. It was too low for any feldspar. I do not think, however, that this explanation applies to the rocks generally, for the feldspars in them appear fairly fresh. Oligoclase appears to predominate, and the density of this species ranges from 2.65 to 2.67. The low specific gravity of these rocks is due, I think, to the acid character of the feldspars; to the fact that they contain inclusions of glass; and to the presence of a glassy base. The mean density of pitchstone is 2.34 and of obsidian 2.40. Glass of low specific gravity seems to be present in sufficient quantity to balance the basic ferromagnesian silicates, and leave the rock, as a whole, at the density of the dominant feldspar contained in them, which in these rocks I would not put higher than 2.65.

The andesites grouped together in the above list are mainly composed (the accessory minerals will be alluded to later) of idiomorphic crystals and microliths of feldspar embedded in a base which appears amorphous in ordinary light, but which when revolved between crossed nicols remains dark in some cases, and in others breaks up into cryptocrystalline or into microgranular felsitic material. In one of the first-named cases the glassy base has been converted into yellow palagonite, but in places the original purple-brown coloured glass remains. The glassy base during the later stages of the lava's history exercised a distinctly solvent action on the comparatively basic minerals that had crystallized out from the still fluid magma, for all the original minerals have been more or less corroded by it.

The feldspar-microliths vary in numbers very much in different slices. In some the base is crowded with them, but in one or two they are sparse. They do not exhibit in their orientation indications of fluxion except partially, and locally, in their relation to the larger feldspars. In all cases they belong to the oligoclase-feldspar species. Binary twinning, combined with simultaneous extinction, is common, though, in some cases, more than two macles are to be seen. The high refraction of those with binary twins, as compared with the refraction of the Canada balsam of the slide, shows that they are not orthoclase.

The feldspars larger than microliths cannot be classed as feldspars of first and second generation, for, as a rule, they dwindle gradually in size from large tabular crystals, or aggregates of crystals, down

to the smallest microlith. In short, there is a gradation in the size of the feldspars from the largest down to the most minute: this characteristic is found not only in the feldspars, but in all the original minerals.

Zonal structure is well seen in all the large phenocrysts; and that this is due to gradual growth is apparent from the fact that the angles of extinction of the different zones vary, and indicate a gradual change in the basicity of the mineral.

The larger feldspars are sometimes oligoclase and sometimes andesine, though the former would seem to predominate. Their species were determined partly by the evidence afforded by the angles of extinction measured in suitable cases, and partly by the determination of the specific gravity of isolated fragments.

There can be no question about the species of a considerable number of the crystals, because the simultaneous extinction of twins is not uncommon; and that those which exhibit binary twinning, combined with simultaneous and straight extinction, are not orthoclase, is shown by the fact that, whenever they occur in contact with the Canada balsam of the slide, their refraction is invariably found to be higher than that of the balsam. This method of distinguishing between orthoclase and oligoclase, recommended by M. Michel-Lévy,<sup>1</sup> seems to be a valuable and reliable test.

The large feldspars are, generally speaking, fairly fresh, but some are considerably altered. No. 1425 contains some calcite, as a secondary product of decomposition, in the interior of the feldspars; and those of No. 1438 contain dusty-looking matter, arranged either in a central core or as a zonal band inside a rim of water-clear feldspar. This dusty matter may be microscopic granules of limonite, but it is not magnetite. Fresh feldspars, notably those of No. 1424, contain very characteristic glass- and stone-inclusions with fixed gas- or air-bubbles, and inclusions of the base. Others possess liquid inclusions, a few of which contain extremely minute moving bubbles.

Magnetite and apatite appear to be original minerals common to all these rocks. Magnetite is present in all the slices and varies in size from large grains to minute dots; sometimes it has been largely converted into ferric oxide. It occurs as a secondary as well as an original mineral.

Apatite is present in seven out of the nine slides, and it is sometimes very abundant. The contact-action of the acid base has in some few cases corroded the crystals, and in some others has produced a dark 'resorption'-ring. The crystals that exhibit this unusual peculiarity are probably mangan-apatites. The hand-specimens treated with nitric acid reacted strongly for phosphoric acid. Apatite appears to have been one of the first minerals to crystallize out of the magma.

The three specimens which stand at the top of my list (p. 295)

<sup>1</sup> 'Étude sur la Détermination des Feldspaths,' 1894, p. 62.

contain, in addition to the minerals above mentioned, a rhombic amphibole. In transmitted light it is of a rich brown-red colour and is powerfully dichroic, changing from a golden yellow, when the direction of elongation of the crystal is at right angles to the principal section (longer diagonal) of the polarizer, to a rich brown-red, or red-brown, when the direction of elongation is parallel to the longer diagonal of the nicol. The mineral possesses straight extinction, and it appears to be anthophyllite.

Slice No. 1424 contains some very characteristic cross-sections of prisms of this mineral, which show the intersection of the prism-faces and the intersection of the prismatic cross-cleavages. They are quite typical cross-sections of amphibole. The major (+) axis is, as in rhombic amphibole, at right angles to the direction of elongation. Moreover, I isolated fragments of this mineral and determined its specific gravity with the aid of a heavy liquid and Westphal's balance, and found it to be exactly that of anthophyllite: namely, between 3.1 and 3.2.

The anthophyllite appears to be an original mineral in these rocks. Crystals of feldspars are caught up in it, and in Pl. XIX, fig. 3, a case is depicted where a large augite has caught up and enclosed a fragmentary-looking crystal of anthophyllite. That the latter is an original inclusion in the augite appears plain, from the fact that contact-action has produced a dark halo round the anthophyllite.

The case represented in Pl. XIX, fig. 4, is an interesting one, and bears directly on the question at issue. The anthophyllite, when it began to crystallize, formed on the lower half of a feldspar-microlith. The growth of the feldspar in that direction was arrested, but it continued to grow and widen along its upper half where the anthophyllite did not interfere with it. Similar cases of interference between growing crystals of augite and feldspar are often seen in basalts; but the case has a special importance in the study of these rocks, as it shows conclusively that the crystallization of the smaller feldspars and the anthophyllite was contemporaneous.

Rosenbusch, in his work on rocks,<sup>1</sup> notes that a brown hornblende with an extinction-angle ranging from small to nothing is known to occur in some andesites. In the slices above described the angle of extinction is uniformly *nil*.

In Nos. 1424, 1438, and 1464 all the amphibole consists of anthophyllite; but the first two contain in addition a considerable amount of augite. In transmitted light it is of a somewhat pale brown-green colour, sometimes putting on a purplish tint: it shows no dichroism. A single cleavage predominates, but more or less distinct traces of a cross-cleavage may sometimes be seen. The augites occasionally exhibit crystallographic outlines, but are more frequently allotriomorphic.

The augite-hornblende-andesites, Nos. 1424 & 1438, are remarkable for containing crystals of olivine. Rosenbusch, in his work already referred to, mentions that olivine sometimes occurs in andesites, but one would certainly not expect to meet with this mineral in a

<sup>1</sup> 'Mikroskopische Physiographie der Massigen Gesteine,' 2nd ed. (1887) p. 659.

rock of the intermediate class which inclines towards the acid type. In transmitted light it is of so pale a greenish-white as to be almost colourless. The refraction is high, and the surface is rough and shagreened. Traces of a fine interrupted cleavage are to be seen, and the mineral has straight extinction with reference to this cleavage. It has also the deeper and more irregular cracks so commonly seen in olivine. The form is sometimes roughly idiomorphic, and photographs of two (one from No. 1424 and the other from No. 1438) are reproduced in Pl. XIX, figs. 5 & 6, which show the pointed terminations characteristic of olivine.

Several of these olivines, as in Pl. XIX, fig. 5, have a deposit of the brown-red anthophyllite round a portion of the outer edge of the olivine. Rosenbusch<sup>1</sup> notes the alteration of olivine, beginning with the periphery of the latter mineral, into needles of tremolite, actinolite, and anthophyllite, owing to the mutual influence of the olivine and the adjacent rock-constituents, and states that this is known to occur only in the Archæan rocks. At first sight, the anthophyllite-fringe above described would seem to be a case of alteration similar to that noted by Rosenbusch; but in view of the fact already shown, that the anthophyllite in these rocks is an original congenital mineral, I think it is more probable that the anthophyllite round the margin of the olivines is of the nature of an intergrowth. It does not occur in needles, and so far from these andesites being of Archæan age, there is reason to believe that they are, geologically speaking, comparatively modern. Numerous crystals of anthophyllite occur in these slides, in forms that could not possibly be referred to olivine.

In the next two slides, Nos. 1425 & 1426, ordinary monoclinic hornblende takes the place of anthophyllite. It is of a brownish-green colour—the green element being very distinct; it is strongly dichroic, and the angle of extinction is small. It was evidently one of the first minerals to crystallize out, and it has suffered much from the corrosive action of the more acid magma. Many of the crystals are rounded and corroded, and all have a broad black ‘resorption’ margin of magnetite.

The condition of the hornblende in these sections confirms the conclusion arrived at regarding the anthophyllite: namely, that the amphibole in these rocks is an original mineral, and crystallized out before the magma ceased to be fluid.

In Nos. 1430 & 1443 amphibole gives place to mica. In transmitted light the mica varies from a yellow-brown to a greenish brown. It has suffered much, and has been corroded by the solvent action of the liquid magma. It is present in good-sized leaves and packets, and also (No. 1443) in the form of fibrous microliths.

No. 1436 closely resembles the rocks above described in its general characteristics, but it does not contain any amphibole. It is much altered and contains some secondary minerals, such as zoisite and ferric oxide, the latter partly infilling some of the felspars. There is also apparently the remnant of an augite.

<sup>1</sup> ‘Microscopical Physiography of Rock-making Minerals,’ transl. & abridged by J. P. Iddings, 1888, p. 217.

## Felspathic Lavas.

No. 1434.	Sp. gr.=2.751.	From the	Shibian Kotal.
„ 1429.	„ 2.847.	„	Amir Chah.
„ 1416.	„ 2.851.	„	Amir Chah.

These rocks seem to lie intermediate between the andesites proper and the basaltic lavas.

No. 1434 is a light greyish, yellow-ochre-coloured, slaty-looking felsite. It is composed of crystals of oligoclase set in a micro-felsitic base. The felspars look like fragments, and suggest the possibility of the rock being an altered ash; but I think this is probably owing to the partial remelting and deep corrosion of the felspars by the base when liquid. The rock is considerably altered, being dotted over with epidote, which has also formed in some of the felspars.

No. 1429 is a dark, blackish-grey, compact lava. The slice is composed of a matted mass of microliths and idiomorphic phenocrysts of felspar, set in what seems to have been originally a glassy base. The base, together with the major part of the large felspars, has been altered into a structureless chlorite. Opalescent quartz and epidote have been introduced along and adjoining cracks, and the slice is dotted over with colourless epidote, and minute spots of a mineral, opaque in transmitted but white in reflected light, which is probably a leucoxenic variety of sphene. The microliths and small felspars have straight extinction, and their refraction is precisely that of the Canada balsam in which the slice is set. They are probably oligoclase.

No. 1416 is a light grey lava, mottled with crystals of felspar visible to the unaided eye. Under the microscope it is seen to be made up of felspar-phenocrysts and a matted mass of microliths, embedded in a microgranular devitrified base. Some of the phenocrysts are quite rounded, others present more or less perfect crystalline forms. (See Pl. XX, fig. 2.)

The porphyritic felspars are so highly altered that their species cannot be satisfactorily made out. For the most part they appear to possess straight extinction, but it is impossible to say whether this is a property of the original felspar or of the pseudomorphous and extremely feeble birefringent mineral that has more or less replaced it. Two fragments of these felspars yielded respectively specific gravities of 2.840 and 2.735. The refractive index of the latter proved to be 1.557. Taken together, these data point to the felspar being labradorite; but the alteration that the mineral has undergone prevents me from pronouncing a definite opinion as to its identity.

The microliths have straight extinction, but the medium-sized felspar-prisms extinguish obliquely. There is no uniformity in their size or shape. Some are rectangular, some lath-shaped. Some are short and stumpy; others are long and slender. Many of them are ragged and 'unfinished' at their ends, and some have rod-like micropisms projecting from their terminal faces. Some are quite skeletal, and contain inclusions of the base. A few exhibit binary twinning obscurely—none multiple twinning. The microliths are presumably oligoclase.

## Basaltic Rocks.

No. 1463. Sp. gr.=2.828. From Bharab Chah.  
 „ 1422. „ 2.888. „ Amir Chah.

No. 1463 occurs as a dyke  $4\frac{1}{2}$  feet wide, running up vertically through the granite of which a hill at Bharab Chah is composed. It is a compact, dark greenish-grey basalt. Under the microscope it is seen to be composed of crystals of augite, felspar, and magnetite. The augites are sometimes club-shaped, but are mostly in very irregular forms. They are much cracked and penetrated by infiltration-canals. The pyroxene exhibits no dichroism, and its double refraction is not strong, showing generally the yellow, and occasionally the red, of Newton's first order. It extinguishes at from  $25^\circ$  to  $30^\circ$  from the cleavage-lines, when only one set is seen. Cross-cleavage is not well developed, but when visible a single bar is seen in converging polarized light.

The felspar-prisms are mostly lath-shaped, and generally show straight extinction. Multiple twinning is not to be seen, but a few show traces of binary macles. The refraction of the felspar is higher than that of the Canada balsam, which shows that they are not orthoclase. The binary twinning and straight extinction seem to indicate that some of the felspars, at any rate, are oligoclase. This is not improbable, as this rock is probably allied to the andesites previously described, and oligoclase is very characteristic of them.

This specimen is highly altered. None of the minerals are at all fresh, and the felspars especially have become very opaque from the formation of secondary granular mineral matter in them. A chloritic-serpentinous mineral, varying in colour from pale green to reddish brown in some cases and yellow-green in others, is very abundant: it is distinctly dichroic. Whether this represents in places a glassy base, or whether it is wholly altered felsitic matter, is difficult to say. The rock would, by many, be called a melaphyre or diabase, but I prefer to name it altered basalt.

No. 1422 is a compact rock of purple-black colour, which is said to be very abundant at Amir Chah. It consists of iron microgranules, set in a base composed of aluminous serpentine.

The iron is in part magnetite and in part limonite. It varies from opaque to translucent, and in colour from a deep brown to a black-brown. It is disseminated through the slice in microgranules and in irregularly-shaped patches, which rarely coalesce into uniform and unbroken masses. It nowhere presents crystalline outlines.

The serpentinous groundmass remains dark when revolved between crossed nicols, but countless fibres and dots of doubly-refracting material, probably chrysotile or kaolin, shine like stars in the Milky Way. In this groundmass, pseudomorphs of felspars, pyroxene, and olivine can be made out, the original shapes of the minerals being outlined by deposits of iron oxide. No trace of twinning can be discerned in the felspars, as none of the original

substance of any of the minerals remains, all having been converted into iron oxide and serpentine.

Pieces of the rock ground down to fine powder were digested in hot hydrochloric acid, and yielded a large amount of iron, a considerable amount of magnesia, an appreciable amount of alumina, and a little lime. The residue consisted of quartz with mineral matter caught up in it. This was treated with hydrofluoric and sulphuric acid, and it yielded a little iron, a little lime, and a good deal of magnesia. The residue untouched by the hydrofluoric and sulphuric acids consisted of iron that dissolved in hot nitrohydrochloric acid.

The rock does not attract the magnet, showing how much limonite preponderates over magnetite.

### Pumice.

No. 1423. From Amir Chah.  
 " 1433. " " "

These are samples of the pumice sprinkled in abundance all over the country around Amir Chah.

No. 1423 is a highly vesicular lava. The remains of felspars are abundant in the slice, but they are all so highly altered that they remain dark between crossed nicols. The slice contains flecks of calcite here and there, and some leucoxene-pseudomorphs after ilmenite.

No. 1433 is also a highly vesicular lava, and is composed of a colourless glass, drawn into fibres and full of air or gas-bubbles round the vesicles. The slice contains some fibres of mica, one or two fragments of hornblende, one or two felspars with straight extinction, and some small flakes of quartz, evidently extraneous fragments. It is dotted over with granules of calcite, and the hand-specimen effervesces strongly with an acid.

### Volcanic Ash-beds.

No. 1418.	From the west side of the great fault.	Sarlat Range.
" 1427.	"	Gazi-Chah hills.
" 1428.	"	" "
" 1439.	"	Shibian Kotal.
" 1440.	"	" "
" 1441.	"	" "
" 1445.	"	Gargarok.
" 1450.	"	west side of the great fault.
" 1465.	"	natural monolith, Neza-i-Sultan.

The above specimens of volcanic ash do not require separate description. They are all fine-grained, almost compact-looking rocks, varying in colour from purple-grey to greenish grey. They are composed of fragments of various kinds of lavas of the intermediate class, fragments of limestones and crystals of felspar. These ashes have been much altered by aqueous agencies, and

some of them intensely so. In No. 1418 the interstitial portions have to some extent been converted into a serpentinous product, and in others epidote and calcite have been found as secondary products.

No. 1427 was difficult to interpret, as the fragments were all of very much the same kind of lava; but on having a thicker slice made, and after digestion in hot hydrochloric acid, the distinction between the different lavas could be well seen, and the fragmentary character of the rock came out clearly.

Among the lapilli are fragments of a dark basic lava, but I have not observed any of olivine-basalt.

No. 1465, from the natural monolith of Neza-i-Sultan, is a fine ash made up of fragments of trachyte-looking andesites, so like each other that it is difficult to distinguish the ash from a lava.

### Holocrystalline Rocks.

#### No. 1462. Biotite-hornblende-granite.

The hill at Bharab Chah previously mentioned (p. 301) is composed of this granite. The slice taken from my hand-specimen contains orthoclase, oligoclase, quartz, apatite, biotite, and a little hornblende, zircon, and sphene.

The hornblende is brown-green in transmitted light. It is not by any means as plentiful as the biotite, which is a good deal decomposed and here and there altered into chlorite. Apatite is rather abundant. The quartz deeply corrodes the feldspars, hornblendes, and micas. (See Pl. XX, figs. 5 & 6.)

The solvent action of the acid matrix on the more basic materials that had previously crystallized out seems to be a rather frequent feature in granites, and it appears to mark that stage in the history of the rock when the granite, full of crystals formed under plutonic conditions, was moved upwards into place, and partial re-solution commenced from relief of pressure and consequent lowering of the point of fusion and from other causes. The corrosion of phenocrysts by the matrix in the case of quartz-porphyrries has been often described; but in the case of granites this partial re-solution of the first-formed minerals does not appear to have been noticed by previous observers.

Liquid inclusions are common in the quartz, but no moving bubbles of any size are to be seen.

#### No. 1421. Quartz-syenite. Sp. gr.=2.750.

From the west side of the great fault at Chili Katch in the Sarlat Range.

The hand-specimen exhibits a somewhat obscure parallelism of structure which is not noticeable under the microscope. The slice contains oligoclase, orthoclase, quartz, hornblende, biotite, apatite, sphene, and magnetite, with some epidote, calcite, and chlorite, as secondary products of decomposition.

Oligoclase is the most abundant mineral. The quartz and orthoclase are present in about equal proportions, but each taken separately is very subordinate to the plagioclase. The latter, by its extinctions and specific gravity, is seen to be oligoclase.

Both feldspars are fairly fresh, and as a rule are allotriomorphic; but there are two crystals enclosed in biotite which possess crystallographic outlines.

In transmitted light the hornblende is of a green to brownish-green, and the biotite of a greenish to reddish-brown colour. The biotite is altered in places to chlorite. Epidote occurs, intergrown with chlorite in elongated granules running in the direction of the biotite and chlorite cleavage-planes. The hornblende and biotite are deeply corroded by both the quartz and the plagioclase. (See Pl. XX, figs. 3 & 4.)

Apatite is abundant, and occurs in the biotite, feldspar, and quartz, while the magnetite, as one so often sees in igneous rocks, is often formed upon the apatite.

Sphene is somewhat abundant, and is in good-sized grains; it rarely shows any approximation to crystalline shape. It is distinctly dichroic, and exhibits a tendency to a fibrous habit. It has the prism-cleavage strongly developed in one direction, with traces of another cleavage crossing it at an angle of  $111^{\circ}$  to  $117^{\circ}$ .

The quartz contains liquid cavities with small moving bubbles and fine needle-shaped crystals which are probably rutile.

### Sedimentary Rocks.

No. 1410.	From Amir Chah.
„ 1411.	„ „
„ 1412.	„ „
„ 1414.	„ „
„ 1415.	„ „
„ 1449.	„ the east side of the great fault.
„ 1453.	„ the west side of the great fault.

The first five samples are apparently very fine-grained sedimentary rocks of the character of indurated muds. They are porcellanous-looking, and not unlike felsites. They do not exhibit cleavage or lamination. They are brittle, and fuse at the edges, but the fused edge is not magnetic.

The groundmass of some felsites and porphyries resembles the structure of these rocks as seen under the microscope; but these samples do not contain any embedded crystals, or other indication of igneous structure.

No. 1449 is a glossy, silty shale, with much of the aspect of a slate. Under the microscope it is seen to be extremely fine-grained.

No. 1453 is a fine-grained, indurated silt, formed of flaky silica deeply impregnated and stained a reddish-brown colour with limonite. The groundmass contains a number of round, oval, and angular grains and elongated fibres of calcite scattered through it. In some cases opal has replaced the calcite. The quartz is in irregularly-shaped flakes.

The rock contains countless vein-like cracks, which are wide at one end and branch out freely until they dwindle down into channels of hair-like fineness and disappear. These cracks anastomose, bifurcate, cross each other at various angles, and sometimes disappear to reappear farther on. They are all filled with calcite. In some of the hand-specimens not sliced, and not enumerated above, the calcite in quantity at least equals the silt with which it appears to be inextricably mixed up.

One of the sub-rounded grains of opal is traversed by two calcite-filled cracks, whence it would appear that the rounded bodies composed of calcite and opal were original components of the silt, and were not introduced by infiltration when the calcite-veins were formed.

The silty part of the rock, from its appearance under the microscope, I should say was probably formed in the sea at or near the foot of a coral reef. Whether the cracking was caused by shrinkage on consolidation, or whether the rock is a fault-breccia, cannot be determined from the examination of hand-specimens alone.

In conclusion, I proceed to enumerate briefly various rocks and ores given to me for determination. The most convenient plan will, I think, be to group them under the localities in which they were found.

### Saindak Mountains.

- (1) Galena, or sulphide of lead. This appears to be fairly pure.
- (2) Silicate of copper (chrysocolla).
- (3) Calcareous epidote-rock. It is composed principally of epidote, calcite, and iron. It is probably the product of the alteration of a volcanic or igneous rock.
- (4) Reddle, or earthy hydrated ferric oxide, containing numerous crystals of selenite, lumps of gypsum, and small crystals of anthophyllite.
- (5) Sand. This fine-grained, somewhat earthy-looking sand was found, on examination under the microscope, supplemented by some chemical tests, to be composed of minute fragments of the following minerals and rocks:—quartz, calcite, dolomite, carbonate of iron, garnet, tourmaline, muscovite, a reddish-brown mica, orthoclase- and plagioclase-feldspars, and fragments of siliceous rocks. The calcite and dolomite were probably derived from limestone and magnesian-limestone rocks, near at hand.

### Koh-i-Sultan.

- (1) Yellow ochre, used by the natives as a dye. This rock is composed of limonite, with some sulphide of iron and a good deal of silica as impurities.
- (2) Red ochre. The red ochre contains many crystals of gypsum and numerous minute crystals of anthophyllite.
- (3) Sulphur, with some yellow limonite as an impurity.

## Koh-i-Malik Siah.

- (1) Red jasper interspersed with white quartz and chalcedony.
- (2) Epidote-rock, composed of epidote- and quartz-crystals, the former predominating. The quartz contains inclusions of ferric oxide.
- (3) Chrysocolla, in a matrix composed principally of silica, with fragments of mica and other minerals.
- (4) Galena or sulphide of lead.
- (5) Small fragments of basic igneous rocks.
- (6) Fragments of fine-grained biotite-granite.

## Malik Dokhand.

Crystalline granular gypsum (alabaster).

## Malik Ainak.

Selenite.

## EXPLANATION OF PLATES.

## PLATE XVIII.

Sketch-map of the Baluchistan-Afghan frontier, on the scale of  $\frac{1}{3,000,000}$  or 47.3 miles=1 inch.

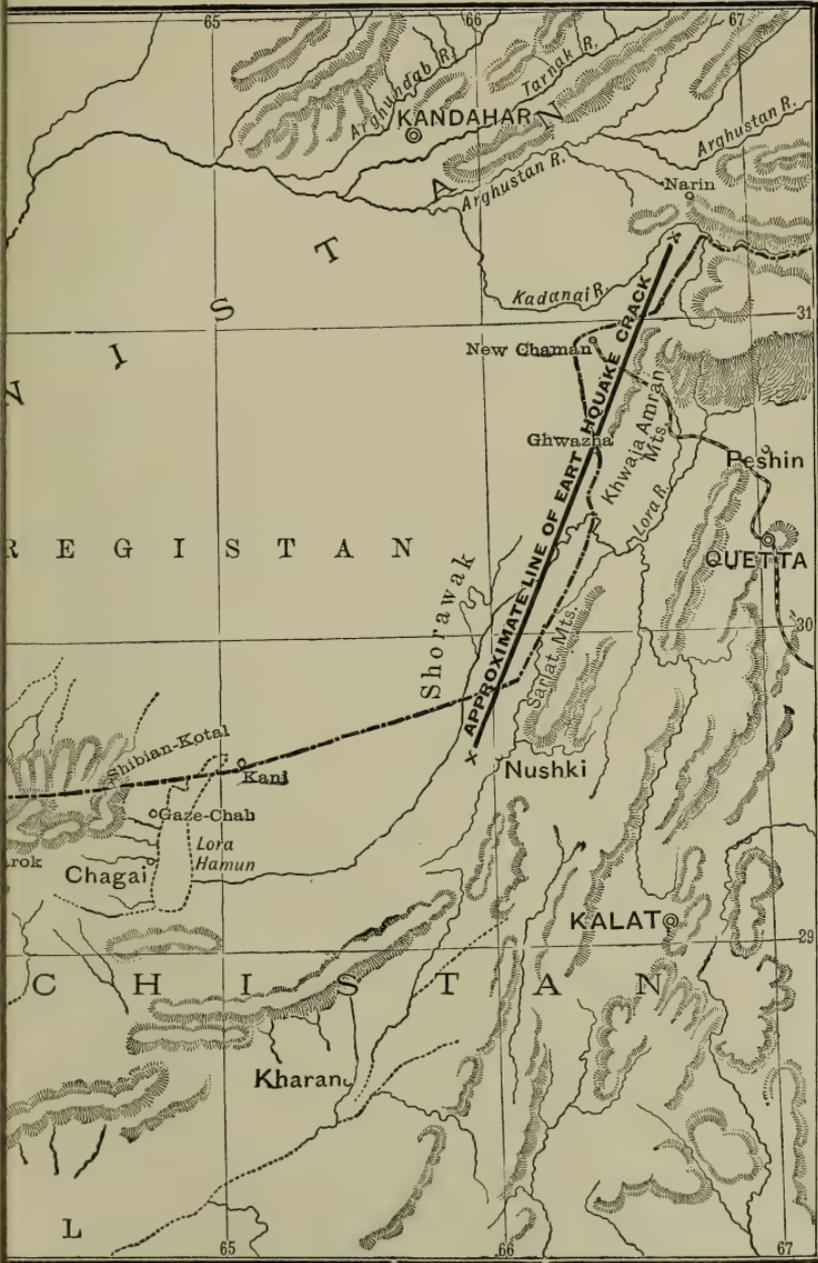
## PLATE XIX.

*a*=biotite. *c d e*=quartz. *f*=anthophyllite. *h*=hornblende. *o*=olivine.

- Fig. 1. General view of augite-hornblende-andesite. No. 1424.
2. Section of the anthophyllite seen in fig. 1 (enlarged).
  3. Brown-red anthophyllite (with contact-halo) enclosed in an aggregate of pyroxene-grains and prisms, the granular complex having the form of a crystal. See p. 298.
  4. Contemporaneous crystallization of plagioclase and brown-red anthophyllite. See p. 298.
  5. Olivine, with deposit of brown-red anthophyllite round its margin; enlarged from No. 1424 (fig. 1). See p. 299.
  6. General view of augite-hornblende-andesite, No. 1438, showing olivine. See p. 299.

## PLATE XX.

- Fig. 1. Augite-hornblende-andesite. Another portion of No. 1438 (Pl. XIX, fig. 6).
2. Felspathic lava. No. 1416. See p. 300.
  3. Quartz-syenite. Corrosion of hornblende by quartz. Between *d* and *h* and between *c* and *h* the quartz has eaten deeply into the hornblende all round. At *d* it has forced its way into cleavage-cracks; while at *b* the process has proceeded further, and a piece has been split off from the main crystal of hornblende. See p. 304.
  4. Quartz-syenite. Corrosion of biotite by quartz. The quartz has cut deeply into the biotite all round its margin. Between *b* and *d* the quartz by its solvent action has nearly severed the biotite into two portions. This can be seen with the aid of a pocket-lens.
  5. Hornblende-biotite-granite. Corrosion of hornblende and biotite by quartz. The biotite has at *d* been cut in half and corroded all round by the quartz. Seven distinct bays of corrosion can be counted.
  6. Hornblende-biotite-granite. Corrosion of hornblende by quartz. Bays of corrosion are to be seen all round the hornblende. See p. 303.



INDIAN-AFGHAN FRONTIER.

[3 miles = 1 inch.]

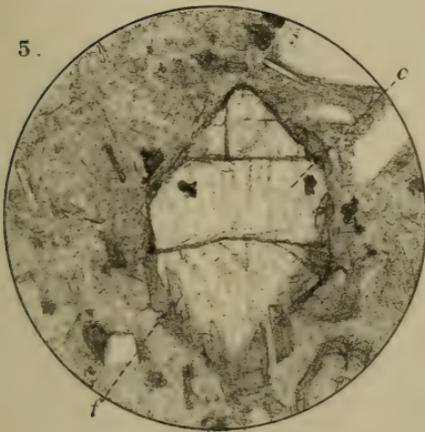
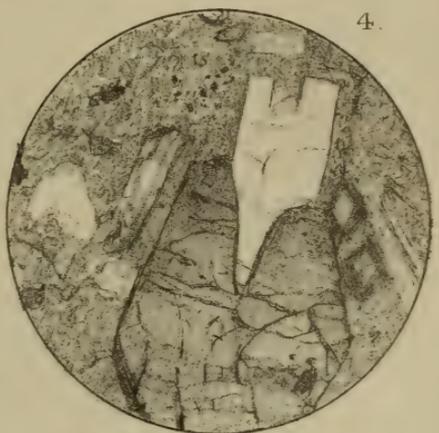
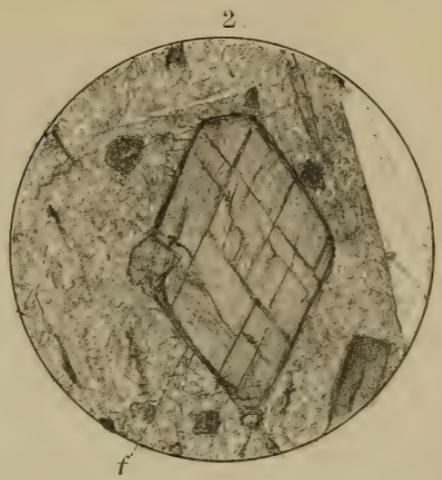
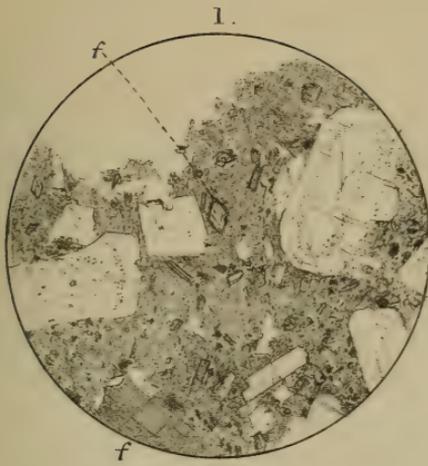




SKETCH-MAP OF THE BALUCHISTAN-AFGHAN FRONTIER.

[Scale:  $\frac{1}{3,000,000}$  or 47.3 miles = 1 inch.]







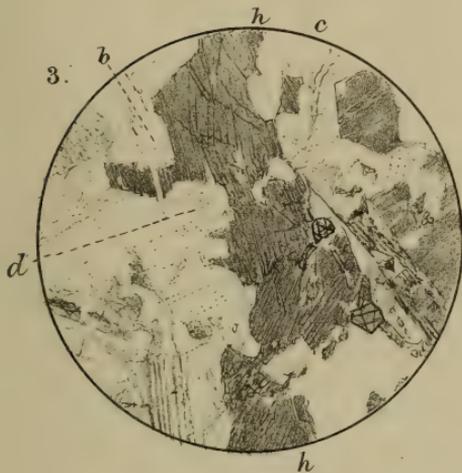
1.



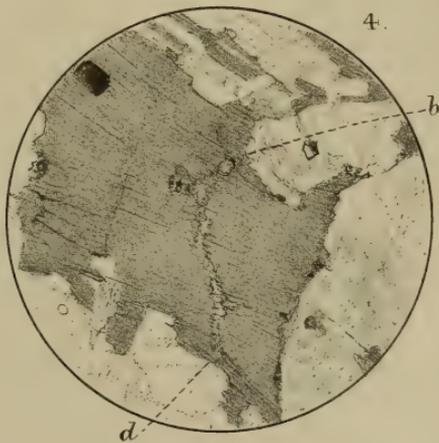
2.



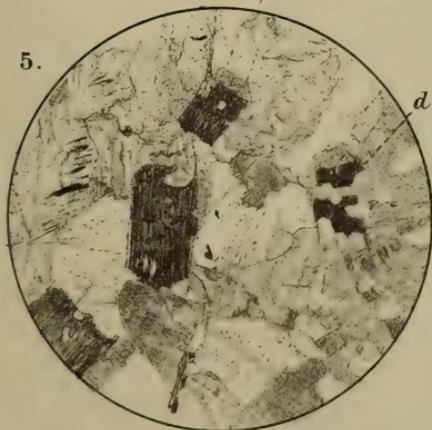
3.



4.



5.



6.





## DISCUSSION.

The PRESIDENT commented on the advantage of heredity in taste, and on the excellent observations made by Capt. McMahon, as well as the valuable information which he had brought back. Concerning the corrosion of basic minerals by silica, he observed that silica might be truly a corrosive mineral, but hitherto the idea had been that the basic mineral had decomposed *in situ*, and that the silica had filled up the hollows and cracks resulting from this decomposition. It was perhaps a general mistake to suppose that faults always run along valleys. Faults may often be indicated by valleys, but in many parts of the country they run across the ridges as well.

Mr. GRIESBACH considered the paper just read a valuable contribution to our knowledge of Baluchistan. But, having spent some years in that part of Asia himself, he wished to point out that there is abundant evidence to show that the Pliocene deposits which are seen in Shorawak and the neighbouring Registan have not been laid down in a lake-basin, but are chiefly of a fluvial nature. The range of hills, of which the northern portion is known as the Koh-i-Khwaja Amran, is composed mostly of rocks belonging to the later Cretaceous and Nummulitic formations, with great masses of intrusive igneous rocks. Of these latter the peak of Khwaja Amran is the nucleus, and represents a remarkable series of acid rocks, followed by 'Nachschübe' of basic rocks. The long fault-line or 'earthquake-crack' does not, however, mark the boundary-line between sedimentary and igneous rocks in that part of the world. Quite close to the line of fault, west of Chaman, Hippuritic Limestone may be seen *in situ*; and rocks of Cretaceous and Tertiary age form great mountain-chains north-east of Chaman and west of the 'earthquake-crack.' It is questioned whether there is any foundation of truth for the rumoured existence of actual recent craters in the desert west of the Koh-i-Sultan. Nearly all the ridges and peaks of volcanic rocks in this Baluchi desert are due to their having been laid bare by the decomposition and removal of the softer sedimentary strata into which they have been intruded.

Dr. W. T. BLANFORD congratulated Capt. McMahon on the series of interesting observations brought before the Society. He noticed the great prevalence of Tertiary and Cretaceous rocks throughout the wide area extending from the Indus to Mesopotamia. The volcanic rocks of Eastern Baluchistan, like the Deccan traps of India, appear to be of Cretaceous and Lower Eocene age; but the igneous formations near the Baluchistan and Persian frontier must be, in part at all events, of far more recent origin, some of the cones of loose materials seen by the speaker between Bampur and Bam having undergone no change through denudation. Possibly the great volcanic eruptions of this area had some connexion with the lateral compression of the rocks in Southern Baluchistan, Tertiary rocks being found vertical or nearly so, from near the shores of the Indian Ocean to Jalk, about 150 miles across the strike. The remarkable

pinnacles of agglomerate noticed by Capt. McMahon were difficult to explain.

The Rev. EDWIN HILL said that the paper teemed with points of interest. The pinnacle shown resembled a magnified earth-pillar. Was the water which disappeared in the sand ultimately evaporated? That the great fault in its course disregarded mountains seemed an indication of its depth.

Prof. MILNE made special reference to the fault which Capt. McMahon had described, and compared it with a fault which in 1891 had been formed in Japan. The time at which the Indian fault had been created was not known; but, from earthquakes which from time to time originated along its length, it was clear that the forces which had crushed together and uptilted the strata in this region were not yet extinct. One of the most striking phenomena which accompanied the formation of the Japan fault was the permanent compression of the land in its vicinity. River-beds were reduced in width to an extent of 1 or 2 per cent., while certain plots of ground had their sides shortened in the ratio of from 10 to 7.

Mr. CADELL said that the remarkable peaks described by the Author, which were said to be of agglomerate, might be explained on the supposition that these were the necks of old volcanoes, the upper parts of which, together with the surrounding strata, had been denuded away.

Prof. JUDD called attention to the great steep-sided masses of volcanic agglomerate which rise up in the midst of the town of Le Puy in Central France, and are crowned by the Cathedral and the church of St. Michel. These seem comparable, though of smaller dimensions, with the great columnar masses described by Capt. McMahon. There is no doubt that the masses of Le Puy are relics left by denudation of a mass of volcanic agglomerate that once filled the whole valley. The reason why these masses have escaped removal by denudation is probably not because they are 'volcanic rocks,' but because these materials have been consolidated by the action of siliceous, calcareous, or chalybeate springs.

Dr. H. WOODWARD and Mr. W. W. WATTS also spoke.

Capt. McMAHON observed, with reference to what Mr. Hill had said about the way in which the drainage from the mountains had disappeared when intercepted by the sand, that, although it disappears below the surface, water can be found in places at a very slight depth below the sand, sometimes only a foot or two below the surface. The great difficulty is to find those spots, as the configuration of the country does not guide one so much in finding it as in the case of sub-surface water under other conditions.

Then with reference to the supposition that the pillar of Neza-i-Sultan may be the neck of some old volcano, he pointed out that there are numerous peaks of grotesque shape in the near neighbourhood of the Neza-i-Sultan, all apparently made of the same rock and all probably reduced to their present curious shapes

by the same natural process. If the Neza-i-Sultan is to be considered the neck of a volcano, these other peaks should, by the same process of reasoning, be also considered to be necks of old volcanoes. But their number and proximity to each other would tend to throw doubt on the correctness of that supposition.

Gen. McMAHON, in reply to Mr. Griesbach, remarked that the Authors had not attempted to determine the precise age of the lavas, as the fossils brought home by one of them were still under examination in the Natural History Museum; but the volcanic eruptions had evidently extended over a considerable period. The Neza-i-Sultan (Spear of Soliman) contained fragments of the peculiar augite-hornblende-andesite identical with the lava found *in situ* elsewhere, showing that the latter must have consolidated before the beds of agglomerate were formed. The subsequent erosion of hundreds of feet of agglomerate, moreover, indicated the lapse of a long period since the formation of these beds.

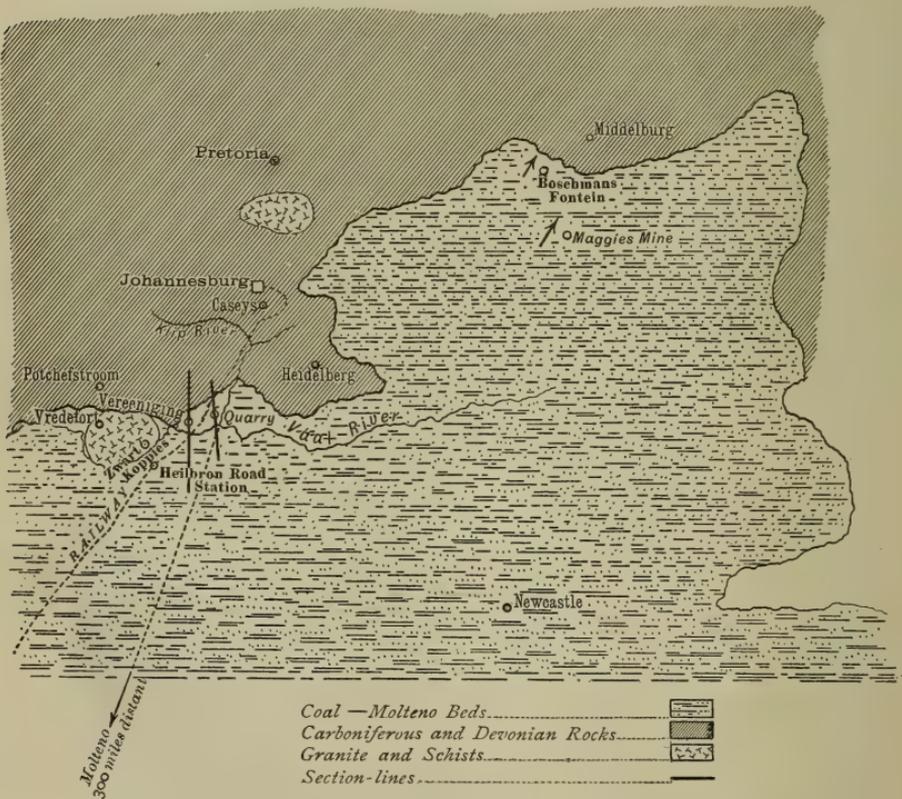
With reference to Mr. Hill's remarks, he suggested that a considerable amount of water might be retained near the surface of sand-hills by capillary attraction, and instanced the growth of good autumn crops on the borders of Bikanir, on hills that seemed to the eye pure drifted sand.

23. NOTES on the OCCURRENCE of SIGILLARIA, GLOSSOPTERIS, and other PLANT-REMAINS in the TRIASSIC ROCKS of SOUTH AFRICA.  
By DAVID DRAPER, Esq., F.G.S. (Read March 24th, 1897.)

A COLLECTION of plants was forwarded by the writer to Mr. A. C. Seward, M.A., F.G.S., for identification. These were found at the following localities, marked on the accompanying map.

1. { Boschmans Fontein.  
Maggies Mine . . . } Middelburg District, Transvaal.
2. Casey's Township. . . Two miles south of Johannesburg.
3. Vereeniging . . . . . Thirty miles south of Johannesburg.
4. Zwart Koppies . . . . . Four miles west of the Heilbron Road Station on the Cape Government Railway-line to Johannesburg.

Fig. 1.—Sketch-map showing the localities where the fossils were discovered.



All these localities are situated within the area which is known to be coal-bearing, excepting No. 2, Casey's Township, which is a small outlier, detached from the main body by denudation.

The coal-bearing rocks of the Transvaal belong to the horizon which is known in South African geology by the name of 'Molteno Beds,' the lower member of the Stormberg Beds (Dunn), generally assumed to be of Triassic age.

The accompanying sections (figs. 2 & 3, pp. 312, 313) demonstrate the position of the Molteno Beds with regard to the underlying rocks. It will be seen that they rest unconformably upon tilted strata, beneath which the beds are generally believed to be of Carboniferous age, though but few fossils have been found in proof of this assumption.

In general, and especially at Vereeniging, a boulder-bed, containing large rounded masses of quartzite, conglomerate, dolomite, and other rocks, all of which have evidently been derived from the older series exposed to the northward, lies upon the eroded surface of the underlying rocks; this boulder-bed apparently represents an ancient beach-line, no traces of which have as yet been found at a higher level than the present outcrop of coal-bearing rocks.

### Geology of the different Localities where the Fossils were discovered.

#### No. 1. BOSCHMANS FONTEIN AND MAGGIES MINE.

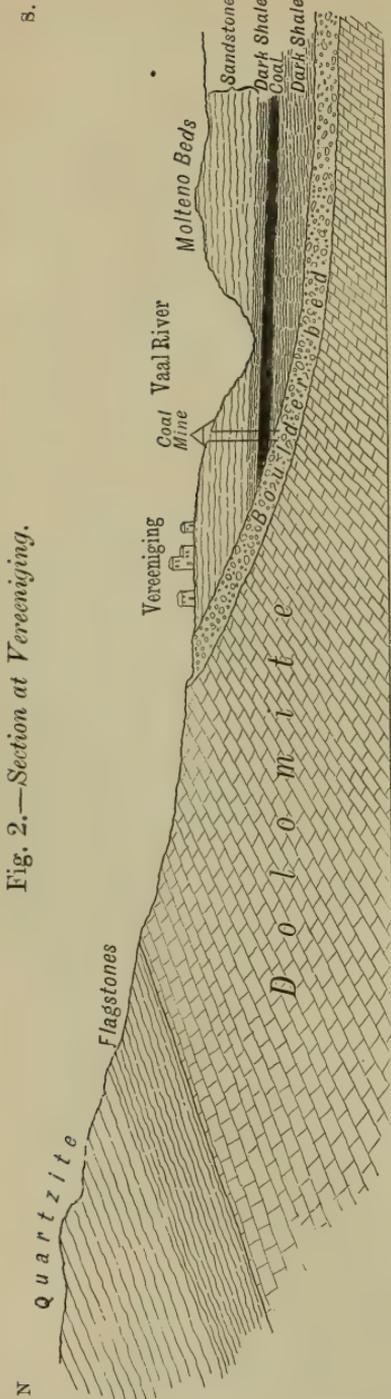
The former of these is situated near the extreme northern limit of the Molteno Beds, lying within the boundaries of the Transvaal. Immediately to the northward, rocks identical with those occurring in the Megaliesberg and Gats Rand (probably Carboniferous) occupy a large extent of country. These are generally much contorted and dip towards the north. The coal-bearing strata (Molteno Beds) lie unconformably upon these older rocks, and terminate on the northern portion of the farm of Boschmans Fontein. A coal-seam has been opened about 1 mile east of the homestead on this farm. It is about 12 feet in thickness, though in the working, which has been continued about 150 feet into the coal, the upper portion (about 6 feet) of this large coal-bed has been removed by denudation, and its position has been filled up by grey shale and coarse gritty sandstone: it is in the former that the fossil plants were found by the writer.

Maggies Mine, situated on the farm of Vaal Bank, lies about 9 miles south-east from Boschmans Fontein, and is on the main bed of coal. Near the present colliery-shaft a bed of fossils was discovered, and the specimens were forwarded to me by Mr. W. H. Roach, then manager of the property.

The coal-mine on this farm is situated at a greater distance from the northern limit of the Molteno Beds than the open working at Boschmans Fontein. (See map, fig. 1.)

#### No. 2. CASEY'S TOWNSHIP (2 miles south of Johannesburg).

At this spot the fossils were found in sinking a well on the property belonging to Mr. Francis (hence called 'Francis' in



M. Zeiller's recent description of some South African fossils sent him by M. de Launay).

Fine sedimentary deposits, grey, white, or red in colour, were traversed in sinking the shafts, and in these the numerous plant-remains were found. The material in which they were preserved was for the most part so soft and crumbly that many very fine specimens were lost when the rock was exposed to the atmosphere.

At the depth attained in the shaft (about 80 feet) coarse gritty sandstone was intersected for the last 6 or 8 feet, and this was found to rest upon the tilted edges of the Upper Quartzite-and-Shale Group, containing conglomerates, which are identified as belonging to the Table Mountain Sandstone Series (Upper Devonian).

As these rocks crop out all round the small patch of horizontal shale and sandstone in which the fossils were found, this latter is undoubtedly an outlier detached from the main body of the Molteno Beds—which lies about 12 miles south-east—by ordinary subaerial denudation.

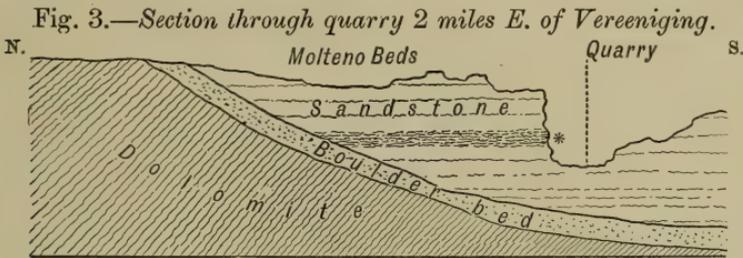
No. 3. VEREENIGING.

This place, a small township, lies about 30 miles due south of Johannesburg on the northern bank of the Vaal River. The main trunk-line of railway connecting the Cape Colonial seaports with the mining centre of Johannesburg passes through Vereeniging, and the coal-mine, from which the greater quantity of fuel-supply for the railway is derived, lies about  $\frac{1}{2}$  mile west of the township.

Two miles east of Vereeniging, and close to the junction of the Klip and Vaal Rivers, a sandstone-quarry was opened for the purpose of supplying material for the construction of a bridge over the Vaal River, and the workmen unearthed a great number of fossil plant-remains, among which were several varieties of *Glossopteris* and fragments of a stem of *Sigillaria*.

These were contained in a layer of horizontal sandstone about 8 feet below the exposed surface of the bed, and about 6 feet from the floor of the quarry. This layer is laminated and somewhat wavy in structure, whereas the beds above and below it are massive and horizontally bedded; the material of which they are composed, however, is similar, fine-grained sandstone of a yellowish-white colour, stained red in the planes of bedding.

The accompanying section (fig. 3) illustrates the principal geological conditions at this spot, and shows the sandstones resting unconformably upon the older tilted rocks which crop out to the north, and are probably of Carboniferous age, the boulder-bed representing perhaps an ancient beach-line.



\* = Layer in which *Sigillaria* was found.

This boulder-bed apparently continues for a great distance along the line of outcrop of the northern edge of the Molteno Beds as well as extending underneath them. A borehole put down some miles to the southward, under the superintendence of Mr. A. R. Sawyer, F.G.S., intersected both the coal-seam and the boulder-bed.

The quarry in which the fossils were found is but a few hundred yards south of the outcrop of this boulder-bed, and there does not appear to be any coal at this spot. In the dark shales which underlie sandstones of similar appearance and structure, and which were intersected in sinking the Vereeniging coal-shaft, several of the specimens which accompany this paper were found by the writer, and there is no doubt that they are from the same geological horizon as those found in the quarry. The connexion between the sandstone at the coal-shaft and that at the quarry is distinctly traceable on the surface.

#### No. 4. ZWART KOPPIES.

At this locality, which is about 4 miles west of the Heilbron Road railway-station and about 15 miles south-west of Vereeniging, a few fragments of a *Lepidodendron* were found some years ago in a well sunk in search of water.

The finder informed me that the stem was about 5 feet long, but unfortunately I arrived too late to secure more than a few fragments, the best one of which is in the Natural History Museum, South Kensington.<sup>1</sup> The strata intersected in sinking the well consisted principally of coarse gritty sandstone lying horizontally upon highly-contorted actinolite-schists and granite, both of which crop out on the surface in the vicinity. This patch of Molteno Beds is detached from the main body, which lies a short distance to the eastward.

The localities enumerated above have all been carefully examined by me, and I have come to the conclusion that the strata there belong to the same geological horizon and are portions of the same series, namely, the Molteno Beds, which are generally recognized as a member of the Triassic system of South Africa.

The following is the generally accepted classification of the South African rocks (after Dunn):—

Volcanic Rocks .....	Fossils.
Cave Sandstones.....	Fragments of reptilian remains and fishes.
Red Beds.....	Nearly perfect reptilian remains.
Coal.....	Plants, ferns, fossil wood.

(Molteno Beds).

Karoo Beds (Dunn) .....	} Ferns, reptilian remains in great abundance from the base to the summit, silicified wood and sedge-like plant-impressions in lower beds. Ganoid fishes, <i>Atherstonia scutata</i> and others.
Kimberley Beds (Green) . . .	
Beaufort Beds (Schenck) . . .	

There is no doubt that the Molteno Beds of South Africa are younger than the strata which contain the great abundance of reptilian remains, and that the Vereeniging and Zwart Koppies fossils, belonging to species generally accepted as typical of the Carboniferous period, have been discovered in the northern portion of these beds. There are two ways of explaining this occurrence:— Either these plant-remains were carried into the Triassic rocks as fossils; or species of plants hitherto looked upon as having disappeared with the close of the Carboniferous period survived into Triassic times. This latter is probably the correct interpretation of the occurrence of *Sigillaria* found at the localities mentioned. The general geology of the country gives the impression that an island composed of Carboniferous and Devonian rocks, on which several varieties of plants of the former period were flourishing, was surrounded by water, in which during the Triassic period the horizontal sedimentary deposits containing coal (Molteno Beds) were laid down along its shores, which are now represented by the ancient beach-line.

I submit that this occurrence of *Sigillaria* in Triassic rocks is strong evidence that this plant, hitherto supposed to be typical of the Carboniferous period, survived in the Southern Hemisphere into Triassic times.

<sup>1</sup> See Mr. Seward's paper, p. 315.

24. *On the Association of SIGILLARIA and GLOSSOPTERIS in SOUTH AFRICA.* By A. C. SEWARD, Esq., M.A., F.G.S., University Lecturer in Botany, Cambridge. (Read March 24th, 1897.)

[PLATES XXI.—XXIV.]

THE fossil plants which form the subject of this paper were forwarded to me by Mr. David Draper, of Johannesburg, and my thanks are due to him for affording me the opportunity of making the following contribution to the palæobotany of the Southern Hemisphere.

The localities<sup>1</sup> from which the specimens were obtained are briefly described in the foregoing communication by Mr. Draper, who expresses the view that the beds of each horizon are probably of the same geological age, namely, the lower portion of the Stormberg Beds of Dunn. The evidence afforded by the plants is, however, strongly in favour of a lower horizon; it points to a Permo-Carboniferous rather than a Triassic age. The interesting association of genera brought to light by Mr. Draper's discoveries, and its significance from the point of view of geological age and plant-distribution, will be best discussed after a description of the individual species.

The following are the principal localities from which the plants were obtained:—(1) Boschmans Fontein and Maggies Mine in the Middelburg district, Transvaal; (2) Casey's Township (Francis), 2 miles south of Johannesburg; and (3) Vereeniging, about 30 miles south of Johannesburg. In a paper by Schmeisser on South African minerals there is a reference to the occurrence of *Glossopteris* and *Schizoneura* in the Middelburg district at the Holfontein Colliery. The rocks are spoken of as belonging to the Stormberg Series.<sup>2</sup> From the second locality, under the name of 'Francis,' M. Zeiller<sup>3</sup> has recently described the following species:—*Glossopteris Browniana*, Brongn., *G. indica*, Schimp., *G. angustifolia*, Brongn., *Vertebraria indica*, Royle, *Sphenopteris* (?) sp., *Phyllothea* sp., *Næggerathiopsis Hislopi* (Bunb.), and two small seeds. No plants have been described from the third locality, Vereeniging; but in a recent work by Goldmann on South African mines the following passage occurs:—'At Vereeniging, 35 miles south of Johannesburg, in the Coal Measures resting unconformably on the dolomite, in addition to many Triassic fossils, *Lepidodendron* and *Favularia*, both unmistakable Carboniferous fossils, have been discovered.'<sup>4</sup>

<sup>1</sup> The '*Lepidodendron*' referred to by Mr. Draper, p. 313, from Zwart Koppies is an imperfectly-preserved *Knorria*-form of a *Lepidodendroid* or *Sigillarian* plant. It is hoped, however, to describe the South African plants in the Natural History Museum in another paper.

<sup>2</sup> 'Ueber Vorkommen u. Gewinnung d. nutzbaren Mineralien in d. Südafrik. Republik,' p. 66 (Berlin, 1894).

<sup>3</sup> Bull. Soc. géol. France, ser. 3, vol. xxiv. (1896) p. 349.

<sup>4</sup> 'South African Mines,' vol. i. p. xxiv (London, 1895-96).

In referring to this statement M. de Launay<sup>1</sup> has suggested that possibly the supposed Coal Measure plants mentioned by Goldmann were obtained from the dolomite underlying the coal-beds. Mr. Draper's fossils enable us to speak with certainty as to the occurrence of *Sigillaria* associated with typical members of the *Glossopteris*-flora in the beds overlying the dolomite. This discovery was recorded in a note communicated to the British Association at last year's meeting.<sup>2</sup>

In the following descriptive notes the collection of plants is dealt with as a whole, and the short table at the end summarizes the species recognized from each locality.

#### Genus GLOSSOPTERIS, Brongniart.

'Prodr. Hist. Vég. foss.' (1828) p. 54; 'Hist. Vég. foss.' (1828) p. 222, pls. lxii. & lxiii.

This generic name was founded by Brongniart in 1828 for certain tongue-shaped leaves from Australia and India. Other specimens from England and Scania to which he gave the same generic name have since been referred to distinct genera. The Australian and Indian leaves were placed in the same species, *Glossopteris Browniana*, and defined as follows<sup>3</sup>:—

'*G. foliis lanceolatis vel subspathulatis obtusis* (1–2 pollicibus latis); nervo medio valido superne canaliculato; nervulis basi obliquis reticulatis, apice tantum simplicibus vel furcatis, marginique subperpendicularibus, vix obliquis.'

On account of the smaller size of the Australian specimens and their obtuse apices, they were referred to by Brongniart as *G. Browniana* var. *α australasica*, while the larger and more sharply pointed Indian forms were designated *G. Browniana* var. *β indica*. Another specific name, *G. angustifolia*, was chosen by Brongniart<sup>4</sup> for some long and narrow Indian leaves with the same venation-characters as in the former species. Brongniart's type-specimens are in the Paris Natural History Museum, Jardin des Plantes. Zeiller<sup>5</sup> has recently published accurate drawings of the venation in each of these types, which should be consulted as more trustworthy than the less detailed figures given by Brongniart.

In 1869 Schimper<sup>6</sup> raised Brongniart's var. *β indica* to the rank of a distinct species, *Glossopteris indica*. After giving a diagnosis of *G. Browniana*, Schimper points out that he has seen *Glossopteris*-leaves on the same slab of rock varying from an oblong spatulate to an almost linear form, and he recognizes the considerable diversity of shape as a necessary accompaniment of difference in age. The very large number of leaves of this genus described by Feistmantel<sup>7</sup>

<sup>1</sup> 'Les Mines d'Or du Transvaal,' Paris, 1896, p. 209 (footnote).

<sup>2</sup> A. C. Seward, Brit. Assoc. Rep. (L'pool) 1896, p. 807.

<sup>3</sup> 'Hist. Vég. foss.' p. 223 & pl. lxii.

<sup>4</sup> *Ibid.* pl. lxiii. fig. 1.

<sup>5</sup> Bull. Soc. géol. France, ser. 3, vol. xxiv. (1896) pp. 363, 367, & 370.

<sup>6</sup> 'Traité de Pal. vég.' vol. i. p. 645.

<sup>7</sup> See 'Fossil Flora of the Gondwana System,' Mem. Geol. Surv. India (Palæontologia Indica), etc.

from different horizons in the Gondwana Series of India have in several instances formed the types of new species founded on quite inadequate grounds. It requires but a brief examination of Feistmantel's figures and some acquaintance with the commoner forms of *Glossopteris* to confirm this statement. Zeiller has recently shown good reasons for identifying Feistmantel's *G. communis* with *G. indica*, Schimp.<sup>1</sup> It is not proposed at present to attempt a general revision of the specific determinations of this Southern Hemisphere genus of ferns, but to demonstrate the extreme difficulty of drawing satisfactory distinctions between such forms as are included under *G. Browniana*, *G. indica*, and *G. angustifolia*. In 1861 Bunbury<sup>2</sup> figured and described several specimens of *Glossopteris* from the neighbourhood of Nágpur, Central India, and instituted some new specific names. The type-specimens of Bunbury are now in the Museum of the Geological Society, and in the Bunbury Collection in the Botanical Museum, Cambridge. It is difficult, or indeed impossible, to admit the existence of adequate grounds for some of Bunbury's species, and he himself calls attention to the variation in the direction and number of the veins; he expresses the opinion that no satisfactory specific distinction can be drawn between the Australian and Indian forms of *G. Browniana*. Tenison-Woods,<sup>3</sup> in speaking of the variation in venation-characters, admits that the distinctions drawn between many of the fossil leaves are not such as would rank as specific features in recent fern-fronds. In Zeiller's interesting paper on African plants, already alluded to, attention is called to the striking variation in form and venation exhibited by the *Glossopteris*-leaves. The drawings which he gives of Brongniart's type-specimens illustrate in a marked degree the close agreement as regards the venation in *G. Browniana*, *G. indica*, and *G. angustifolia*. In one of Zeiller's specimens the veins on the two sides of the midrib are by no means identical, but exhibit a striking difference as regards the angle and direction.<sup>4</sup> While endeavouring to avoid the dangerous and unscientific practice of needlessly multiplying specific names, we must be careful to bear in mind the possibility of carrying too far the system of linking together distinct types by a long series of intermediate forms. It is no easy matter to decide as to the best course to adopt with regard to *G. Browniana*, *G. indica*, and *G. angustifolia*; but my impression is that these three names cannot be maintained as standing for three well-marked species of *Glossopteris*. Attention has been called by several writers to the variations in both form and venation, and an examination of similar single fronds of recent ferns seems to demonstrate the want of a definitely fixed form among living species. The test of size is always dangerous, and cannot as a rule be regarded as a taxonomic character of much value. From the widespread occurrence in Australia, Africa, and India of layers

<sup>1</sup> Bull. Soc. géol. France, ser. 3, vol. xxiv. (1896) p. 368.

<sup>2</sup> Quart. Journ. Geol. Soc. vol. xvii. (1861) p. 325.

<sup>3</sup> Proc. Linn. Soc. N. S. Wales, vol. viii. (1883) p. 122.

<sup>4</sup> *Op. supra cit.* pl. xvii. fig. 2.

of rock formed largely of *Glossopteris* leaf-beds, it would seem that vast tracts of country must have been covered with this common genus of ferns. The fact of this very great abundance of the leaves of a plant differing but little in shape and venation, may afford some confirmatory evidence in favour of including the closely similar forms of leaves in one species. This is not, indeed, a point to be emphasized; but the crowded state of the plants over wide areas is not entirely favourable to the association of closely-allied species.

GLOSSOPTERIS BROWNIANA, Brongn.

'Prodr. Hist. Vég. foss.' p. 54; 'Hist. Vég. foss.' p. 223 & pl. lxii.

Our knowledge of this species has recently been extended by the exceedingly interesting facts and ingenious interpretations presented by M. Zeiller in favour of the opinion that Royle's genus *Vertebraria* is the rhizome of *Glossopteris*. The nature of *Vertebraria*, first described by Royle in 1839,<sup>1</sup> has long been a puzzle to palæobotanists. Previous to Zeiller's note published in the 'Comptes Rendus' of March 23rd, 1896, and the more complete account in the paper previously quoted, the nearest approach to the true explanation was that suggested by Bunbury<sup>2</sup> à propos of an unusually good specimen which he described from Nágpur. This specimen, now in the Geological Society's Museum, is in the form of a main axis of the *Vertebraria*-type giving off numerous branched roots. Bunbury expressed the opinion that *Vertebraria* was probably the root of a plant, possibly *Phyllothea*, and now Zeiller has given proof of its rhizome nature.<sup>3</sup> For another addition to our knowledge of *Glossopteris* we are also mainly indebted to M. Zeiller. Among the *Glossopteris*-fronds from 'Francis,' near Johannesburg, Zeiller noticed several smaller scale-like leaves having the same anastomosing venation as the normal and larger leaves, but without a midrib; and he was led to the conclusion that *Glossopteris Browniana* had two kinds of leaves. He compares the two leaf-forms borne by the same rhizome with the large fronds and small, stiff, scale-like appendages of *Onoclea struthiopteris*, Hoffm. Among some specimens in the Bunbury Collection I have found some small leaves without a midrib, exactly similar to those figured by Zeiller in association with the typical leaves of *Glossopteris Browniana* from the Newcastle Beds of the Hudson River, New South Wales. A small portion of this specimen is shown in Pl. XXIII, fig. 1; at *s*, *s'*, *s''* are seen three smaller leaves with slightly spreading and anastomosing veins. The most perfect of these leaves, *s*, has a length of 1 cm. and a breadth of 6 mm.; the upper surface is strongly

<sup>1</sup> 'Illustrations of the Botany, etc., of the Himalayan Mountains & of the Flora of Cashmere,' vol. i. (1839) p. xxix.\* pl. ii.

<sup>2</sup> Quart. Journ. Geol. Soc. vol. xvii. (1861) p. 339.

<sup>3</sup> [Since this paper was read M. Zeiller's conclusions have been confirmed by Mr. R. D. Oldham, who has published figures and descriptions of *Glossopteris*-fronds attached to a Vertebrarian rhizome, Rec. Geol. Surv. India, vol. xxx. pt. i. (1897) p. 45.—June 1st, 1897.]

convex, as shown more clearly in the shell-like appearance of the specimen next to it. A comparison of these small leaves with the scale-leaves figured by Zeiller leaves no doubt as to their identity. Among recent ferns we may quote certain species which show a much closer correspondence in their leaves to *Glossopteris Browniana* than is afforded by *Onoclea*. In *Drymoglossum carnosum*, Hk.,<sup>1</sup> we have a Polypodiaceous fern in which the creeping rhizome bears two distinct kinds of simple fronds, linear-spathulate fertile fronds and smaller suborbicular or elliptical barren fronds. Similarly in *Drymoglossum piloselloides*, Presl<sup>2</sup>; also in *Acrostichum villosum*, Sw.,<sup>3</sup> *Polypodium vacciniifolium*, F. & L., *P. serpens*, Forst.,<sup>4</sup> etc., there are two distinct forms of leaves. In *P. vacciniifolium* the linear leaves are fertile, and the smaller roundish or elliptical leaves sterile; while in *A. villosum* the small suborbicular leaves are fertile. Other ferns might be named illustrating the same kind of dimorphism as that which appears to have characterized *Glossopteris Browniana*. We are still without satisfactory evidence as to the nature of the sori and sporangia of *Glossopteris*. It is, at all events, unwise to attach any taxonomic importance to the very doubtful examples of fertile fronds described by Bunbury, Feistmantel, Carruthers, and others, as some authors have done. In a recent paper by Etheridge on a *Glossopteris*-plant in which several leaves are attached to a stem, undue importance is given to the supposed systematic value of the sorus-like impressions.<sup>5</sup> The specimens of Bunbury and Zeiller which I have had an opportunity of examining, wherein there occur more or less elliptical patches or holes in the lamina, certainly suggest the sori of a Polypodiaceous fern, and such evidence as we have favours the reference of *Glossopteris* to this family of ferns. It must be remembered, however, that no trace of a sporangium has so far been seen on a *Glossopteris* leaf.

As bearing on this question it may be mentioned that the entire simple leaf occasionally met with in Polypodiaceous ferns is unknown in recent Cyatheaceæ and Gleicheniaceæ.<sup>6</sup>

In a paper by M'Coy in 1847<sup>7</sup> there occurs a passage in his account of some Australian leaves where he speaks of scale-like appendages which may have been the smaller leaves described by Zeiller in the African *Glossopteris*:—‘I believe I have ascertained the rhizoma of this species, which is furnished with ovate, clasping

<sup>1</sup> W. J. Hooker, ‘Gen. Filicum,’ pl. lxxviii. A (London, 1842); see also R. H. Beddome, ‘Ferns of British India,’ vol. i. pl. lv. (Madras, 1866).

<sup>2</sup> Hooker, ‘Garden Ferns,’ pl. xlvi. (London, 1862); Beddome, ‘Ferns of Southern India,’ ed. 2, pl. lv. (Madras, 1873).

<sup>3</sup> W. J. Hooker & R. K. Greville, ‘Icones Filicum,’ vol. i. pl. xcv. (London, 1831).

<sup>4</sup> Hooker & Greville, *op. cit.* pl. xxiii.

<sup>5</sup> This subject is more fully dealt with in an article in ‘Science Progress,’ 1897, p. 178.

<sup>6</sup> ‘Recherches anatomiques sur les Cryptogames vasculaires,’ G. Poirault, Ann. Sci. Nat. [Bot.] vol. xviii. (1894) p. 113.

<sup>7</sup> ‘On the Fossil Botany & Zoology of the Rocks associated with the Coal of Australia,’ Ann. & Mag. Nat. Hist. ser. 1, vol. xx. (1847) p. 151.

(or at least very convex) subcarinate scales, having a divaricating reticulated nervation, resembling that of the perfect frond, but much less strongly marked; these scales are of large size, some of them being nearly an inch in length, and terminating at the apex in a long, flat, linear appendage, about one line in width, which occasionally gives off small, lateral, flat membranous branches nearly at right angles . . .’ He compares the scales with some ramenta figured by Fée in *Acrostichum* and other genera.<sup>1</sup>

#### DESCRIPTION OF THE SPECIMENS.

(Pl. XXI, fig. 1.)

Portion of a frond 5 cm. long, showing distinct anastomosing and crowded veins, with several elongated and irregular elliptical or circular holes in the lamina. Probably these sorus-like patches are the result of tearing; the specimen illustrates the danger of attaching any great importance to characters of this kind. In venation and leaf-form the fragment agrees with the Australian examples of *G. Browniana* seen on the piece of shale represented in Pl. XXIII, fig. 1, and with *G. Browniana* figured by Zeiller from Francis (*op. jam cit.* pl. xvi. figs. 3 & 4), and I believe also with the specimen named by this author *G. angustifolia*, in which there occur what are very probably the impressions of sori. Compare also the leaf figured by Feistmantel as *G. communis* var. *stenoneura*.<sup>2</sup>

*Locality.* Boschmans Fontein, Middelburg.

Pl. XXI, fig. 2. (*G. Browniana* var. *indica*.)

A small piece of a large frond; from the midrib to the leaf margin 2.8 cm. in breadth. This fragment is of interest as illustrating the difficulty of drawing any sharp line between *G. Browniana* and *G. indica*. It is considerably larger than the leaf shown in fig. 1, but the venation is of the same type. Zeiller’s figs. 1 and 2, pl. xvii., of *G. indica* agree exactly with the fragment represented in our fig. 2. It is also identical, as regards both size and venation, with some of the large fronds described by Bunbury from Nágpur as *G. Browniana* var. *indica*, *G. stricta*, Bunb., and other species. It is impossible to recognize a distinct difference between the numerous well-preserved fronds on the two large slabs of rock (in the Botanical Museum, Cambridge) from which Bunbury described his species *G. stricta*. One is able to trace a gradation, from the large fronds referred to *G. Browniana* var. *indica* with the lateral veins disposed as shown in Pl. XXI, fig. 2, to the fronds which Bunbury referred to *G. stricta*,<sup>3</sup> in which the lateral veins are almost at right angles to the midrib. Some of the leaves figured by

<sup>1</sup> See Fée, ‘Genera Filicum’ (Polypodiaceæ), 1850-52.

<sup>2</sup> ‘Flora of the Damuda & Panchet Divisions,’ Foss. Flor. Gondw. System, Mem. Geol. Surv. Ind. (Pal. Ind.) vol. iii. (1881) p. 99 & pl. xxxii. A, fig. 3, etc.

<sup>3</sup> Quart. Journ. Geol. Soc. vol. xvii. (1861) pl. ix. fig. 5.

Feistmantel from New South Wales as *G. Browniana*<sup>1</sup> agree very closely with this form of frond, at least as regards the venation. The specimen represented in Pl. XXI. fig. 2 is from Casey's Township (Francis).

A much larger portion of a frond, 15 cm. long and 5 cm. broad, which agrees exactly with the fragment shown in Pl. XXI. fig. 2, has been found by Mr. Draper in the coal-beds of Maggies Mine.

Pl. XXI. fig. 3. (*G. Browniana* var. *indica*.)

This specimen shows the venation much less clearly than those of figs. 1 and 2, Pl. XXI. It is in the form of an indistinct impression on sandstone, and was obtained from the same quarry at Vereeniging as that which afforded the specimens of *Sigillaria* described below. The length of the leaf is 14.5 cm., and the broadest part measures 6 cm.; the midrib is well marked and broad, gradually tapering towards the frond apex. The lateral veins are very numerous, and oblique to the midrib, agreeing with those of fig. 2, Pl. XXI.; the leaf should most probably be referred to the same species—*G. Browniana* var. *indica*.

On the same piece of sandstone, which is practically full of imperfect leaf-impressions and forms part of a leaf-bed, there are several long and narrow *Glossopteris*-leaves like that from Casey's Township (Francis) shown in Pl. XXI. fig. 4a, also portions of *Næggerathiopsis*, and in one case possibly a fragment of *Gangamopteris* like the large specimen of Pl. XXII. fig. 1. This form of leaf bears a close resemblance to those named by Feistmantel '*Glossopteris damudica*,'<sup>2</sup> which it is difficult to distinguish from his *G. communis* (= *G. Browniana* var. *indica*). Compare also *G. ampla*, Dana.<sup>3</sup>

Pl. XXI. fig. 4a. (*G. Browniana* var. *angustifolia*.)

Leaf imperfect; length of the portion preserved 17 cm., and breadth about 2 cm. The venation agrees with that of Brongniart's type of *G. angustifolia*, and indeed with *G. Browniana*. The specimen figured by Zeiller as *G. Browniana* in pl. xvi. fig. 4 (*op. cit.*) bears a close resemblance to this specimen, which is from the same locality. Several smaller and less perfect specimens of this form of leaf have been found in the sandstone at Vereeniging in the beds containing *Sigillaria*, and in one or two of these impressions the broader basal part of the short petiole is clearly shown. In cases where these narrow leaves do not show the apical portion, it is possible to mistake the long and narrow basal portion of a large leaf of *G. Browniana* var. *indica* for an almost complete linear leaf. The example shown in fig. 4 and some of the impressions from

<sup>1</sup> Mem. Geol. Surv. N.S.W., Palæontology No. 3 (1890), pls. xvii., xx. etc.

<sup>2</sup> 'Flora of the Damuda & Panchet Divisions,' p. 105 & pls. xxx. A, xxxi. A. etc.

<sup>3</sup> For example, a specimen figured by Jack & Etheridge in their 'Geology & Palæontology of Queensland and New Guinea,' pl. xvi. fig. 7 (Brisbane, 1892).

Vereeniging are, however, almost certainly portions of long and narrow leaves. In specimens from the leaf-beds of both Australia and India it is possible to trace a gradual alteration in leaf form from the narrow linear type to the much broader spatulate or elongate-oval form; this is well seen in specimens in the Bunbury Collection, which includes Australian (Newcastle Beds) and Indian examples of *Glossopteris*-leaves. It is in any case convenient to designate the long narrow fronds by some distinctive term, but we have not, I believe, sufficient evidence to justify the use of a distinct specific name; for this reason I propose to speak of such fronds as *G. Browniana* var. *angustifolia*.

Several specimens of *Vertebraria* (*Glossopteris*-rhizome) have been found at Casey's Township (Francis), but the pieces sent by Mr. Draper are not so well preserved as those figured by Zeiller from the same beds. The largest example in the Draper collection is one from Vereeniging, which has a length of 10 cm., and shows the characteristic transverse markings which have recently been cleverly interpreted by Zeiller.

#### NÆGGERATHIOPSIS HISLOPI (Bunb.).

Quart. Journ. Geol. Soc. vol. xvii. (1861) p. 334, pl. x. fig. 5.

The generic name *Næggerathiopsis* was proposed by Feistmantel in 1879<sup>1</sup> for certain leaves previously referred by Bunbury to *Næggerathia*. The precise nature of this plant is still undecided, and the fragments obtained in the Transvaal do not add anything of botanical importance to our previous knowledge.

Pl. XXI. fig. 4*b*. This basal leaf-fragment, 5 cm. in length, agrees exactly with the specimens described by Zeiller from the same locality. In another specimen from Casey's Township (Francis) there are two tapered portions of leaves lying parallel to one another, and in such a position as to suggest the attachment of two pinnæ to a rachis; but the bases are not seen, and it is equally possible that their position may be entirely accidental. Imperfect impressions of what are most probably *Næggerathiopsis*-leaves occur in association with the *Sigillaria* at Vereeniging.

*Locality.* Casey's Township (Francis).

Pl. XXI. fig. 6. In this specimen there is a portion of a leaf seen at *a*, with a strongly convex surface and narrow base; the upper portion is torn across irregularly at *x*. The surface-features are not very distinct, but the leaf is traversed by parallel or slightly spreading veins which appear to fork occasionally and possibly anastomose, although it is very difficult to follow accurately their course owing to imperfect preservation. Above the broken distal end *x*, and at a lower level on the rock, there are two slightly concave impressions of *Glossopteris*-leaves at *g* and *g'*. In both

<sup>1</sup> 'Flor. Talchir-Karharbâri Beds, Foss. Flor. Lower Gondw.,' Mem. Geol. Surv. India, Palæontologia Indica, vol. iii. (1879) p. 23.

leaves *g* and *g'* the oblique anastomosing veins may be readily distinguished, but as the two fragments lie in different planes the veins are not clearly shown in the photograph. The whole specimen is by no means clear; it is possible that we have simply an accidental association of what appears to be a portion of a *Næggerathiopsis*-leaf with two leaves of *Glossopteris*. On the other hand, the relative positions of the leaf *a* and the leaves *g* and *g'*, and the fact that we have only half the breadth of the lamina in each of the *Glossopteris*-leaves, suggest the possibility of a torn scale-leaf (*a*) covering partially-expanded *Glossopteris*-leaves. The imperfection of the specimen precludes the expression of any very decided opinion as to its nature.

*Locality.* Boschmans Fontein, Middelburg.

#### GANGAMOPTERIS CYCLOPTEROIDES, Feistm.

Feistmantel, Rec. Geol. Surv. India, vol. ix. (1876) pt. iii. p. 73.

(Pl. XXII. fig. 1, and text-fig. 1c, p. 324.)

The specimen shown in Pl. XXII. fig. 1 is an imperfect impression on a slab of iron-stained sandstone from Vereeniging. It measures 10 cm. in length, and is about 6 cm. broad; the form is obovate or broadly oval. The veins spread from the narrow basal portion in a flabellate manner, and along the median line they are almost vertical; the details are not at all clearly seen on the sandstone-surface, but there appear to be indications here and there of lateral anastomoses. The form and general appearance of the leaf remind one of the European genus *Psymphyllum* figured by Lindley and Hutton<sup>1</sup> from England as *Næggerathia flabellata*, by Schmalhausen<sup>2</sup> from Russia, etc. A comparison may also be made with *Rhipidopsis ginkgoides*, Schmalh., and *Palæovittaria Kurtzi*, Feistm. Among Southern Hemisphere fossils, some of the Indian leaves figured by Feistmantel as *Gangamopteris cyclopteroides*<sup>3</sup> agree fairly closely with the present specimen, which may probably be referred to that species. The same author has also figured a very similar leaf from near Kimberley.<sup>4</sup>

The smaller leaf (4·8 cm. long) represented in text-fig. 1c (p. 324) is from the shales of Casey's Township, and is probably an example of the same species.

<sup>1</sup> 'Foss. Flor.' pl. xxix.

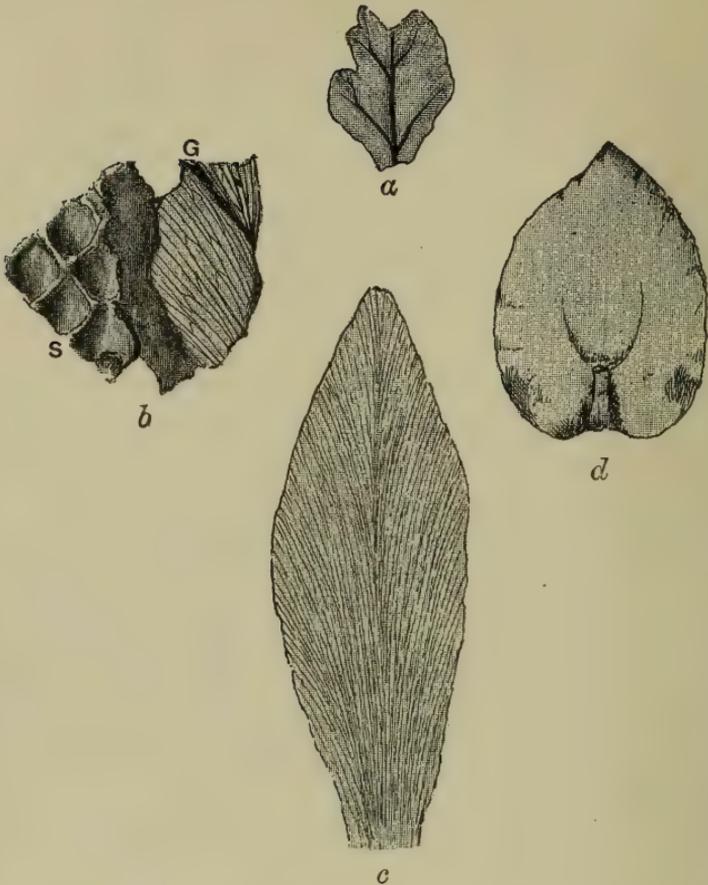
<sup>2</sup> 'Die Pflanzenreste der Artinskischen und Permischen Ablagerungen im Osten des Europäischen Russlands.' Mém. Com. géol. vol. ii. (1887) no. 4, pl. iii. Compare also *Baiera gigas*, Schmalh., pl. v. fig. 10.

The resemblance between certain forms described by Schmalhausen and some of the types of the *Glossopteris*-flora is a matter of considerable interest, and has been recently discussed by Zeiller, Bull. Soc. géol. France, ser. 3, vol. xxiv. (1896) p. 466. See also Schmalhausen, Mém. Acad. Imp. Sci. St. Pétersb. ser. 7, vol. xxvii. 1879.

<sup>3</sup> 'Foss. Flor. Talch.-Karh.' Pal. Ind. vol. iii. (1879) pl. xxvii. fig. 1, etc.

<sup>4</sup> 'Uebersichtliche Darstellung der geol. u. pal. Verhältnisse Süd-Afrikas, pt. i. (1889) pl. iv. fig. 2, Abh. k. Böhm. Ges. Wiss. vol. iii. [vii.]. See reference to the determination of the specimen by MM. Zeiller & Renault.

Fig. 1.



a. *Sphenopteris* sp.  $\times 5$ .  
 b. S. ? *Sigillaria* sp. G. *Glossopteris*  
 sp. Nat. size.

c. *Gangamopteris cyclopteroides*,  
 Feistm. Slightly enlarged.  
 d. *Cardiocarpus* sp.  $\times 3$ .

### Equisetaceous Stems.

PHYLLOTHECA sp. (Pl. XXIV. fig. 1.)

This photograph shows one of the large and well-preserved impressions of a stem from Maggies Mine. It is 16 cm. long and nearly 4 cm. broad, the internodes having a length of about 4 cm. The surface shows narrow, prominent ridges, separated by broad, flat depressions, which do not alternate at the nodes, but are continuous from one internode to the next, as in *Phyllotheca* and *Schizoneura*. Several specimens of smaller stems identical in form with this larger example have been found at the same locality. In the absence of leaves it is perhaps unwise to refer the specimens to a particular species, but the stems agree very closely with those

figured by Feistmantel as *Schizoneura gondwanensis*, Feistm.,<sup>1</sup> from the Lower Gondwanas. There is, however, a close resemblance between the African stems and the specimens of *Phyllotheca australis* figured by Feistmantel<sup>2</sup> from the Newcastle Beds of New South Wales. See also the specimen figured by Bunbury as *Phyllotheca indica*, Bunb.,<sup>3</sup> from Central India, *Ph. Hookeri*, M'Coy, figured by M'Coy<sup>4</sup> from New South Wales, and *Phyllotheca* sp. described by Schmalhausen from Russia.<sup>5</sup>

In the absence of leaves it would seem impossible to define the distinctive characters for *Phyllotheca* and *Schizoneura*. The comparison of several leaf-bearing stems of these two genera leads one to express the opinion that possibly the retention of both generic names may be unnecessary. Some exceedingly interesting specimens of *Phyllotheca* from Heraclea,<sup>6</sup> which I have recently had the opportunity of examining through the kindness of my friend M. Zeiller, appear to throw some further light on the affinity of this genus; but this question will be dealt with by M. Zeiller in his description of the new material.

#### Fossils of doubtful Affinity.

Pl. XXII. fig. 4*b*. This long, finely-ribbed specimen has a length of 27 cm. and a breadth of 5.5 cm. The ribs, separated by very narrow grooves, have a breadth of about 1 to 1.8 mm., and there occasionally occurs a less distinct groove traversing the middle of some of the ridges. Towards the narrower end the ribs are slightly narrower and the stem is somewhat curved, in a manner suggesting an approach to the point of attachment. There is no absolutely certain indication of a node; the irregular transverse lines at *x x* are no doubt casts of accidental cracks, but near the upper and broader part of the specimen there is an indistinct transverse line which may be the impression of a feebly-marked node. It is not easy to decide in the case of a fossil such as this between a broad parallel-veined leaf and a flattened stem with long internodes. In the present example there are no indications of forked veins or of lateral anastomoses between the veins. There is a close resemblance between this fossil and some of the larger *Cordaites*-leaves from the European Coal Measures. The still larger parallel-veined leaves described by MM. Renault & Zeiller as *Titanophyllum* might well be mistaken for stems. One may compare their figures in pl. lxi. of the 'Commentry Flora'<sup>7</sup> with the present doubtful fossil. On the whole, however, I am disposed to refer the specimen to some

<sup>1</sup> 'Flora of the Damuda & Panchet Divisions,' pl. ix. A. fig. 7, pl. v. A, etc.

<sup>2</sup> Mem. Geol. Surv. N.S.W., Palæontology No. 3 (1890), pl. xiv. fig. 5.

<sup>3</sup> Quart. Journ. Geol. Soc. vol. xvii. (1861) pl. xi. fig. 1.

<sup>4</sup> M'Coy, Ann. & Mag. Nat. Hist. ser. 1, vol. xx. (1847) pl. xi. fig. 7.

<sup>5</sup> Schmalhausen, Mém. Acad. Imp. Sci. St. Pétersbourg, ser. 7, vol. xxvii. (1879) pls. i., ix., etc.—The rocks spoken of by Schmalhausen as Jurassic are probably Permian: see Zeiller, Bull. Soc. géol. France, ser. 3, vol. xxiv. (1896).

<sup>6</sup> See note by Zeiller in the Compt. Rend. vol. cxvii. June 4th, 1895.

<sup>7</sup> 'Flor. houill. Commentry,' Atlas Soc. Industr. Minér. 1890, pl. lxi.

Equisetaceous plant. It is possible that it may be the impression of a Calamite, such as *C. ramosus*, Brongn., as figured by Weiss,<sup>1</sup> but the evidence hardly justifies the reference to this genus.

Pl. XXIV. fig. 2. This figure represents a portion (7.5 cm.) of a long cast of a stem, 26.5 cm. in length and 2 cm. broad. In the part seen in the figure there is a prominent transverse ridge at *n*, which no doubt marks the position of a node. The transverse ridge may represent the projecting zone of wood which characterizes the nodal region of a Calamitean stem, but the exact nature of the specimen must be left doubtful.

#### SIGILLARIA BRARDI (Brongn.).

Brongniart, 'Class. Vég. foss.' (1822) p. 22 & pl. i. fig. 5.

(Pl. XXIII. fig. 2 & Pl. XXII. fig. 3. Also text-figs. 2*a-p*, p. 327 and 3, p. 329.)

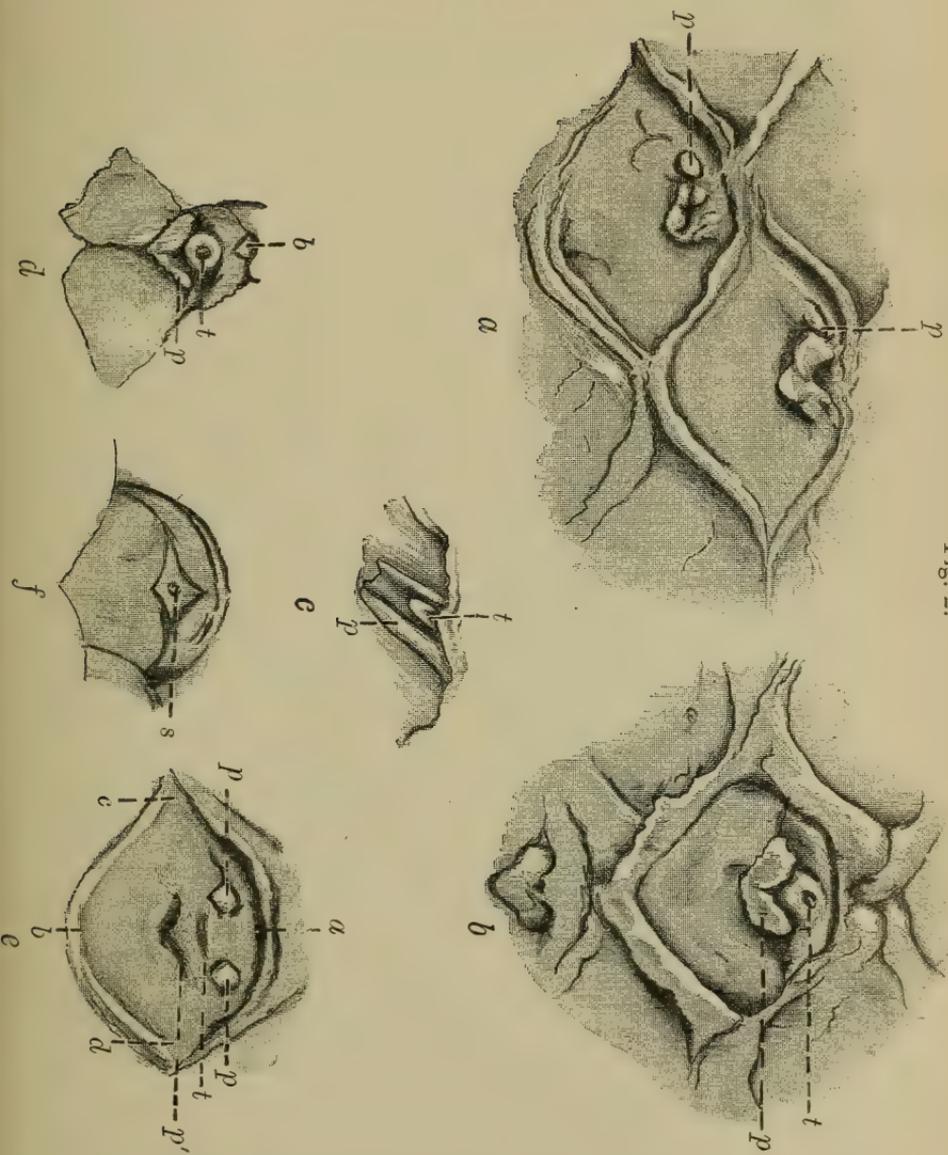
At the British Association Meeting at Liverpool in 1896, I communicated a short note to the Geological Section 'On the Discovery of a Lepidodendroid or Sigillarian Plant by Mr. Draper in the Sandstone of Vereeniging, associated with some Typical Members of the *Glossopteris-flora*.' A more complete examination of the specimens has left no doubt in my mind that at least most of the casts are those of *Sigillaria*, and in all probability specifically identical with the well-known *S. Brardi*. My friend Mr. Kidston, who saw the specimen exhibited at Liverpool, expressed himself in favour of *Sigillaria* rather than *Lepidophloios*, as was suggested in my preliminary note. M. Zeiller has also seen the best specimen and agrees with the reference to Brongniart's species of *Sigillaria*. A comparison of the specimen shown in Pl. XXIII. with the type-specimen of *Sigillaria Brardi* in the Paris Natural History Museum<sup>2</sup> confirmed me in the above identification.

The specimen of which the greater part is seen in Pl. XXIII. fig. 2 measures 18.5 cm. in length, and about 12 cm. in breadth; it is in the form of a fairly well-marked cast on sandstone of a stem covered with closely-set and spirally-disposed leaf-scars. The leaf-scars are about 9 mm. in breadth and 7 mm. in height; they do not afford an exact reproduction of a surface-view of the stem, but represent a cast of the surface of a stem in which decay had already removed a small amount of some of the less resistant tissues. Instead of the three characteristic marks on each leaf-scar—the small round central scar of the leaf-trace bundle with a larger and slightly curved scar on either side—we usually find in their place an obliquely sloping sandstone-projection from the upper third of each scar. The nature of the cast of each leaf-scar will be more clearly understood from the enlarged drawings in fig. 2, described below.

<sup>1</sup> 'Steinkohlen-Calamarien,' Abhandl. k. Preuss. geol. Landesanst. vol. v. (1884) pt. ii. Atlas, pls. v., vi., & vii.

<sup>2</sup> Compare Brongniart's figure in his 'Class. Vég. foss.' pl. i. fig. 5; also in 'Hist. Vég. foss.' pl. clviii. fig. 4. Compare also Germar's figures of *S. Brardi* in 'Die Verstein. Steinkohlgeb. Wettin u. Löbejün,' fasc. iii. pl. xi. (Halle, 1849, etc.).

Fig. 2.



a-e = *Sigillaria Brardi* (Brongn.). ×3.

f = ? *Sigillaria* sp. ×3.

In Pl. XXIII. fig. 2 each leaf-scar is more or less completely surrounded by a narrow sloping plate of sandstone with an irregular margin. This is the last of the grooves which separated the leaf-scars from one another on the stem-surface.

In text-fig. 2e (p. 327) a single scar of the stem reproduced in Pl. XXIII. fig. 2 is drawn on a larger scale. The scar measures 6 mm. from *a* to *b*, and 8.5 mm. from *c* to *d*. At *p*, *p* are two slight elliptical depressions, and at *t* a small and laterally elongated scar; the two former represent the familiar oval scars which are characteristic of Sigillarian and Lepidodendroid leaf-scars, the latter (*t*) represents the scar of the leaf-trace bundle. The meaning of the lower V-shaped prominence (*p'*) will be more easily explained after an examination of other leaf-scars, and a brief reference to the facts of internal structure in Lepidodendroid stems. The occurrence of the three small marks on the leaf-scars of *Sigillaria* has long been known, but their precise relation with the internal structure has only recently been explained. The smaller middle mark has been recognized for some time past as that of the leaf-trace bundle, and the two larger lateral marks have been described as lateral lacunæ<sup>1</sup> consisting of strands of thin-walled and large-celled tissue. Much additional light has, however, been thrown on the structure of these tissue-strands by the investigations of Williamson, Bertrand, and Hovelacque.<sup>2</sup> Williamson published a detailed account of the structure of these tissues in the case of *Lepidophloios* and *Lepidodendron Harcourtii*.<sup>3</sup> He found that the vascular tissue of the leaf-trace is surrounded by a sheath of delicate parenchyma as it passes through the outer cortical tissues of the stem; in traversing the prosenchymatous zone of the cortex which is situated immediately internal to the leaf-bases, the trace is found to be accompanied by a distinct strand of fairly large parenchymatous cells. Soon after leaving the prosenchymatous cortical zone, this parenchymatous strand, which Bertrand has named the *parichnos*,<sup>4</sup> bifurcates, and the two arms bend away right and left of the leaf-trace, finally coming to the stem-surface as two strands, one on either side of the outgoing leaf-bundle. The two lateral marks are therefore the ends of the two short arms of the *parichnos*. It has been suggested that the *parichnos* consists of glandular tissue, and that it may serve as 'transpiration-strands.'<sup>5</sup> Its precise physiological significance is, however, still a matter of doubt.

<sup>1</sup> See I. Felix, 'Untersuch. über d. inneren Bau Westfälischer Carbon-Pflanzen,' Abh. k. Preuss. Geol. Landesanst. vol. vii. (1886) pt. iii. pl. ii. Also Renault & Grand' Eury, 'Rech. sur les Vég. silic. d'Autun,' Mém. Acad. Sci. vol. xxii. pl. i.

<sup>2</sup> 'Recherches sur le *Lepidodendron selaginoides*, Sternb.,' Mém. Soc. Linn. Normandie, vol. xvii. (1892).

<sup>3</sup> 'On the Organization of the Fossil Plants of the Coal Measures,' pt. xix., Phil. Trans. vol. clxxiv. B (1893). Several figures are given illustrating the structure of the leaf-trace and accompanying tissues: some of these are drawn in an inverted position.

<sup>4</sup> 'Remarques sur le *Lepidodendron Harcourtii*,' Trav. et Mém. Facult. Lille, vol. ii. (1891) Mém. 6, p. 84.

<sup>5</sup> H. Potonié, Ber. Deutsch. bot. Gesellsch. 1893, p. 325.

This short account of the parichnos and leaf-trace may render easier the interpretation of the appearance presented by the leaf-scars of the African stem. In the scar shown in text-fig. 2 *e* (p. 327), I regard the V-shaped projection *p'* as the cast of the parichnos at that point where the two short arms have united into a single strand which accompanies the leaf-trace for a short distance through the outer cortex.<sup>1</sup> The two marks *p*, *p* represent the ends of the arms. The leaf-scars seen in fig. 2 *a* show the shape very clearly, also the almost complete absence of any leaf-cushions. At *pp* there is faintly seen the cast of the parichnos-arms, and lower on the leaf-scars the prominent cast of the fused arms of the parichnos. In fig. 2 *b* the crescent-shaped parichnos-cast is very prominent, with a projecting knob above it, having a small hole in the centre; this is also seen in fig. 2 *d*. The central hole may represent the position of the harder and more durable elements of the leaf-trace, and the surrounding sandstone may be the cast of the cylindrical cavity which resulted from the decay of the delicate parenchyma accompanying the leaf-bundle. In fig. 2 *d* the uppermost scar *b* is probably that of the ligule. In fig. 2 *c* the cast of the parichnos is clearly seen as a grooved trough-like structure containing the cast of the leaf-trace *t*. The thin-walled parenchyma of the parichnos and the delicate cells immediately surrounding the leaf-trace would naturally decay more readily than the harder tissues, and the depressions or cavities so produced being filled in with sand have given rise to the appearance presented by the stem shown in Pl. XXIII.

fig. 2. If the above interpretation is correct, we have an interesting example of the aid afforded by a knowledge of internal structure towards the explanation of special features exhibited by structureless casts.

The other specimens of this stem agree in most respects with that represented in Pl. XXIII. fig. 2. In some of the casts the surface

Fig. 3.—*Sigillaria Brardi* (*Brongn.*).  
*Nat. size.*



<sup>1</sup> The crescent-shaped projection shown in a leaf-scar in one of Brongniart's figures of *Sigillaria Menardi* ('Hist. Vég. foss.' 1828, pl. clviii. fig. 6 A) is possibly the cast of the parichnos.

with the leaf-scars is partially overlain by a comparatively thick layer of sandstone, which is marked by numerous fine longitudinal and transverse lines. This is no doubt the cast of some deeper-lying tissues, either the wood or the regularly-disposed tissue of the outer cortex.

In text-fig. 3 (p. 329) a small piece of a stem is shown in which the leaf-scars are clearly seen at A; at B the cast presents a *Knorria*-like appearance: the somewhat irregular elongated projections no doubt represent the casts of elliptical spaces, left in the cortical tissue of the stem after the decay of the delicate tissue accompanying the outgoing leaf-bundles.

Turning to Pl. XXII. fig. 3, we have a very imperfect cast of a stem with smaller leaf-scars, and, as in the larger specimens, without any leaf-cushions. It is impossible to attempt an exact specific identification of so indistinct a cast, but it is probably a smaller form of *Sigillaria Brardi*, or at least it may be referred to that species. It bears a fairly close resemblance to a specimen which Grand'Eury has described from the Gard as an example of *Sigillaria Grasiana*, Brongn.<sup>1</sup>

? SIGILLARIA sp.

(Pl. XXII. fig. 4 a & Pl. XXIV. fig. 3; text-fig. 2 f, p. 327.)

In Pl. XXII. fig. 4 a there is a fairly well-marked impression, reduced about one-half in size, of a stem-surface covered with leaf-cushions which in a few places show the outlines of a leaf-scar. Part of the same specimen is shown nearly natural size in Pl. XXIV. fig. 3.

In text-fig. 2 f (p. 327) one of the best leaf-cushions is drawn on a larger scale, showing the leaf-scar s. The preservation is too imperfect to allow of a more detailed description, and one cannot feel quite certain as to the true affinities of the stem. The cushion shown in fig. 2 f has a breadth of 7 mm. In certain forms of stems it is not an easy matter, indeed in badly-preserved specimens it is an impossibility, to distinguish between *Sigillaria* and *Lepidodendron*. In the specimen shown in Pl. XXII. fig. 4 a, the outlines of the leaf-cushions are fairly distinct, but it is only in a few places that the leaf-scars can be made out; the more minute surface-features cannot be seen. There is a certain amount of resemblance between this impression from Vereeniging and those of *Lepidodendron Pedroanum* (Carr.) from Brazil,<sup>2</sup> but it would be unwise to press the agreement too far. The slightly enlarged drawing in fig. 2 f shows the leaf-scar to be much smaller than that of *Sigillaria Brardi* (Pl. XXIII. fig. 2); the leaf-cushion, on the other hand, is much larger. This difference in the size of the leaf-cushion is, however, not a character of essential importance as regards a comparison with *S. Brardi*. It has been clearly shown by Weiss<sup>3</sup> and Zeiller<sup>4</sup> that in stems of the *S. Brardi* type there

<sup>1</sup> 'Bass. houill. Gard,' pl. x. fig. 11.

<sup>2</sup> Zeiller, Bull. Soc. géol. France, ser. 3, vol. xxiii. (1895) pl. viii.

<sup>3</sup> Zeitschr. Deutsch. geol. Gesellsch. vol. xl. (1888) p. 565; also Weiss & Sterzel, Abh. k. Preuss. geol. Landesanst. 1893, p. 89.

<sup>4</sup> Bull. Soc. géol. France, ser. 3, vol. xvii. (1889) p. 603.

is very considerable variation as regards the proximity of the leaf-scars and the size of the leaf-cushions. In Weiss's paper on this subject he gives a figure of a single cushion and scar of a form spoken of as *Sigillaria wettinensis*, Weiss,<sup>1</sup> which cannot be separated specifically from *S. Brardi*; in this form the leaf-cushion is well marked and prominent, and the relative size of the leaf-scar and cushion agrees closely with that shown in fig. 2 *f*. If this specimen were, however, specifically identical with that shown in Pl. XXIII., we should expect a greater equality in the size of the leaf-scars. On the whole I incline towards the view that this impression may be that of a *Sigillaria*, but the preservation is too imperfect to admit of any accurate determination. A comparison of Pl. XXII. fig. 4 *a*, Pl. XXIV. fig. 3, and text-fig. 2 *f* with such a drawing as that given by Potonie of *Lepidodendron Volkmannianum*, Sternb.,<sup>2</sup> shows a very close agreement. This species, however, characterizes a much lower horizon than that at which *Sigillaria Brardi* is usually found.

The same piece of rock as that on which this Lepidodendroid impression occurs contains several fragments of *Glossopteris*, one of which is seen in Pl. XXII. fig. 4 at *c*, and on a larger scale in text-fig. 1 *b* at *G* (p. 324).

In the important posthumous monograph by Weiss,<sup>3</sup> completed by Sterzel, the name *Sigillaria mutans*, Weiss, is adopted as the designation of a specific type which includes a very great variety of forms. In this species *Sigillaria Brardi*, *S. wettinensis*, and numerous other examples of both Leiodermarian and Clathrarian forms are included. The reasons advanced by Weiss for the substitution of the specific term *mutans* for such well-marked types as *Brardi* and others are hardly convincing. The imperfect specimen from Vereeniging bears a very close resemblance to *S. mutans* forma *Brardi* var. *sublævis* figured by Weiss & Sterzel in their pl. xvi. Compare also *S. mutans* forma *wettinensis* var. *convexa* (pl. xii); and *S. mutans* forma *urceolata* (pl. xiii).

CONITES sp. (Pl. XXII. fig. 2.)

Sternberg, 'Flor. Vorwelt,' fasc. iii. (1823) p. 36; Seward, Cat. Mesozoic Plants Brit. Mus., Wealden Flora, vol. ii. (1895) p. 113.

This specimen, 2 cm. in length and 1 cm. broad, occurs on the same slab of sandstone as the *Gangamopteris*-leaf of Pl. XXII. fig. 1. The surface shows several distinct four- to six-sided areas, measuring 2 mm. in length and from 1 to 1.5 mm. in breadth, which appear to be the proximal ends of thick scales which expanded distally, as seen on the sloping side of the fossil at *s*. The proximal ends appear to be solid; the fractured appearance of a few of the areas is probably accidental, and does not indicate originally hollow scales. Had the scales been hollow, the specimen would have presented a

<sup>1</sup> Zeitschr. Deutsch. geol. Gesellsch. vol. xl. (1888) p. 569. (Included by Weiss in a later work as a 'form' of *S. mutans*, Weiss.)

<sup>2</sup> Abh. k. Preuss. geol. Landesanst. n. s. pt. xxi. (1896) p. 43, fig. 43.

<sup>3</sup> 'Die Sigillarien der Preuss. Steink. Roth. Gebiete,' pt. ii., Weiss & Sterzel, Abh. k. Preuss. geol. Landesanst. n. s. pt. ii. (1893).

close agreement with an Araucarian cone, and it is still possible that it may represent a number of Araucarian scales detached from a broad central axis and seen from the inside. The distally-expanded portions of the scales are opposed to a reference to an Equisetaceous strobilus. On the whole, the specimen is probably a portion of some Gymnospermous cone, either Cycadean or Coniferous, and may be referred provisionally to the genus *Conites*.

*Locality.* Vereeniging.

#### SPHENOPTERIS sp.

Text-fig. 1 a (p. 324). This small fragment of a leaf with a lobed lamina and forked lateral veins is in all probability a piece of a *Sphenopteris*-frond. Zeiller figures a fragment from the same locality (Casey's Township, Francis), which he refers to this genus, but probably it is specifically distinct from the present example. The piece is too small to admit of specific identification.

#### CARDIOCARPUS sp.

Text-fig. 1 d (p. 324). This solitary example of a seed among the fossils sent by Mr. Draper was found on splitting open a small piece of shale from Casey's Township (Francis). It measures 9 mm. in length, and 6.5 mm. in breadth. When first seen there was a loose thin lamina of coal marking the position of the seed, occupying the slightly depressed area faintly indicated in the drawing. The broad carbonaceous margin surrounding the oval central region is interrupted at the base by what appears to be a canal leading to the base of the seed. Several examples of fossil seeds from Palæozoic rocks have been figured by different authors which show a close resemblance to the specimen from Francis. Reference may be made to *Samaropsis* sp.<sup>1</sup> figured by Feistmantel in his supplement to the 'Flora of the Talchir-Karharbári Beds,' *Cardiocarpus nervosa*, Kidst.<sup>2</sup>; *Samaropsis affinis*, Schk., from the Coal Measures of China,<sup>3</sup> *Samaropsis fluitans*, Weiss,<sup>4</sup> from the Upper Ottweiler Beds; *Cardiocarpus simplex*, Lesq.,<sup>5</sup> from the Carboniferous of North America, etc. The specimen is no doubt a Gymnospermous seed, of that particular type placed by some authors in the genus *Samaropsis*. Schimper includes certain seeds of this form under Brongniart's comprehensive term *Cardiocarpus*,<sup>6</sup> and this is probably the wisest course to adopt. In dealing with detached portions of plants such as seeds or cones, it is better to use comprehensive generic terms rather than to make use of names instituted

<sup>1</sup> 'Flor. Talch.-Karh.,' Pal. Ind. vol. iii. (1879) pl. xxviii. fig. 8

<sup>2</sup> Proc. Roy. Phys. Soc. Edinburgh, vol. xii. (1894) pl. v. figs. 3-5. (It is not intended to suggest that there is a possibility of specific identity between this and other examples quoted and the seed represented in fig. 1 d; but the references may serve to illustrate the wide distribution of this form of seed.)

<sup>3</sup> Richthofen's 'China,' vol. iv. (Schenk) pl. xlv. p. 213 (Berlin, 1883).

<sup>4</sup> 'Foss. Flor. d. jüngst. Steinkohl. u. Roth. im Saar-Rheingebiet,' pl. xviii. figs. 24-30 (Bonn, 1869-1872).

<sup>5</sup> Second Geol. Surv. Pennsylvania (1879), 'Coal Flora,' pl. lxxxv. figs. 48-50.

<sup>6</sup> 'Traité de Pal. vég.' vol. iii. (1869) p. 567.

on the grounds of very slight differences in form. As Schenk<sup>1</sup> has pointed out, the wide margin surrounding the central oval seed is the impression of a fleshy seed-coat and not a membranous wing, as many authors have termed it. The researches of Brongniart<sup>2</sup> and Williamson<sup>3</sup> and others have enabled us to correlate the various forms presented by fossil seed-impressions and casts with the tissues of the seed and seed-coat. The canal at the base of the seed in fig. 1*d* no doubt marks the position of the chalazal vascular bundle.

#### Fossil of doubtful Affinity. (Pl. XXI. fig. 5.)

This imperfect leaf, 3.8 cm. in length and 7 mm. broad, cannot be referred with certainty to a particular genus. Its convex surface is traversed by a number of parallel veins; at the apex it terminates in a sharp, narrow point, but the base is very imperfectly preserved. The form of the leaf suggests a comparison with the incomplete example represented in Pl. XXI. fig. 6. A leaf such as this, especially if imperfect, might belong to various genera, and in the case of a single specimen it is better to refrain from any attempt at exact identification. It may be compared with a small example of *Cordaites*, *C. lancifolius*, Schmal., figured by Schmalhausen<sup>4</sup> from the Permian rocks of Russia. On the other hand, certain Cycadean pinnæ or the broad leaves of such a Conifer as *Araucaria* or *Agathis* afford close parallels with this type of leaf.

*Locality.* Casey's Township (Francis).

The following table shows the distribution of the plants in Mr. Draper's collection among the three localities, Francis or Casey's Township, Boschmans Fontein and Maggies Mine, and Vereeniging:—

	Casey's Township (Francis).	Boschmans Fontein & Maggies Mine.	Vereeniging.
<i>Glossopteris Browniana</i> .....	×	.....	×
<i>G. Browniana</i> var. <i>indica</i> .....	×	×	×
<i>G. Browniana</i> var. <i>angustifolia</i> ...	×	.....	×
( <i>Vertebraria</i> ) .....	×	×	×
<i>Neggerathiopsis Hislopi</i> .....	×	×	×
<i>Gangamopteris cyclopteroides</i> .....	×	.....	×
<i>Phyllothea</i> .....	.....	×	.....
? Equisetaceous stem, cf. <i>Calamites</i> .	.....	.....	×
? <i>Sigillaria</i> sp. ....	.....	.....	×
<i>Sigillaria Brardi</i> .....	.....	.....	×
<i>Conites</i> sp. ....	.....	.....	×
<i>Cardiocarpus</i> sp. ....	×	.....	.....
<i>Sphenopteris</i> sp. ....	×	.....	.....

<sup>1</sup> Zittel's 'Handbuch der Paläontologie,' pt. ii. p. 249 (Munich & Leipzig, 1890).

<sup>2</sup> 'Recherches sur les Graines silicifiées,' pl. xiii. fig. 1, etc. (Paris, 1881).

<sup>3</sup> 'Organ. Foss. Plants Coal Measures,' pt. viii., Phil. Trans. vol. clxvii. (1877).

<sup>4</sup> Schmalhausen, Mém. Com. géol. vol. ii. (1887) No. 4, pl. vi. fig. 2.

## CONCLUSIONS.

It remains for us to consider the probable geological horizon indicated by this assemblage of plants.

In discussing this question in the case of the Francis beds, Zeiller<sup>1</sup> decides in favour of assigning the plant-beds to the horizon of the Beaufort stage, which he speaks of as Permo-Triassic, and correlates them with the Damuda Beds of India. The absence of the genus *Gangamopteris* is quoted by Zeiller as indicating the upper rather than the lower division (Barakar) of the Damuda stage. This genus has, I believe, now been recognized at Francis (fig. 1 c, p. 324), and this makes it possible to correlate the Francis plant-beds with the Lower or Middle Damudas. The plants from Francis are on the whole indicative of a Permo-Carboniferous age. The agreement of the plants is closer with the Damuda flora than with that of the underlying Karharbári stage or the overlying Panchet Beds.

The plants from Boschmans Fontein and Maggies Mine are not sufficiently numerous to afford very conclusive evidence, but they do not offer any obstacle to the correlation of these rocks with those of Casey's Township (Francis), which Draper considers to be of the same geological age.

We turn next to the sandstones and leaf-beds of Vereeniging, which present the most interesting problem on account of the occurrence of *Sigillaria*.<sup>2</sup> The occurrence of *Gangamopteris* points to the Damuda or Karharbári stage of India as the probable representative of the Vereeniging beds. The abundance of the long and narrow *Glossopteris*-leaves, which I have spoken of as *G. Browniana* var. *angustifolia*, would seem to point rather to the Damuda than to the Karharbári horizon; but this is by no means conclusive evidence. Draper considers these beds to belong to the same horizon as those of the other two localities. We must next consider the relation of the Vereeniging rocks to those of other countries in which *Sigillaria Brardi* occurs.

In Europe *Sigillaria Brardi* usually characterizes an Upper Coal-Measure or Permian horizon. Kidston has recorded this species from the Middle as well as from the Upper Coal Measures of Staffordshire,<sup>3</sup> but as a general rule it is a distinctly Upper Coal-Measure and Permian form. *Sigillaria Brardi* has been recorded from the following, among other, European localities:—The Upper, Middle, and Lower Coal Measures of England; the Commentry<sup>4</sup> Coalfield of France, referred to an Upper Coal-Measure age, and as characteristic of the upper beds of the Gard<sup>5</sup> Coalfield.

<sup>1</sup> Bull. Soc. géol. France, ser. 3, vol. xxiv. (1896).

<sup>2</sup> Molengraaff speaks of a specimen of *Sigillaria* from some coal-beds in the Transvaal, but does not describe it: see Neues Jahrb., Beilage, vol. ix. (1894-95) p. 174.

<sup>3</sup> Proc. Roy. Phys. Soc. Edin. vol. xii. (1894) p. 252, & Trans. Roy. Soc. Edin. vol. xxxvi. pt. i. (1891) p. 84. See also Zeiller, Bull. Soc. géol. France, ser. 3, vol. xxii. (1895) p. 496.

<sup>4</sup> 'Études sur le Terrain houiller de Commentry,' Flor. Foss. Renault & Zeiller, p. 539 (1890).

<sup>5</sup> Grand' Eury, 'Géol. & Pal. Bass. houill. Gard,' p. 250 (St. Étienne, 1890)

Potonié mentions *Sigillaria Brardi* as a typical species in the Ottweiler Beds and in the Upper Coal Measures and Permian rocks generally.<sup>1</sup> This species is recorded by Zeiller from the Upper Coal-Measure and Permian beds of Brive,<sup>2</sup> as well as from the Coal Basin of Valenciennes,<sup>3</sup> also from the Permian rocks of Bohemia<sup>4</sup> and the Permian of Autun.<sup>5</sup> The same form occurs moreover in beds referred to a Permian age in Pennsylvania.<sup>6</sup> Without multiplying references to this species, enough has been said to show that it points to a high horizon in the Coal Measures, or to a Permian age; as Göppert says in his 'Permian Flora,' the species is not uncommon in Permian rocks.

There is also some evidence, but not of the best, of another species of *Sigillaria*, *S. oculina*, occurring in the Bunter Sandstone of Germany. Blanckenhorn<sup>7</sup> figured a specimen from this horizon in 1886, and Weiss<sup>8</sup> subsequently confirmed his determination. The preservation is by no means good, and an examination of a cast of the specimen in the Bergakademie Museum, Berlin, did not thoroughly convince me as to the Sigillarian nature of the fossil. Blanckenhorn's determination has, however, been accepted by Sterzel,<sup>9</sup> Potonié,<sup>10</sup> and other authors in addition to Weiss.

The occurrence of *Sigillaria Brardi* at Vereeniging is decidedly in favour of the view already expressed, that these beds should be referred to a Permo-Carboniferous age.

The most interesting feature in connexion with the occurrence of *Sigillaria* in South Africa in association with *Glossopteris* and *Gangamopteris* is the coexistence of members of the *Glossopteris*-flora and a typical representative of the Northern Hemisphere vegetation of Permo-Carboniferous times. In 1895 Zeiller recorded a similar association of *Gangamopteris*, *Lepidodendron*, and *Lepidophloios* in the coal-beds of Rio Grande do Sul in Brazil.<sup>11</sup>

In a paper contributed by Dr. Blanford<sup>12</sup> to a recent number of the Records of the Geological Survey of India, it is stated that Dr. Kurtz has found a *Lepidodendron* in Argentina associated with the *Glossopteris*-flora. It is only lately that we have had satisfactory

<sup>1</sup> 'Die floristische Gliederung des deutschen Carbon u. Perm,' *Abh. k. Preuss. geol. Landesanst. n. s. pt. xxi.* (1896) p. 14.

<sup>2</sup> 'Bass. houill. & Perm. Brive' (1892).

<sup>3</sup> 'Bass. houill. Valenciennes' (1886).

<sup>4</sup> 'Geologie von Böhmen,' Katzer, pp. 1172, 1208 (Prag, 1892).

<sup>5</sup> Renault, B., 'Bass. Houill. & Perm. d'Autun et d'Épinac,' fasc. iv. p. 192 (1896).

<sup>6</sup> Fontaine & White, 'Permian or Upper Carb. Flora,' *Second Geol. Surv. Pennsylvania*, PP. 1880.

<sup>7</sup> *Palæontographica*, vol. xxxii. pl. xx. fig. 9, p. 132.

<sup>8</sup> 'Ueber eine Buntsandstein-Sigillaria'... *Jahrb. k. Preuss. geol. Landesanst.* (1885) p. 356.

<sup>9</sup> 'Die Flora des Rothliegenden im Plauen'schen Grunde bei Dresden,' *Abh. k. Sächs. Gesellsch. Wiss.* vol. xix. (1893) p. 153.

<sup>10</sup> *Abh. k. Preuss. geol. Landesanst. n. s. pt. xxi.* (1896) p. 41.

<sup>11</sup> 'Note sur la Flore fossile des Gisements houillers de Rio Grande do Sul,' *Bull. Soc. géol. France*, ser. 3. vol. xxiii. (1895) p. 601.

<sup>12</sup> *Rec. Geol. Surv. India*, vol. xxix. pt. ii. (1896) p. 58.

evidence of the occurrence of the *Glossopteris*-flora in South America, but the work of Kurtz and Zeiller, following the earlier account of Brazilian plants by Carruthers,<sup>1</sup> has yielded most important results.

Stated briefly, the questions suggested by these recent discoveries of Lepidodendroid and Sigillarian plants associated with the *Glossopteris*-flora of South America and Africa are these:—(i) Was there a land-connexion between the continent of Gondwanaland and the Northern Hemisphere continental areas towards the close of the Palæozoic epoch? (ii) May we regard the Lepidodendroid and Sigillarian species of South America and South Africa as survivals from an older period which preceded the typical *Glossopteris*-flora?

The *Glossopteris*-flora is best known from the Indian rocks, and in that region no specimens of *Calamites*, *Sigillaria*, or *Lepidodendron* have so far been discovered. As Zeiller maintains, the Indian genus *Trizygia*<sup>2</sup> of Royle is no doubt a *Sphenophyllum*, and there are other connecting-links between the older *Glossopteris*-flora of India and the Permo-Carboniferous vegetation of the Northern Hemisphere.

From the Malay Archipelago we have only the most meagre evidence as to the occurrence at Sarawak of one or two members of the *Glossopteris*-flora, and there is as yet no satisfactory evidence of the existence of this flora in New Zealand. In Australia the *Glossopteris*-flora is abundantly represented, but no instance has been recorded of the association of a *Lepidodendron* or *Sigillaria* with *Glossopteris*, *Gangamopteris*, or other characteristic member of the *Glossopteris*-flora.

Several authors have made us familiar with the existence of two great botanical provinces in Permian times, and probably during the later phases of the Carboniferous period, but the facts on which this view is founded need not be dealt with here.<sup>3</sup> There is not wanting evidence in favour of the *Glossopteris*-flora having been first differentiated in an Antarctic continent towards the close of the Carboniferous epoch. It has left abundant traces of existence in the now scattered regions which originally formed part of a large continent to which the name Gondwanaland has been applied by Süss and other writers. In connexion with this southern flora, it is a matter of considerable interest to consider the possible significance of the widespread boulder-beds of India, Australia, Africa, and South America; but this question has been elsewhere discussed by several writers, especially by Dr. Blanford, who has thrown out many valuable suggestions bearing on the general problem of plant-distribution. It is of interest to note a reference in one of Darwin's letters to the possibility of an Antarctic

<sup>1</sup> Geol. Mag., 1869, p. 151.

<sup>2</sup> 'Sur la Valeur du Genre *Trizygia*,' Bull. Soc. géol. France, ser. 3, vol. xix. (1891) p. 673.

<sup>3</sup> See Blanford, W. T., Brit. Assoc. Rep. (Montreal) 1884, Pres. Addr. to sect. C, p. 691; Quart. Journ. Geol. Soc. vol. xlv. (1889) Proc. p. 95; 'Nature,' vol. lii. (1895) p. 595; Seward, A. C. 'Science Progress,' 1897, p. 178; also an excellent article by Zeiller, on 'Les Provinces botaniques de la Fin des Temps primaires,' Rev. gén. Sciences, Jan. 1897.

continent. In writing to Hooker, he says:—‘I have sometimes speculated whether there did not exist somewhere during long ages an extremely isolated continent, perhaps near the South Pole.’<sup>1</sup>

In rocks older than those containing *Glossopteris* or the associated genera in Australia and South Africa, some plants have been described by Feistmantel<sup>2</sup> and others which prove the existence in the Southern Hemisphere of Culm, Lower Carboniferous, and Devonian species prior to the appearance of the *Glossopteris*-flora. In earlier Carboniferous times some at least of the characteristic plants seem to have had an almost world-wide distribution. May we recognize in the *Lepidodendra* and *Sigillariae* of South Africa and South America survivors of this older pre-*Glossopteris* vegetation? Or, on the other hand, does the commingling of Northern and Southern Hemisphere forms recently recorded point to local southerly extensions of certain members of the northern flora?

It is difficult to give a decided answer to these questions. In certain plant-beds of Culm age in Argentina there occur *Lepidodendron* and other genera which have been recorded also from beds of the same age in Australia. In the latter country we have as yet no evidence that these Culm types survived into the period of the *Glossopteris*-flora, nor have we any evidence of the existence of such types in India.

Bearing in mind the danger of relying too much on negative evidence, we may, however, express the view that in Australia the Lower Carboniferous and Devonian plants gave place in Permo-Carboniferous times to a practically new set of forms, *Glossopteris*, *Gangamopteris*, and other genera. In India we know nothing as to the vegetation of Lower Carboniferous times. In Africa and South America there was not so complete a break between the Lower Carboniferous and Permo-Carboniferous floras. We know that typical Coal-Measure species existed in the Zambesi region in the Upper Carboniferous period, and it would seem that the coal-beds of Tete may be regarded as near to the most southerly extension of the northern Coal-Measure vegetation. In the rocks of Vereeniging, probably somewhat younger than those of Tete,<sup>3</sup> we have evidence of the continuous existence and probable southerly extension of at least one typical Permo-Carboniferous plant of the Northern Hemisphere, namely, *Sigillaria Brardi*. Similarly in South America there was the same southerly extension of northern forms. On the whole, the simpler explanation of the facts appears to be to conclude that in South America and South Africa the *Glossopteris*-flora contained a few southern offshoots of the widely-spread vegetation which covered an enormous area in late Carboniferous and early Permian times. As Blanford and Zeiller have suggested, the two botanical provinces

<sup>1</sup> ‘Life and Letters of Charles Darwin,’ vol. iii. p. 248 (London, 1887). I am indebted to Mr. Thiselton-Dyer for calling my attention to this remark.

<sup>2</sup> Mem. Geol. Surv. N. S. Wales, Palæontology, No. 3, 1890. See also Szajnocha, L., ‘Ueber einige Carbone Pflanzenreste aus der Argentinischen Republik,’ Sitzb. k. Akad. Wiss. Wien, vol. c. pt. i. (1891) p. 203.

<sup>3</sup> Zeiller, Ann. Mines, Mém. ser. 8, vol. iv. (1883) p. 594.

overlapped in South America, and the same may now be asserted as regards a certain area of South Africa.

There can be no doubt that the whole problem connected with the geography and plant-distribution in the Southern Hemisphere at the close of the Palæozoic and at the beginning of the Mesozoic Era is well worthy of careful consideration. Our knowledge of the palæobotany of Gondwánaland is still far too fragmentary and imperfect to admit of very definite and far-reaching conclusions, but such data as we already possess are in need of a thorough and comparative study. A superficial acquaintance with the scattered literature of Southern Hemisphere fossil botany suffices to show the need of a general survey of the plant records undertaken from a botanical point of view, in order to afford the geologist a more trustworthy contribution which may aid towards the solution of important geological and botanical questions.

#### EXPLANATION OF PLATES.

(The photographs from which the figures have been reproduced were taken by Mr. Edwin Wilson, Cambridge. The figures are slightly less than natural size, except where otherwise stated.)

All the specimens, with the exception of that figured in Pl. XXIII. fig. 1, are in the British Museum (Natural History).

#### PLATE XXI.

- Fig. 1. *Glossopteris Browniana*, Brongn., p. 320.  
 2. " " var. *indica*, p. 320.  
 3. " " " " p. 321.  
 4 a. " " var. *angustifolia*, p. 321.  
 4 b. *Næggerathiopsis Hislopi* (Bunb.), p. 322.  
 5. Leaf of doubtful affinity, p. 333.  
 6. Fragments of *Glossopteris*-leaves, *g*, *g'*, and one of ? *Næggerathiopsis*, *a*, p. 322.

#### PLATE XXII.

- Fig. 1. *Gangamopteris cyclopteroides*, Feistm., p. 323.  
 2. *Conites* sp., p. 331.  
 3. *Sigillaria* cf. *S. Brardi*, Brongn., p. 326.  
 4 a. ? *Sigillaria* sp., p. 330.  
 4 b. Equisetaceous stem, p. 325.  
 4 c. *Glossopteris Browniana*, Brongn., p. 331. } Rather less than  $\frac{1}{2}$  nat. size.

#### PLATE XXIII.

- Fig. 1. *Glossopteris Browniana*, Brongn., New South Wales, p. 318.  
 2. *Sigillaria Brardi*, Brongn., p. 326.

#### PLATE XXIV.

- Fig. 1. *Phyllothea* sp., p. 324.  
 2. Calamitean (?) stem, p. 326.  
 3. ? *Sigillaria* sp., p. 330.

## DISCUSSION (ON THE TWO PRECEDING PAPERS).

Dr. BLANFORD said that it was a source of much gratification to those who, despite the views of many European palæontologists, had maintained for many years on geological evidence that the *Glossopteris*-fauna was Palæozoic, to find their contention confirmed by recent botanical discoveries.

Mr. GRIESBACH pointed out that the fossil plants exhibited on the table, showing true Carboniferous types associated with *Glossopteris*, constituted another and valuable contribution to our knowledge of these beds, which we know as Gondwânas in India; and they confirmed in a striking manner the fact, already accepted in India and Australia, that the lowest beds of this group of strata belong to the later Carboniferous and Permian systems. With regard to the diagrams shown on the wall, he wished to point out that they were not in strict accordance with the features as actually seen on the spot. Neither does it appear probable that the various areas of coal-bearing beds—as, for instance, Newcastle in Natal, Vereeniging, Boksburg and Middelburg in the Transvaal—have been laid down in one continuous basin as shown in the diagrammatic map exhibited. These deposits show evidence, as do our Indian coal-basins, of having been laid down in separate basins, probably marking systems of rivers, in Permo-Carboniferous and later times.

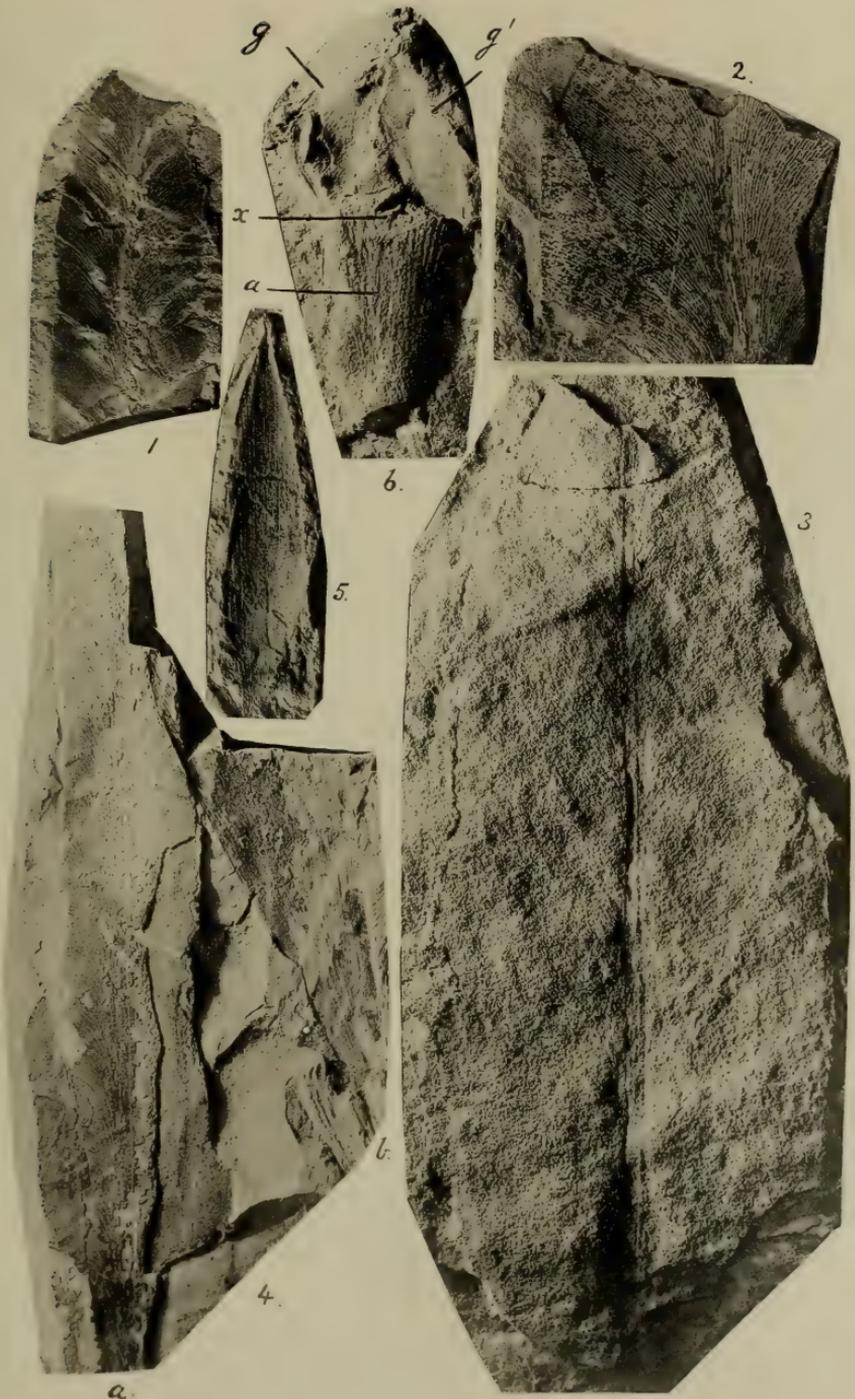
Prof. SEELEY stated that when he visited Aliwal North in 1889 Mr. Alfred Brown showed him many plants which he had obtained in white sandstone. They included *Glossopteris* and Lepidodendroid plants, together with a variety of ferns, which might be new. There was no opportunity of visiting the locality; but Aliwal North is near the top of the Karoo Series, and he thought that Mr. Brown's plants might be from beds yielding *Euskelesaurus*, which he would place above the Indwe coal. There are indications of coal near the base of the Karoo and in the middle, but the workable beds which he had seen were towards the top: although their flora was not the same as in the beds worked by Mr. Brown, which resembled the types now exhibited. He should like to see better evidence of the age of the beds before admitting them as Permo-Carboniferous, because the whole of the South African vertebrata of the Karoo appear to be below the beds which are found near Aliwal North. The Lower Karoo comprised the zone of *Pareiasaurus*; then came the zone of *Dicynodon*; above that is the zone of *Ptychognathus*; and at the top is the zone of the Theriodont reptiles, which he placed below the Cape coal. He had regarded all these beds as Permian.

Mr. STONIER observed that in New South Wales *Glossopteris* is characteristic of the more important of the productive Coal-Measures. While on the Geological Survey staff, he spent two years with Prof. David in the Farley and West Maitland districts, where strata with workable coal-seams are sandwiched between marine beds considered by De Koninck and others to be of Carboniferous or Permo-Carboniferous age. Not only is the section

particularly clear, but the speaker had found *Glossopteris* in the Marine Series, thus placing the matter beyond all doubt.

Feistmantel has described the Palæozoic plants; but there is a difficulty, as stated by Mr. Seward, in distinguishing forms; and in 1894 Mr. R. Etheridge, Jun., pointed out that the whole question of generic name, specific characters, etc. of *Glossopteris* had become almost hopelessly involved. *Gangamopteris* and *Glossopteris* are associated at Lochinvar and Newcastle (N.S.W.).

Mr. MARR, in the absence of the Authors, pointed out that Mr. Seward's paper, which had been read in very brief abstract, was mainly palæobotanical, and that the evidence brought forward by Dr. Blanford, Dr. Waagen, and others as to the age of the beds was relied upon by Mr. Seward.

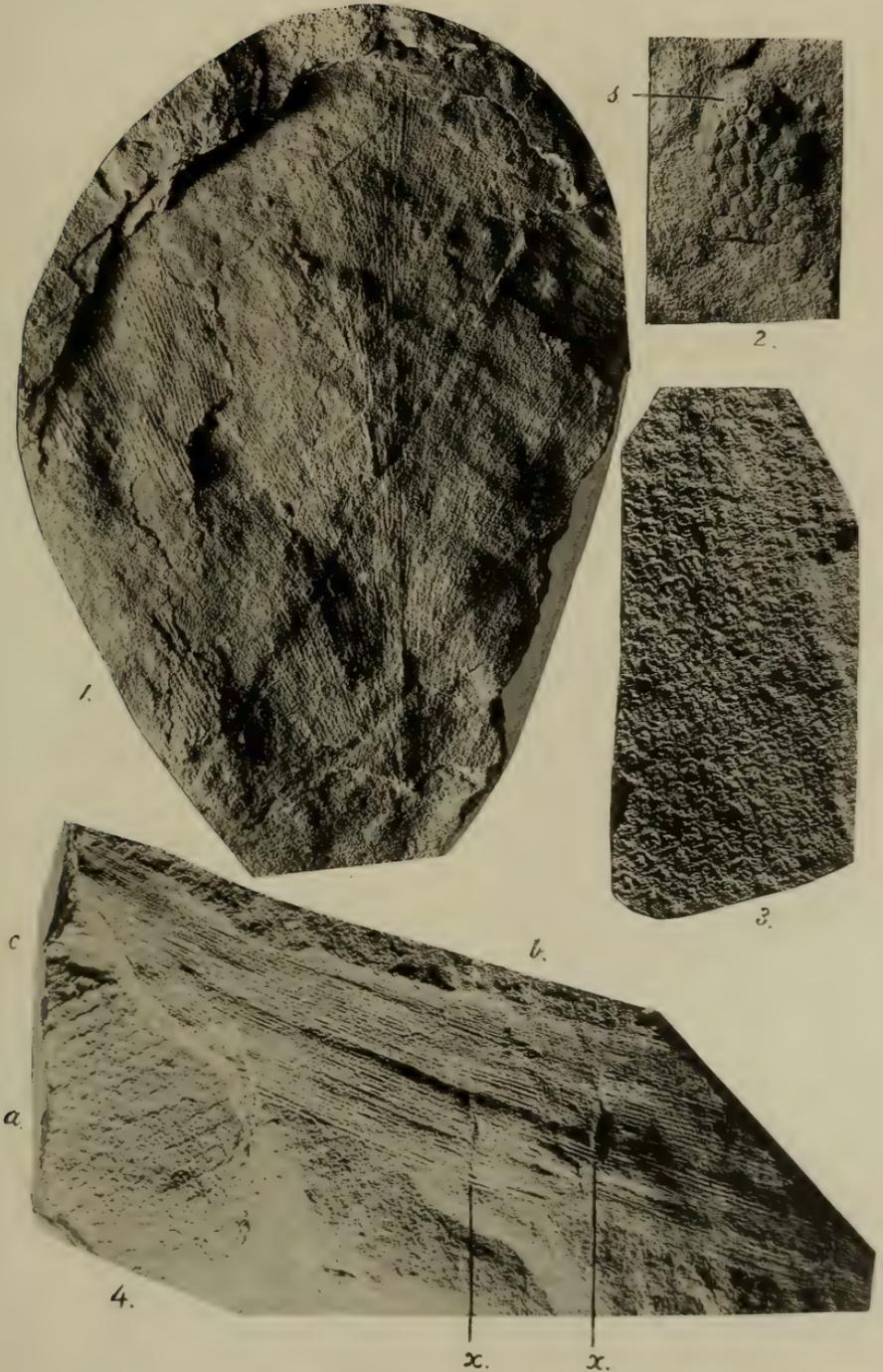


GLOSSOPTERIS.

NÆGGERATHIOPSIS.

BEMROSE & SONS, LTD., COLLO.





GANGAMOPTERIS.  
♀ EUISETACEOUS STEM.

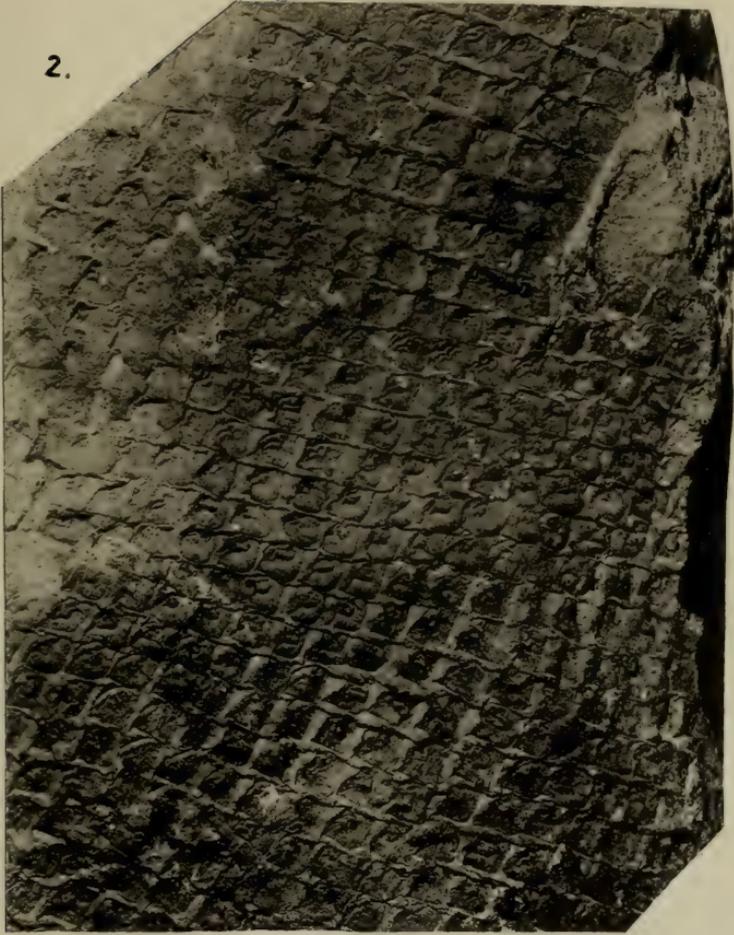
CONITES.

SIGILLARIA.

BEMROSE & SONS, LTD., COLLO.



2.



S' S.

1.



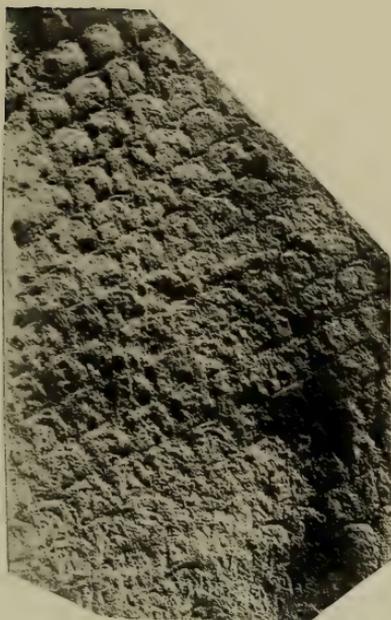
S.

BEMROSE & SONS, LTD., COLLO.

SIGILLARIA.

GLOSSOPTERIS.





3



2



1

BEMROSE & SONS, LTD., COLLO.

PHYLLOTHECA.

♀ SIGILLARIA.



25. *The GLACIO-MARINE DRIFT of the VALE of CLWYD.* By T. MELLARD READE, Esq., C.E., F.G.S., F.R.I.B.A. (Read April 7th, 1897.)

[PLATE XXV—MAP.]

IN a paper on the Drift Deposits of Colwyn Bay, I pointed out that the bulk of the materials of the sands and clays forming the Colwyn drift had been derived from the Vale of Clwyd.<sup>1</sup> In January, 1896, I had the opportunity of tracing the deposits farther westward past Llandulas and into the Vale itself. These later observations quite bear out my original statement.

(1) Boulder Clay from Craig, west of Llandulas, to the Vale of Clwyd, south-east of Abergele.

Immediately east of Craig, between Llandulas and Colwyn Bay (No. 1 in the Map) the Boulder Clay stands out in vertical cliffs about 30 feet high, and so compact that it is undercut by the waves, in a manner similar to that often seen in rock-cliffs. A closer examination shows that it is very full of angular fragments of limestone, derived from the Carboniferous Limestone-rock against which it lies. Several large blocks of Welsh felstone and blocks of slate-rock—showing banding or original bedding—occur on the shore, and I found a small boulder of Eskdale granite in the clay. At one place the clay appears to be foliated in a vertical direction. It does not appear that there are many shell-fragments in the clay, as I found only one example. All the Boulder Clay described in this paper is of a brown or reddish-brown colour, containing northern erratics, and is similar to the low-level Boulder Clays of Lancashire and Cheshire, excepting where it is mixed with the waste of the hills against which it may happen to lie.

A microscopic examination of a specimen of the clay by Mr. Joseph Wright, F.G.S., for foraminifera yielded negative results.

The following is a mechanical analysis showing the constitution of the clay; specimen taken about 5 feet above the shore:—

Weight before washing = 1·000 = 5 oz.

Caught in $\frac{1}{20}$ -inch mesh.....	0·191
" $\frac{1}{40}$ "    .....	0·033
" $\frac{1}{80}$ "    .....	0·075
Passed do. & deposited by subsidence .....	0·208
	0·507

This leaves 50 per cent. of clay, if we count as clay all the material washed out in the operations.

<sup>1</sup> Quart. Journ. Geol. Soc. vol. xli. (1885) pp. 102-107.

Immediately west of the West pier at Llandulas, there is a spur of extremely fine Boulder Clay standing out from the cliff; out of this I took one granite-pebble. Notwithstanding its freedom from stones, the clay is extremely hard where unweathered.

Mechanically analysed, the specimens taken (No. 2 in the Map) yielded 80 per cent. of clay. Between 4 and 5 lbs. troy of the Boulder Clay yielded to Mr. Wright the following foraminifera<sup>1</sup>:—

W.	<i>Miliolina seminulum</i> (Linn.).	Very rare.
W.	„ <i>subrotunda</i> (Mont.).	Rare.
C.W.	<i>Bolivina dilatata</i> , Rss.	Rare.
C.W.	„ <i>plicata</i> , d'Orb.	Common.
C.W.	<i>Cassidulina crassa</i> , d'Orb.	Common.
C.W.	<i>Lagena sulcata</i> (W. & J.).	Very rare.
C.W.	„ <i>hexagona</i> (Will.), var.	Very rare.
C.W.	„ <i>levigata</i> (Rss.).	Rare.
C.W.	<i>Uvigerina angulosa</i> , Will.	Rare.
C.W.	<i>Globigerina bulloides</i> , d'Orb.	Common.
	<i>Patellina corrugata</i> , Will.	Very rare.
C.W.	<i>Discorbina rosacea</i> (d'Orb.).	Rare.
C.	„ <i>Bertheloti</i> (d'Orb.).	Very rare.
C.	„ <i>Wrightii</i> , Brady.	Rare.
C.W.	<i>Truncatulina lobatula</i> (W. & J.).	Rare.
C.W.	<i>Nonionina depressula</i> (W. & J.).	Very common.
C.W.	<i>Polystomella striato-punctata</i> (F. & M.).	Rare.
	„ <i>macella</i> (F. & M.).	Rare.

One hundred specimens of *Nonionina depressula* were obtained from this gathering, while the other 17 species numbered in all only 69 specimens.

Farther east, between the East and West piers, the cliffs of drift are well developed. A very shelly clay occurs here, and I picked out *Turritella terebra*, *Trophon truncatus*, *Cardium edule*, etc. The lower part of the cliff is grass-grown, but in a good exposure about 30 feet above the shore I took a specimen of the clay (No. 3 in the Map). Mechanically analysed, it yielded 35 per cent. of clay, showing, curiously enough, a smaller proportion of that material than the strong clay to the east of Craig already described, but this arises from the preponderance of sand-grains having a diameter between  $\frac{1}{100}$  and  $\frac{1}{40}$  inch, together with the flour of rock deposited in the washing. This specimen is interesting from the numerous foraminifera it contained. Mr. Wright examined 1 lb. 1 oz. troy, and found the following species:—

<sup>1</sup> For purposes of comparison I have marked those species that occur in the Boulder Clay of Great Crosby with a C (see 'Foraminiferal Boulder Clay at Great Crosby,' Proc. Liverpool Geol. Soc., Session 1895-96, vol. vii. pt. iv. pp. 388-390), and those that occur in the Boulder Clay of Wirral, Cheshire, with a W (see paper by Davies & Reade, Proc. Liverpool Geol. Soc., Session 1894-95, vol. vii. pt. iii. pp. 334-335 & pp. 342-344).

- W. *Miliolina seminulum* (Linn.). Very rare.  
W. " *subrotunda* (Mont.). Frequent.  
C. " *tenuis* (Cz.). Common.  
*Ammodiscus gordialis* (J. & P.). Very rare.  
C.W. *Bulimina pupoides*, d'Orb. Rare.  
C.W. " *fusiformis*, Will. Very rare.  
C.W. *Bolivina dilatata*, Rss. Frequent.  
C.W. " *plicata*, d'Orb. Very common.  
C. *Cassidulina levigata*, d'Orb. Very rare.  
C.W. " *crassa*, d'Orb. Very common.  
C.W. *Lagena sulcata* (W. & J.). Very rare.  
C.W. " *Williamsoni* (Alcock). Rare.  
C.W. " *lineata* (Will.) var. Very rare.  
C.W. " *hexagona* (Will.) var. Very rare.  
C.W. " *squamosa* (Mont.). Very rare.  
C.W. " *Orbignyana* (Seg.). Very rare.  
C.W. " *levigata* (Rss.). Rare.  
*Rhabdogonium tricarinatum*, d'Orb. Rare.  
*Polymorphina lactea* (W. & J.). Very rare.  
" *myristiformis*, Will. Very rare.  
C.W. *Uvigerina angulosa*, Will. Frequent.  
C.W. *Globigerina bulloides*, d'Orb. Very common.  
*Sphaeroidina bulloides*, d'Orb. Rare.  
W. *Pullenia sphaeroides* (d'Orb.). Very rare.  
*Patellina corrugata*, Will. Very rare.  
*Spirillina vivipara*, Eliz. Very rare.  
C.W. *Truncatulina lobatula* (W. & J.). Common.  
*Pulvinulina Menardii* (d'Orb.). Rare.  
C. " *Karsteni* (Rss.). Very rare.  
C. *Rotalia Beccarii* (Linn.). Very rare.  
C. *Discorbina Wrightii*, Brady. Common.  
C.W. *Nonionina depressula* (W. & J.). Very common.  
C.W. *Polystomella striato-punctata* (F. & M.). Frequent.  
" *macella*<sup>1</sup> (F. & M.). Very rare.

About 650 specimens of *Nonionina depressula* were obtained from this gathering, while the other species numbered in all 235 specimens.

Mr. Wright observes that some of the forms from this sample are extremely rare as British specimens. *Rhabdogonium tricarinatum* and *Sphaeroidina bulloides* have been met with at a few places only off the west coast of Ireland; *Pullenia sphaeroides* has been recorded only from off Dublin and the estuary of the Dee, and *Pulvinulina Menardii* from the Isle of Man and from off the coast of Dublin.

These drift-cliffs continue at a lower elevation to the River Dulas, at the mouth of which is a pebble-ridge, forcing it to the eastward. The valley of the Dulas has been drift-filled and since then denuded, the gravels in it being of later date.

Beyond the Dulas to the east is a low bank of drift grassed over. The same kind of Boulder Clay as that hitherto described may be seen in a section at the large limestone-quarries at Llandulas, at a level of 150 feet above O.D., lying upon the irregular surface of the Carboniferous Limestone.

<sup>1</sup> In the Brit. Assoc. Report on the 'High-level Shell-bearing Deposits of Kintyre,' (L'pool) 1896, p. 397, Dr. David Robertson states that, so far as he knows, *Polystomella macella* has not been found in recent deposits in the British Isles, and in Scotland it is only found in the shelly deposits of Kintyre.

A walk of about a mile along the St. Asaph road from Abergele shows drift banked up against the limestone-cliff on the west side of the Vale of Clwyd: it is conterminous with that of the shore-cliffs just described.

East of the St. Asaph road, and at a level of about 140 feet above O.D., is a disused brick-pit, showing a plastic red Boulder Clay, very like that in the cutting of the Wirral Railway at Seacombe.<sup>1</sup> In it are a good many shell-fragments, mostly very rotten, among which *Cardium*, *Turritella*, and *Tellina* are distinguishable.

A mechanical analysis of this clay (No. 4 in the Map) showed that the matter separated by the sieves was mostly sand, the larger part of which passed the  $\frac{1}{100}$ -inch mesh. The sand consists to a great extent of most beautifully rounded and polished quartz-grains. The proportion of clay was very high, amounting to 82 per cent.

Three lbs. of this clay were submitted to Mr. Wright, in which he discovered the following species of foraminifera:—

- C.W. *Bulimina pupoides*, d'Orb. Rare.
- C.W. " *marginata*, d'Orb. Very rare.
- C.W. *Bolivina dilatata*, Rss. Rare.
- C.W. " *plicata*, d'Orb. Frequent.
- C.W. *Lagena lineata* (Will.). Very rare.
- C.W. " *hexagona* (Will.). Very rare.
- Nodosaria* (*D.*) *communis*, d'Orb. Very rare.
- C.W. *Globigerina bulloides*, d'Orb. Frequent.
- C.W. *Discorbina rosacea* (d'Orb.). Very rare.
- C. " *Wrightii*, Brady. Rare.
- C.W. *Truncatulina lobatula* (W. & J.). Rare.
- C.W. *Nonionina depressula* (W. & J.). Very common.
- C.W. *Polystomella striato-punctata* (F. & M.). Rare.

Ninety specimens of *Nonionina depressula* were obtained from this gathering, while the other 13 species numbered in all only 34 specimens.

On the east side of the St. Asaph road, a short distance up the road, immediately N.W. of Parc-y-Meirch, is a limestone-quarry about 280 feet above O.D., and it is seen here that the drift runs up and chokes the valley. It is full of Wenlock Shale, mixed with limestone and much rounded shingle. Following the valley upwards, it is evident that the whole is drift-filled, and not only so, but the drift sweeps over the hills, giving them their rounded outlines. Parc-y-Meirch is an old entrenched camp on a drift-covered hill. At a level of about 555 feet above O.D. I found a large boulder of nodular volcanic ash, which looked to me very like Arenig. I submitted the specimen to Mr. Thomas Ruddy, of Palé, who is very familiar with the volcanic rocks in this part of North Wales, and he says that he considers it to be the nodular ash described by Ramsay at p. 93 in vol. iii. Mem. Geol. Surv. He has found boulders of it near the village of Cerrig-y-Druidion. At the road crossing the

<sup>1</sup> Davies & Reade, Proc. Liverp. Geol. Soc., Session 1894-95, vol. vii. pt. iii.

St. Asaph road, north-west of Parc-y-Meirch, 220 feet above O.D., a stream has cut into the drift, over which it falls for a few feet as a waterfall, and here is disclosed a well-stratified sandy deposit.

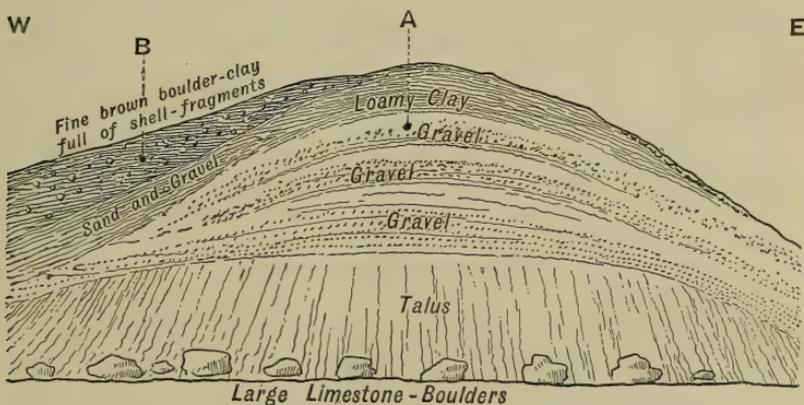
My observations generally go to show that the drift here described represents a shore sloping up gradually from the lowland of the Vale of Clwyd, until it is backed up at a greater angle against the limestone-cliffs forming the west side of the Vale.

## (2) Glacial Sands and Gravels, east side of the Vale of Clwyd.

The country between Rhyddlan and Diserth is mostly covered with red sand, evidently derived from the Trias, which is the bottom rock of the Vale.<sup>1</sup>

South-east of Diserth Castle, near Prestatyn Branch Railway, is a striking grass-covered mound of sand and gravel (No. 5 in the Map),<sup>2</sup>

### *Esker south-east of Diserth Castle.*



the structure of which may be investigated where it is broken into by the excavations for gravel. The axis of this mound has a north-easterly trend, and it forms a spur from the hill on which it lies. Orographically it resembles an Irish esker. The excavation shows that the bedding of the sand and gravel largely follows the external form, the flank, where exposed, being covered with a layer of Boulder Clay, as illustrated in the above diagram. In the

<sup>1</sup> Between Abergele and Rhyddlan the Glacial beds are masked by post-Glacial deposits, but borings seem to show that Boulder Clay and Sands alternate. There are good sections of the Marine Drift on the river-bank at Rhyddlan, and these have been described by Prof. M<sup>c</sup>K. Hughes, 'Geol. of the Vale of Clwyd,' Proc. Chester Soc. Nat. Sci. 1884, no. 3. See also remarks on Drift in 'Trias of the Vale of Clwyd,' Proc. Liverp. Geol. Soc., Session 1890-91, vol. vi. pt. iii. p. 285.

<sup>2</sup> See 'Geology of Rhyl, Abergele, and Colwyn' (p. 32 & map), by Aubrey Strahan, Mem. Geol. Surv.

gravelly sand that runs loosely down the flanks of the excavated portion were marine shell-fragments of the usual type.

The pebbles are preponderatingly of Carboniferous Limestone. There are too a great many boulders of the same rock lying about that have been taken out of the mound. Boulders and pebbles of a fine-grained felstone also abound, and these may have come from the Snowdon range. There are, moreover, other rocks which both Mr. Ruddy and I consider to be from the Arenig.

At A (see diagram, p. 345) I took a specimen of the sand and gravel, at a level of about 350 feet above O.D. The result of mechanical analysis was as follows:—

Weight before washing = 5 oz. = 1·000.			
Caught in	$\frac{1}{20}$ -inch mesh	.....	0·700
"	$\frac{1}{40}$ "	.....	0·083
"	$\frac{1}{80}$ "	.....	0·100
Passed	$\frac{1}{80}$ "	.....	0·050
Clay? = 7 per cent.			0·933

The  $\frac{1}{20}$ -inch material contained some extremely rounded and beautifully polished pebbles, measuring from  $\frac{1}{2}$  inch on the longer axis down to  $\frac{1}{8}$  inch, of very hard, green, igneous rock; there were also pebbles of limestone, sandstone, vein-quartz, and a few shell-fragments. None of this material was striated, but it had a beach-worn appearance.

The material from the smaller meshes consisted, as is generally the case, of a larger proportion of quartz-grains as the material became smaller. Many of them were rounded and polished, but mixed with irregular quartz-splinters. The material is largely calcareous, as shown by its bubbling up strongly on the application of acid.

The Boulder Clay on the flanks of the mound, although it was seen on the ground to contain small shell-fragments, did not yield foraminifera to Mr. Wright, who examined a specimen from B (see diagram, p. 345). The stones, he reports, were more or less rounded.

The Boulder Clay appears to cover the surrounding country, being seen in the cutting of the Prestatyn Branch Railway, according to Mr. Strahan, so that the gravel-mound must rise up through it. On the road to Newmarket, at a level of about 500 feet, a sand-pit (No. 6 in the Map) shows yellow stratified sand, with frequent shell-fragments.

These flanking deposits on either side of the Vale of Clwyd bear all the appearance of marine clays and sands, and are, as I have shown in detail, full of the remains of marine organisms. Similar deposits, in this case consisting mainly of the red sand of the Vale of Clwyd, can be traced up the River Wheeler into the valley of the Alyn and down to its junction with the Dee. Farther up the Vale of Clwyd this marine drift gives place to a more local drift, which has come, as shown by Mr. Strahan, from

the south-west. We have also seen that the Arenig rocks are to be found at various localities, even among the marine deposits of the mouth of the Vale.

It is not my object here to attempt to explain these phenomena, but to place on record the results of a more minute examination of the nature of the clays and sands found at the entrance of the Vale of Clwyd than appears to have been hitherto made. It is interesting, however, to observe from the lists and localities given that the Marine Boulder Clays of Lancashire, Cheshire, and Denbighshire contain more frequently, and in a much greater profusion than was suspected, the tests of foraminifera. As a rule, these are found in the finer and more plastic brown or red Boulder Clays, which often contain intensely-striated erratic stones, and they occur in just the sort of deposits in which they are mostly found at the present day. It is certainly remarkable that they are so well preserved, when frequently large boulders of dolerite and other originally hard rocks have crumbled to sand in the same beds.

#### PLATE XXV.

Geological Map of part of the Vale of Clwyd on the  
scale of 2 miles to the inch.

#### DISCUSSION.

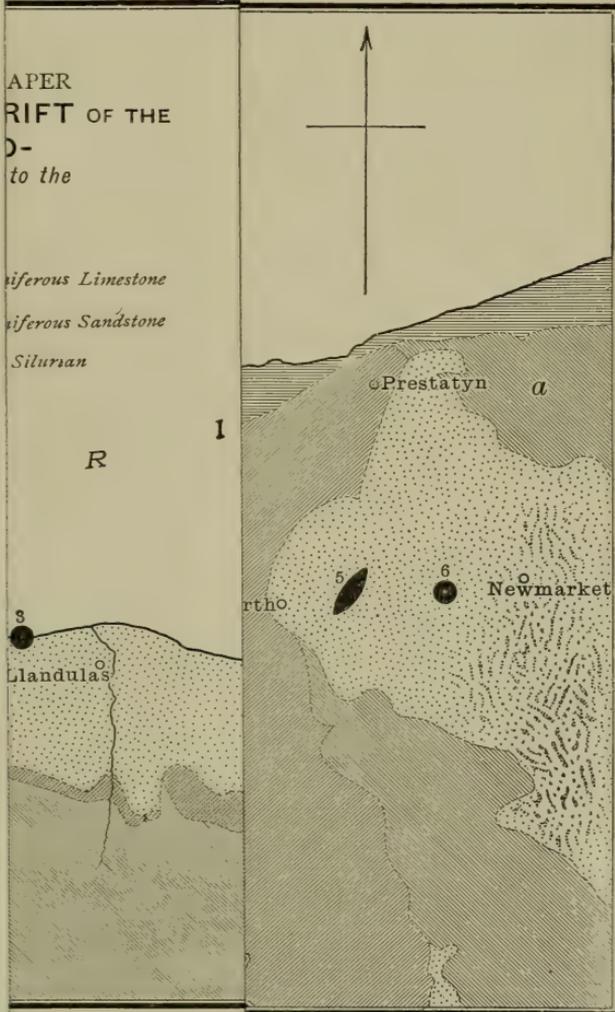
Mr. STRAHAN drew the attention of the Author to Prof. Hughes's exhaustive papers on the drifts of the Vale of Clwyd. The occurrence of foraminifera was to be expected in clay so similar to that of Cheshire, in which they had long since been recorded by Mr. Shone. One of the most interesting points in the drifts of the Vale was the meeting of drift from the north with the local drift of North Wales. He congratulated the Author on the result of his careful examination of the clay.

Prof. HUGHES said that he had laid pretty fully before the Society his views as to the origin and classification of the drifts of the Vale of Clwyd (Quart. Journ. Geol. Soc. vol. xliii. 1887, p. 73); and he gathered from the too short exposition of Mr. Mellard Reade's recent observations in that area, that the foraminifera which he had obtained all occurred in the newer or St. Asaph Drift. This had all the characteristics of the shore-deposits on that coast at the present day. It contained boulders washed out of pre-existing Boulder Clays, thus commingling the products of the land-ice from the Welsh mountains with the northern boulders rolled in the shore-deposits. There were lumps of the older clay which had been trundled along the shore, so that the outside was covered with gravel, sand, and shells which had stuck to it. There were fragments and rarely whole specimens of shells thrown up from various habitats, just as they occur in the shore-shingle at the present day; and in some of the gasteropods foraminifera were found washed up from sea-bottoms of various character and depth, as at the present time.

The shells in the St. Asaph Drift were, with few exceptions, of the same species as those which now occur on that coast, and the exceptions were Scandinavian, not Arctic.

Mr. P. F. KENDALL also spoke.

The AUTHOR, in reply to Mr. Strahan, said that Mr. Shone obtained his foraminifera from the material in the interior of *Turritellæ*, and not from the clay-matrix in which they were embedded. The late Dr. Robertson examined Boulder Clay from the Atlantic Docks, Liverpool, for the Author; and the list of foraminifera is given in his paper on the 'Drift Beds of the North-West of England,' published in the Society's Journal. It was not, however, until the Boulder Clays in the Wirral Railway-cutting, Cheshire, were examined by Mr. Wright and found to be rich in foraminifera, that the Author realized the importance of the subject. Since then many samples of clays from Great Crosby, Lancashire, Blackpool, the Vale of Clwyd, and Ayrshire have been examined by Mr. Wright with the same result. The organisms occur most plentifully in the finer clays and are well preserved, the facies being very similar from all the localities in England, Wales, and Scotland—jointly pointing to the conclusion that they are not derived fossils, but have lived and died where they are found. The Boulder Clay of the Vale of Clwyd here described is identical with the Low-level Marine Boulder Clay of Lancashire and Cheshire.

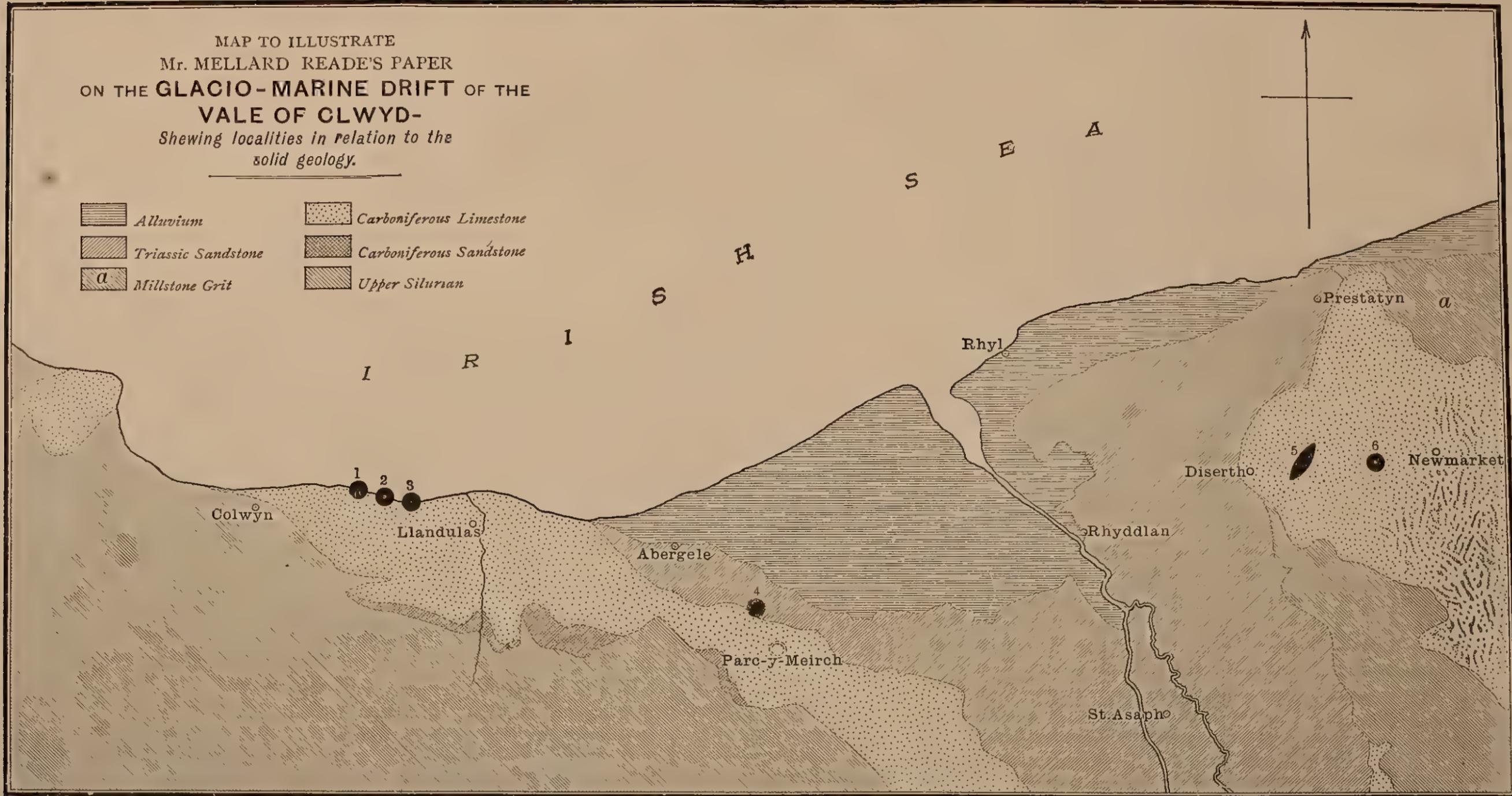


The black spots indicate



MAP TO ILLUSTRATE  
 Mr. MELLARD READE'S PAPER  
 ON THE **GLACIO-MARINE DRIFT** OF THE  
**VALE OF CLWYD-**  
*Shewing localities in relation to the  
 solid geology.*

- |  |   |
|--|---|
|  Alluvium           |  Carboniferous Limestone |
|  Triassic Sandstone |  Carboniferous Sandstone |
|  Millstone Grit     |  Upper Silurian          |



Scale of 0 1 2 3 4 5 6 Miles

[The black spots indicate the localities at which the specimens described in the text were taken.]



26. *On the ORIGIN of some of the GNEISSES of ANGLESEY.* By CHARLES CALLAWAY, M.A., D.Sc., F.G.S. (Read April 28th, 1897.)

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## INTRODUCTION.

THE comparative ages of the subdivisions of the schistose and gneissic rocks of Anglesey have been discussed with very varied conclusions, but these discrepancies have been in great part the result of the unsettled state of opinion on the subject of metamorphism. The former belief that the granite was of metamorphic origin, and that a parallel structure necessarily indicated an original sedimentation, could not fail to mislead the stratigraphical geologist. It is therefore requisite that the genesis of the respective rocks should be determined before attempting to revise the old classifications.

Before entering upon my task, I wish to indicate briefly the present state of our knowledge of the Archæan (pre-Cambrian) rocks of Anglesey. Dr. H. Hicks, F.R.S., divided them into three groups:—Dimetian (granite), Arvonian (hällfinta), and Pebidian (schistose), these divisions being named in ascending order.<sup>1</sup> I have never been able to define more than two systems, an older one, which, to avoid theory, I simply designated as 'Gneissic,' and a newer one, which I described as 'Slaty,' and provisionally identified with the Pebidian.<sup>2</sup> The Rev. J. F. Blake, F.G.S., admits the pre-Cambrian age of all these rocks, but he describes them as one continuous series, which he calls 'Monian.'<sup>3</sup> Prof. T. G. Bonney, F.R.S., also regards the crystalline schists as Archæan,<sup>4</sup> but Sir A. Geikie,<sup>5</sup> F.R.S., and Prof. T. M<sup>c</sup>K. Hughes,<sup>6</sup> F.R.S., place some of the less altered schists at a higher horizon. The pre-Cambrian age of the bulk of the granitic, gneissic, and schistose rocks of Anglesey may therefore be regarded as a settled question; but

<sup>1</sup> Quart. Journ. Geol. Soc. vol. xxxv. (1879) p. 302.

<sup>2</sup> *Ibid.* vol. xxxvii. (1881) p. 211.

<sup>3</sup> *Ibid.* vol. xlv. (1888) p. 463.

<sup>4</sup> *Ibid.* vol. xxxv. (1879) pp. 303, 304.

<sup>5</sup> *Ibid.* vol. xlvii. (1891) *Proc.* p. 130.

<sup>6</sup> Proc. Phil. Soc. Cambridge, vol. iii. (1880) p. 347.

whether they are to be referred to one, two, or three epochs remains still in dispute.

My own views as to the broad outlines remain unchanged after many years' intermittent study of Anglesey geology. The newer series I still regard as Pebidian, and I have nothing material to alter in the details of the distribution of this group and the succession of its members. The gneissic rocks belong, I have no doubt, to an older epoch; but I now believe them to be an igneous complex, which has undergone great chemical and structural changes under the influence of pressure and heat. In these rocks I once described a succession-in-time, which must of course be abandoned.

In this paper I shall not touch upon the Pebidian rocks, or attempt an exhaustive study of the older masses; but will confine myself to a description of the production of the gneissic structure in some very interesting sections in the south of the island. This will, I hope, be of service in clearing the ground for further research.

#### I. THE MATERIALS OUT OF WHICH THE GNEISSES ARE FORMED.

These gneisses have been produced out of a granite, a felsite, and a diorite, either separately or in combination.

*The Granite.*—This rock has been described by Prof. Bonney<sup>1</sup> as consisting mainly of quartz and felspar. It is clearly of igneous origin, for, on the shore near Porth Nobla, masses and veins of it are seen to penetrate the adjacent rocks. It will be but slightly noticed in this paper.

*The Felsite.*—This is in part the Arvonian of Dr. Hicks. Great difficulty has attended the study of this rock, owing to the enormous mechanical pressures to which the igneous complex has been subjected. Ordinarily it presents the appearance of the rock which has been vaguely described as 'hällefinta.' In hand-specimens it is seen to be fine in grain and of uniform texture, more like a felspathic mud than an eruptive rock. A specimen of it was described by Prof. Bonney<sup>2</sup> in 1881 as similar to the Treffgarn (St. David's) hällefinta, but as 'more gneissic' under the microscope. At that date he leaned to the opinion that the Anglesey hällefinta<sup>3</sup> is of 'fragmental origin,' but admitted that the structure sometimes comes 'nearer to that of some microcrystalline felsites.' Mr. Blake considers<sup>4</sup> the hällefinta of Roche Castle (St. David's) to be an altered andesite, and probably few will now dispute that hällefinta is often an eruptive. The subsequent study of a large number of the Anglesey slides has convinced me that the fragmental structure is merely hypoclastic, and is the result of crushing, being in fact an

<sup>1</sup> Quart. Journ. Geol. Soc. vol. xxxv. (1879) pp. 307, 308, nos. vii, ix, & xi.

<sup>2</sup> *Ibid.* vol. xxxvii. (1881) p. 233.

<sup>3</sup> This rock must not be confounded with the quartz-felsites associated with the granite, which are truly a part of the granitic intrusion, and often imperceptibly grade into the granite.

<sup>4</sup> Quart. Journ. Geol. Soc. vol. xl. (1884) p. 308.

early stage in the conversion of felsite into schist. Evidence of this conclusion will be offered further on.

*The Diorite.*—This rock is now well known. Near Gaerwen it is modified into hornblendic and chloritic gneiss, as I showed<sup>1</sup> in 1887. Mr. Blake<sup>2</sup> has confirmed and extended this result.

## II. THE PRODUCTS OF THE METAMORPHISM.

In a series of papers<sup>3</sup> on the Malvern crystallines, I have expounded the changes which, in that area, take place in plutonic rocks during dynamo-metamorphism. It was seen that schists and gneisses are formed sometimes by pressure acting upon a single rock, but the most important results were shown to be produced in diorite interlaced by granite-veins. Similar results have been observed by me in Anglesey. Diorite alone is converted into various gneisses, felsite alone is changed to mica-gneiss; while extremely interesting gneisses of another type are formed where diorite is interveined with felsite.

The processes of metamorphism in Anglesey bear so close a resemblance to those which have operated at Malvern that the classification of gneisses and schists adopted in my researches in the last-named area will be usually applicable in this paper.

### A. SIMPLE SCHISTS, or those formed from one kind of rock.

*Mica-gneiss from Granite.*—This change is sometimes seen near the margin of the central granite-band, but it is of the ordinary kind, and need not be described here.

*Hornblendic and Chloritic Gneisses from Diorite.*—These types have been already noticed, and references to descriptions of their origin have been given.

*Mica-gneiss from Felsite.*—A fine section showing this change is exposed along the western end of a crag in a field at Y Graig, near Gaerwen, at a little distance from the gate leading into it from the road from Gaerwen. The rock is very sound and clean, and the transition can be traced inch by inch without any break caused by fracture or turf-covering. At the northern end is felsite, which passes *gradatim* through the intermediate form of hälleflinta into a typical mica-gneiss. At the British Association Meeting at Manchester in 1887, I exhibited a series of slides from this section. The first (No. 379<sup>4</sup>) of the set was admitted by Profs. Bonney and Renard, and by Mr. J. J. H. Teall, to be a true felsite. Under the microscope, it polarizes as an aggregate of granules of various sizes, with foliate interlocking margins. Several crystals of felspar, some of them plagioclase, are scattered through the groundmass. A few of them have been broken, and the parts shifted, and the granular

<sup>1</sup> Brit. Assoc. Rep. (Manchester) 1887, p. 706.

<sup>2</sup> *Ibid.* (Bath) 1888, p. 405.

<sup>3</sup> Quart. Journ. Geol. Soc. vol. xliii. (1887) p. 525; *ibid.* vol. xlv. (1889) p. 475; *ibid.* vol. xlix. (1893) p. 398; Geol. Mag. 1892, p. 545; *ibid.* 1893, p. 535; *ibid.* 1894, p. 217; & *ibid.* 1895, p. 220.

<sup>4</sup> The numbers in parentheses are those of the slides in my cabinet.

constituents have also been somewhat crushed. There is also present a fair sprinkling of small highly-refracting crystals. Amongst them are both epidote and sphene. A few small patches of quartz are scattered through the slide. This felsite passes within an inch or two into a rock which, megascopically, appears rather less compact, and would be called a hällflinta. Microscopically (418), it does not essentially differ from the last, but there is a slightly parallel structure among the granules, and quartz has been developed in a more streaky manner, the streaks running with the incipient foliation. A very minute quantity of chlorite and white mica accentuates the parallel arrangement, and streams of minute sphenes run in the same direction. Another slide (380) at about the same distance from the first shows a structure similar to that of no. 418; but the parallel arrangement is rather more marked, and the colourless mica is somewhat more abundant. The hand-specimen, however, from which the slide is cut is a fairly typical hällflinta, the schistosity and the presence of mica being scarcely perceptible. The streaks of quartz do not occur in this or any of the following slides.

Seven more thin sections, taken at intervals of a few inches, show the progressive change into a well-marked gneiss. In 381 the mica is more abundant than in the last. Felspar can be identified in distinct folia of idiomorphic crystals, both plagioclase and microcline being present. No. 382 contains rather less mica. Nos. 383 and 384 are generally similar to the two preceding slides. A little brown mica appears in 385, seemingly in distinct shear-planes, as if it might have resulted from infiltration, the diorite in mass being at no great distance. No. 386 is very gneissic, white mica being fairly abundant, and several distinct folia of fresh-looking felspar being present. The last slide (387) of the series is a beautifully foliated gneiss. Micas, both white and brown, are plentiful, the latter, as before, appearing in well-marked shear-planes. I do not mean to suggest that the white mica also is not generated at shear-planes; but with the brown mica the planes are very conspicuous, being indicated, where the biotite thins out, by brown iron-oxide. The folia intervening between the mica-seams display mosaic polarization, and very little felspar can be identified. Strain-shadows are well-marked in this slide. A few small garnets are present.

I have traced similar gradations in rocks at Holland Arms, on the Menai Straits, and elsewhere. It is easy to obtain hand-specimens which show hällflinta in one part and mica-gneiss in another, with gradations between. I have examined a large number of microscopic slides of these specimens. The part which would be described as hällflinta usually shows signs of great crushing, and the specimen (379) from Y Graig still remains the only example which can be positively identified as felsite.

We are not, however, left to the unsupported testimony of the microscope, for, as we shall see in the next division of this paper, the hällflinta behaves like a true eruptive, penetrating other rocks in veins, and enclosing blocks of the adjacent masses.

## B. INJECTION-SCHISTS.

In two of my Malvern papers I have described two kinds of injection-schist, those produced by the injection of rock (primary injection) and those formed by the infiltration of mineral matter along shear-planes subsequent to consolidation (secondary injection). Both of these varieties of schist<sup>1</sup> are to be seen in Anglesey.

In Anglesey the felsite plays the part which at Malvern is taken by the granite, but certain important differences arise. The granite of Malvern is very coarse in grain, and the shear-lenticles are normally short, thick in the middle, and irregular, so that the gneissic banding is also more or less irregular. The Anglesey felsite, however, being fine-grained and compact, shears under pressure into very regular lenticles. These are often very thin, almost like sheets of paper. When the intervening shear-planes are covered by infiltration-products and the laminae are puckered, a very striking and beautiful effect is produced.

## (1) Gneiss of Primary Injection.

This variety is formed by the parallel interveining of felsite and diorite. According to the Rev. J. F. Blake,<sup>2</sup> the diorite is intrusive in the gneissic rock, which, in my view, has been formed from the felsite. My own impression is that the diorite is the older rock, and that portions of it which look like dykes are really included masses. The sections at Llangaffo and Y Graig, which I am about to describe, seem to support this opinion, but the point is not very material.

*Section in the Llangaffo Railway-cutting.*

In fig. 1 (p. 354) we see numerous<sup>3</sup> felsite-veins included in a dark-green rock of somewhat gneissose structure, passing within a few feet into foliated diorite, and even into a diorite which is scarcely foliated at all. Mr. Blake truly affirms (*loc. cit.*) that this dark rock agrees in all respects with the well-known diorite at Gaerwen. The felsite-veins vary in thickness from several inches or even feet to the tenuity of a wafer. Many of them are entirely surrounded (in section) by the diorite. They lie in the direction of the prevailing schistosity, and frequently run out into sharp points, as if compressed.

*Section at Y Graig, Gaerwen.*

Further evidence of the eruptive origin of the grey gneiss is seen in a small quarry on the east side of the road at Y Graig. The vertical face exposed in the bank mainly consists of hornblende gneiss (modified diorite) dipping at nearly 90°. Running

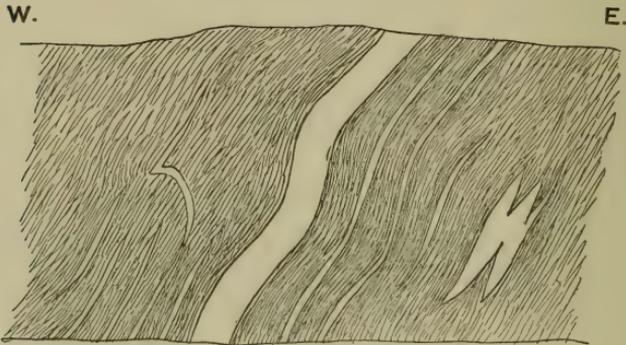
<sup>1</sup> I use the term 'schist' in preference to 'gneiss,' since felspar may be sometimes absent in this type of rock.

<sup>2</sup> Quart. Journ. Geol. Soc. vol. xlv. (1888) p. 504.

<sup>3</sup> Only a small proportion of them are shown.

parallel with the foliation are several veins of grey fine-grained rock, some of which are a kind of hälléfinta, while others are foliated. They range in breadth from several inches to less than a line. Some of the thicker veins show a gradation within an inch or so between hälléfinta and gneiss. Similar veins appear in the floor of the quarry, and strike across the road, sometimes branching. They thin out to a point. It is incredible that this grey rock should be sedimentary, and it is almost equally difficult to believe that it can be older than the diorite in which it is enclosed.

Fig. 1.—*Gneiss of primary injection, Llangaffo.*



In thin sections some of the felsite (or hälléfinta) exhibits the minutely-granulated structure of the grey veins at Llangaffo; but it contains numerous granules of epidote, the effect, perhaps, of the chemical action of the enclosing diorite. Junction-specimens show this felsite to be interlaminated with bright, clear hornblende (whether by veining or infiltration I cannot say), and sometimes we observe the hornblende to alternate with fresh, clear plagioclase in long prisms lying in different directions. It would thus appear that in this locality there has been an actual fusion of some of the constituents, resulting not only in the generation of new minerals, but in the regeneration of the hornblende.

Turning into the field close at hand, we come to the typical section (p. 356) of felsite graduating into grey gneiss, and we are thus led to infer that the veins in the road proceed from the same mass.

*Section at Porth Gwyfen.*

On the shore at this locality there is a very clear exposure of a striped gneiss similar to the section shown in fig. 1. Grey gneiss and dark-green schist run into each other in numerous thin bands. The gneiss passes in places into hälléfinta, and veins of the grey rock, in the form of either hälléfinta or gneiss, are also seen in the green schist at a distance from the junction of the two rocks. In an easterly direction the grey veins come in more and more abundantly, till we reach a large mass of grey gneiss.

*Diorite-blocks in the Grey Gneiss.*

The eruptive origin of the gneiss is also shown by another kind of evidence. In the Llangaffo section a number of irregular blocks are enclosed in the grey gneiss (fig. 2). They consist largely of

Fig. 2.—*Blocks of altered and squeezed diorite in grey gneiss.*



[At *a* and *b* portions of the contorted gneiss are represented.]

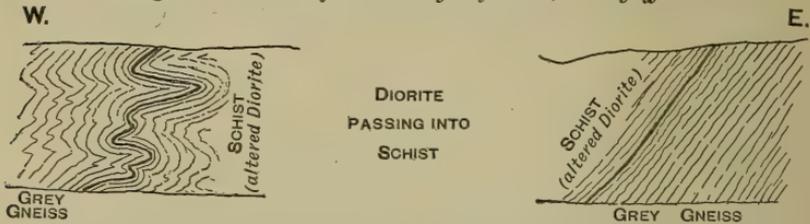
chlorite and other decomposition-products, but there is no doubt that they were originally diorite. The shape of the masses indicates that they have been compressed by a force acting vertically. The direction of the foliation in the grey gneiss is determined by the dark blocks. It bends in between them, and curves outward where they project, just as if a high-dipping foliation had been contorted by the vertical pressure.

(2) *Gneiss of Secondary Injection.*

Excellent examples of this kind of gneiss are seen in the Llangaffo cutting. Near the eastern end is exposed a mass of dark rock about 25 yards wide, with grey gneiss on each side of it (fig. 3, p. 356). In the centre the dark mass is normal diorite, but towards both margins it graduates into a chloritic micaceous gneiss. The eastern margin is nearly straight, hading at a high angle to the west, and the grey gneiss in contact has the foliation coinciding in direction

with this hade. On the western side the altered diorite is very irregular, projecting into several promontories; but here also the grey gneiss is foliated parallel to the margin of the diorite, the laminae following exactly the projections and recesses of the latter. This foliation is accentuated by very thin dark lines.

Fig. 3.—Gneiss of secondary injection, Llangaffo.



[The grey gneiss or sheared felsite is injected with decomposition-products from the adjacent diorite. The black lines in the grey gneiss represent planes of injection, but only a few are shown.]

The explanation of this gneiss is similar to that which I have given<sup>1</sup> of an infiltration-gneiss at Malvern, felsite being substituted for granite. The infiltration-products are substantially the same as at Malvern, consisting mainly of chlorite, iron-oxide, and epidote; and out of the chlorite and iron-oxide, with the addition of materials from the felsite, black mica has in like manner been sometimes constructed. The following is a description of a slice of this gneiss. It shows a breadth of  $\frac{3}{8}$  inch cut across the foliation, and is taken at the junction of the grey gneiss with the altered diorite.

1. A seam of minute transparent granules, generally elongated in the direction of foliation, many of them being lenticular in shape. It is rarely possible to determine which of these are quartz and which felspar, but scattered among them are several comparatively large lenticles of quartz. Some minute crystals of epidote, elongated with the foliation, are present.
2. A dark seam, chiefly composed of interfelted chlorite, pale green in ordinary light, almost extinguishing under crossed nicols. It occasionally passes into greenish, or even brownish, mica. There is a little epidote, and lenticles of clear quartz or felspar lie amid the meshwork.
3. A minute interfoliation of several of the felsitic seams with the dark green material.
4. A comparatively thick folium of the chloritic rock.  
Veins of calcite cross the slide transversely to the foliation.

This specimen may be taken as typical of the structure at the junction of the grey and green rocks. It does not contain much mica, but in some of the junction-slides there is a fair proportion of that mineral, the white variety being predominant.

<sup>1</sup> Quart. Journ. Geol. Soc. vol. xlv. (1889) p. 496 & vol. xlix. (1893) p. 412.

That the foliation of the grey gneiss should follow the margins of the diorite is not difficult to explain. When the rocks were sheared the diorite was a dyke-like mass with nearly vertical sides, and the foliation in both felsite and diorite was parallel to them. A vertical pressure subsequently distorted the western margin, and at the same time contorted the gneiss in contact, compelling its foliation to follow the outlines of the diorite.

The distance from the diorite to which the chlorite, etc., are injected varies considerably. Where the shear-planes are numerous and close the rock is very permeable to liquids, and a considerable fringe of dark-lined gneiss is the result. This variety of injection-gneiss is sometimes seen where no basic rock appears in proximity, though of course hidden masses of it may be near.

I need hardly point out that the genesis of this kind of gneissic structure in the felsite was posterior to its consolidation, since planes of discontinuity could not have been produced in a fluid or plastic magma. It is further to be noted that the gneiss is sometimes traversed by irregular cracks, and that the infiltrated liquids have passed into these cracks as well as into the shear-planes.

The diorite also must have been in a solid state at the time of injection. It is not molten rock that has been injected into the grey gneiss, but the products of decomposition, such as are caused by the passage of liquids through a crushed solid.

#### SUMMARY.

1. The gneisses described in this paper have been formed out of plutonic igneous rocks by crushing and shearing subsequently to their consolidation.
2. Occasionally the process has been accompanied by a partial remelting of the rock.
3. The most interesting varieties of gneiss have been produced where there has been a complex of diorite and felsite, primary injection giving rise to banded gneiss, and secondary injection accentuating gneissic structure in sheared felsite by dark lines.
4. Simple gneisses have been formed out of granite, diorite, and felsite respectively, the last-named originating the well-known grey gneiss of Southern and Central Anglesey.
5. The so-called hälleflinta is merely the felsite in the first stage of conversion into gneiss.

#### DISCUSSION.

The PRESIDENT said that the Author was doubtless right in regarding the older pre-Cambrian rocks in Anglesey as formed from a great igneous complex; but it was difficult to say in all cases how and when the gneissic structure had been produced. As to the blocks of diorite in gneiss, shown in fig. 2 (p. 355), he thought it possible that they might be broken portions of a thin dyke, the result of pressure and crushing, rather than masses of rock caught up

in fluxion. The paper opened up numerous questions of considerable importance.

Prof. BONNEY said that for many years he had been working in other regions in the hope that he might understand districts like Anglesey. There we had to bear in mind that we were dealing with rocks which originally had structures of their own, and had had structures impressed on them. These he thought the Author had not always distinguished. As for the included blocks of diorite in the grey gneiss it was difficult to say what was the explanation; for the diagram would bear more than one. He thought it impossible that the specimens of gneiss exhibited could have been formed from a felsite. He doubted whether chlorite could be converted into mica except in cases of contact-metamorphism. But no doubt many changes had taken place in our views during the last twenty years.

The Rev. J. F. BLAKE was glad on this occasion to agree with all the remarks of the last speaker, especially upon the larger crystals of the gneisses supposed to be derived from a fine-grained felsite. He also agreed with the Author that in the distortions of the rocks it was quite possible that rifts might be made that were now filled by a different crystalline material from the neighbouring rock, or into which felsite was intruded in thin sheets, thus making the Author's 'gneisses of primary injection'; or where a diorite was intrusive, as at Llangaffo cutting, materials from it might easily be, and no doubt were, carried by water and deposited between the folia of the adjacent gneisses, thus making the Author's 'gneisses of secondary injection.' But in both cases the phenomena were purely local—limited in fact to a few feet or inches, and threw no light upon the general mass of gneiss which covered many square miles of country. With regard to the so-called 'diorite-blocks,' they were simply the ends of offshoots from some larger mass of diorite which had been subsequently distorted.

As to the Author's 'felsite,' the speaker was entirely at variance with him. It is true that a microscopic section of it was examined by some eminent petrologists at the British Association Meeting in 1887, and pronounced to be felsite, and this the speaker regretted; for, as it was perfectly clear to him on stratigraphical grounds that the rock was not a felsite, he could only conclude that it was impossible, by the microscopical examination of a rock-section, to ascertain whether or not that rock was a felsite. He showed, however, the locality of this supposed felsite to a large number of foreign geologists after the International Geological Congress in 1888, but none of them suggested that the rock was a felsite. It is true that the rock referred to by the Author is very fine-grained and resembles a felsite—and that it passes by insensible gradations into the ordinary grey gneiss; the phenomenon is, however, a purely local one, and over many square miles of country there is no sign of such a felsite-mimicking rock; but the folia of the gneiss are clear and parallel. The specially compact appearance is limited to the neighbourhood of, and is probably due to the pressure from, the largest dioritic

intrusion of the district; and in just the same way the 'hällefinta' which borders the exposed edge of the great granitic intrusion of the centre is due to the pressure of that mass, which has pounded the earlier gneiss into the minutest fragments, as already pointed out by Prof. Bonney and agreed to by the speaker. If we were to regard the so-called 'felsite' as the normal rock from which the gneiss had been derived, it would be very remarkable that it should be found in its most unaltered condition exactly at those spots where it must have been subjected to the greatest amount of pressure. The origin of the gneiss appeared to the speaker to be still an entirely open question, though he was not disposed to regard it as igneous.

Mr. MARR did not quite understand how the occurrence of irregular blocks of dioritic rock in the gneiss of Llangaffo proved the intrusive origin of the latter. Judging from the diagram, he could well imagine that the dioritic blocks might be dissevered portions of a folded dyke of diorite, though he did not wish to press this explanation as the correct one.

27. NOTE on a PORTION of the NUBIAN DESERT SOUTH-EAST of KOROSKO: I. FIELD GEOLOGY. By Capt. H. G. LYONS, R.E., F.G.S. II. PETROLOGY. By Miss C. A. RAISIN, B.Sc. (Communicated by Prof. T. G. BONNEY, D.Sc., LL.D., F.R.S., V.P.G.S.) III. WATER ANALYSES. By Miss E. ASTON, B.Sc. (*Idem.*) (Read April 28th, 1897.)

[PLATE XXVI—MAP.]

### I. FIELD GEOLOGY.

In the month of December, 1894, while on a military patrol in the Nubian Desert to the south and east of Korosko, I was able to examine a portion of this area which has not previously been described. Linant de Bellefonds, in his 'L'Etbaye,' and Col. Colston, of the Egyptian General Staff, have given short accounts of the rocks met with on the Korosko—Abu Hamed caravan-road, while the traveller Burckhardt<sup>1</sup> in 1814 passed by Bir Ongat, and then rather to the east of the area now described, along the Berber road. From these different accounts it seemed that the Nubian Sandstone of this part reached as far east as long. 33° E. of Greenwich, but the topography of all this part was very inaccurate, and the object of the patrol was to correct this. Surveying and marching from 22 to 25 miles a day gave little time for geological investigation, and all that was possible was to indicate the boundary-line between the Nubian Sandstone and the crystalline rocks, and to form a small collection of specimens from the latter.

A set of microscope-slides has been prepared from 33 of these and submitted to Prof. Bonney, F.R.S., under whose supervision they have been described by Miss C. A. Raisin, B.Sc., at University College, London. In the sketch-map attached to this paper (Pl. XXVI) no attempt has been made to distinguish the minor varieties of rocks which occur in this district; but the Nubian Sandstone, and the crystalline rocks respectively, have been indicated, as well as one or two areas where schistose rocks are especially developed.

#### (1) General Description.

Between Korosko and Siala the Nile runs through a comparatively narrow channel excavated in the Nubian Sandstone, which here on the eastern bank forms cliffs some 200 feet in height descending to the water's edge, while on the western bank the sandstone desert, with its patches of drift quartz-sand, rises more gradually and does not attain to the height of the eastern plateau.

Cultivation is restricted to small patches and strips; while in places the foot-track passes through the hills, since there is no room

<sup>1</sup> 'Travels in Nubia.'

at the base of the cliffs by the river. This lowest part of the great plain of Nubian Sandstone is at Korosko about 380 feet above the Mediterranean, and it rises to about 1700 feet at the foot of Jebel Raft in the eastern desert, while in the western desert much lower altitudes are met with, and the plateau 100 miles south of the oases of Kharga and of Dakhla has only attained an altitude of 500 and 800 feet respectively.

The caravan road from Korosko to Abu Hamed, which passes by the Murrat Wells, ascends for the first 50 miles through the sandstone plateau and finally comes out upon the high plateau, passing through a gap in the escarpment which overlooks the former plateau at the Bab el Korosko. This is approximately 1600 feet above sea-level. The higher plateau is a gently undulating plain with isolated hills of sandstone, and it drains to the east into the Wadi Kabkaba; this in its turn joins the Wadi Allaki, which meets the Nile at Siala.

To the south and east this plain is bounded by hills of crystalline rocks, against the flanks of which the sandstone has been horizontally laid down.

## (2) The Crystalline Rocks (massive and schistose).

Coming from Korosko to the Murrat Wells the crystalline rocks are first met with in the Wadi Mogharin on the east side of Jebel Raft, which seems to consist mainly of granite, diorite, etc., while the Nubian Sandstone is laid down horizontally on the flanks of these on the north side. It is possible that Jebel Khatáb el Atshan may be an outlier of these crystalline rocks; this is inferred from the appearance of its black summit rising above the sandstone which forms its lower slopes, and also from the statement of the Arabs that there is a rainwater-reservoir in this hill. On the south and east side of Jebel Raft there is an area of low ground occupied by schists, dipping at various angles from  $40^{\circ}$  to vertical, and much intersected by dykes. Those south of Jebel Raft have a direction of strike which varies a few degrees on either side of east and west, while those to the east of this hill and in the neighbourhood of Jebel Banat Raft and Kageritbar have a distinct north-and-south strike, which is continued until the massive crystalline rocks of Tilat Abda are reached.

The schists occur on the south side of Jebel Raft and at a short distance to the north of Murrat Wells, but are seen in their greatest development between this place and the west side of Jebel Raft. Here, in the Wadi Om Nabadi, are the ancient gold-workings which are indicated by Linant de Bellefonds in his map of the Etbai. The valley is crowded with ruins of small circular huts, about  $6\frac{1}{2}$  feet in diameter, built of loose rubble-stone, which were the dwellings of the workmen, and the lower part of a granite hand-mill lay near, but this probably was for grinding corn rather than for crushing the rock, for that was done with rubbing-stones about 3 to 4 pounds in weight. I had not time to make a very detailed examination of

the spot, but the small size of the stones used and the piles of coarse broken (but not crushed or ground) quartz lying about would lead one to think that the schists rather than the quartz had been worked as the source of the metals, the quartz having been thrown aside as rubbish. I could see no signs of gold in the pieces of quartz which I examined. At this part the strike of the schists and of the veins of white quartz is W.S.W.-E.N.E.

North of Bir Tilat Abda, and as far as Bir Ongat, the massive crystalline rocks alone are seen, while to the north of Bir Ab Araga is a very large exposure of greyish-red granite. Not until north-west of Bir Ongat do the schistose rocks again appear, and along Wadi Nayit their strike coincides generally with the direction of the wadi (from N.-S. to N.N.W.-S.S.E.), while granite forms a low chain of hills to the west.

Down the Wadi Allaki, which takes all the drainage of this part, schistose rocks alone appear, having a strike generally at right angles to the valley, that is, N.E.-S.W.

### (3) Pre-Cretaceous (?) Conglomerate.

On the crystalline rock-mass of Jebel Raft, and apparently overlain by the Nubian Sandstone, there is a very coarse conglomerate formed of fragments of the crystalline rock, both rounded and subangular, with intercalated patches of sandstone here and there. The rainwater-reservoirs of Wadi Mogharin occur in this rock.

It was not seen elsewhere, so that its true position could not be determined, but it appeared to be older than the Nubian Sandstone which was seen lying close to it (if not overlying it). The latter, however, has a basal bed of quartz-conglomerate with pebbles of no great size and very different in appearance from this coarse conglomerate.

### (4) The Nubian Sandstone.

The Nubian Sandstone is laid down on the flanks of the crystalline hills, with little or no dip. It shows very slight variation in composition, being a quartzose sandstone of different degrees of fineness, passing from a pure white colour through all the shades of yellow, brown, and red, from staining by oxides of iron and manganese. Black nodular concretions of sand cemented by these minerals are very common, and, in consequence of their power of resistance to weathering, lie everywhere on the surface of the desert. Sometimes a more argillaceous bed is seen, but it has no great extent, and no beds could be found sufficiently constant to be of any stratigraphical value. No rock was anywhere seen intrusive in the sandstone.

The main obstacle in traversing the Nubian Desert is the want of water and the uncertainty of finding a sufficient supply at any of the wells. Unlike the western desert, where the water is derived from deep-seated sources, and the supply, though only available at a few

places, is abundant, the water of the Nubian Desert is directly dependent on the rainfall. This is irregular and may not occur for several years, during which time the wells become very low and their water strongly saline.<sup>1</sup> The sources of supply in this Nubian Desert are two:—firstly, from wells (Bir), and secondly from reservoirs (Makhzan).

The first of these are sunk to a depth of from 8 to 20 feet in the detritus of the valleys, and are fed by the water which percolates into them from the neighbouring rocks, being full after heavy rain and diminishing as the drought continues. As a consequence, nearly all these wells contain a considerable amount of mineral matter in solution, and the waters of some are almost undrinkable.

*Rounded boulders in pot-hole, reservoir of Wadi Om Risha  
(Jebel Raft).*



[Height represented in figure = about 20 feet.]

The second source of supply, the rainwater-reservoirs, are deep holes in the gullies and ravines which intersect the crystalline hills; these are filled by rainstorms, and as they are partly screened from the sun by the steep side of the ravine they often retain the water for nearly a year. Some of these in Jebel Raft are of considerable size, that in the Wadi Om Risha being  $33 \times 44 \times 20$  feet in cubical capacity. The origin of these deep holes worn in the ravines must be attributed to water-action, and in the reservoir of Medina in Jebel Raft lie the rounded stones which have assisted in forming this pot-hole. (See the accompanying figure.) It is hardly conceivable that this has been effected by the rare, though often violent, rainstorms of the present time, and it must, I think, be attributed to an earlier period when the rainfall was heavier and carved out the ravines and valleys which we see at this day. Similar rainwater-reservoirs occur in the hills on the western coast of the Red Sea.

<sup>1</sup> Within the last few years the only rains capable of filling all the wells in the neighbourhood of Murrat fell in November 1891 and August 1896. In this long interval only a few showers fell.

## II. PETROLOGY.

By Miss C. A. RAISIN, B.Sc.

The collection of specimens sent by Capt. Lyons includes many rocks of similar class, but I have given short notes of all, as they represent a district on which no petrological information is available, and they show some variations. I have to thank Prof. Bonney for much kind help in my investigation.

In order to avoid repetition, the specimens have been grouped petrologically. Those in Groups vii & ix come from the 'schistose' area, but the majority are from the areas marked by Capt. Lyons as 'crystalline rocks,' among which only one specimen (Group viii) is sedimentary. The 'crystalline' districts may be described as (1) the 'Southern' (around Murrat), and the 'Western' (around Jebel Raft) separated by the southern tract of 'schistose' rocks; (2) an 'Eastern' district beyond the schistose outcrops just mentioned, extending over the watershed to the head of the Wadi Allaki. Of the crystalline rocks, those which bear most distinct signs of modification are treated first.

## (i) Gneiss.

(18<sup>1</sup>: Murrat, from the Southern area). Of this only one specimen occurs; it is jointed, and has a rather fragmental aspect.—*Microsc.* The original constituents are often reconstituted. The quartz forms a clear mosaic enclosing minute zircons and other prisms. The clustered felspar-crystals or grains (sometimes plagioclase and somewhat idiomorphic) are altered, and may be bordered by minute mica; and a small amount of a green, rather dichroic, altered biotite occurs with some ferrite. The rock is a fine-grained biotite-gneiss, which appears to be granitic in its origin, probably somewhat pressure-modified, but it possibly bears traces of a slight original banding.

## (ii) Hornblendite.

(7: Abu Sinaiyat, in the Southern area.) A greyish-green schistose rock of rather friable actinolitic hornblende.—*Microsc.* The crystals are pale green, often iron-stained, scarcely dichroic, well cleaved, and resemble the small prisms of secondary hornblende in many of the other rocks. The mineral is orientated. The macroscopic aspect suggests pressure-modification, and the microscopic would accord with it.

## (iii) Altered Gabbro or Dolerite, Diabase, etc.

(a) *Altered Gabbro.*—Several rocks, all coming from the southern area, are evidently altered forms of gabbro (11, 15: Murrat; 10, 19: Abu Sinaiyat). In three specimens (11, 10, 19) the mineral constituents are almost entirely changed into an actinolitic aggregate and a mass of zoisite with some epidote, but diallage can be recognized in one rock (11). In this the hand-specimen shows abundant

<sup>1</sup> The numbers are those attached to the specimens by Capt. Lyons.

felspar, whitish and fatty-looking, and grass-green pyroxene or amphibole with one cleavage and a well-marked form. The appearance recalls that of some Alpine gabbros.—*Microsc.* Diallagoid and hornblendic cleavages, and sometimes twinning, are seen in the greenish mineral in the midst of a felted hornblendic mass. The rock bears no definite signs of crushing. In 15 the green mineral (less in amount) is partly now a chloritic aggregate, partly a yellowish-green, non-dichroic product which seems flaky as if derived perhaps from diallage. The edges are corroded by the surrounding mass. Much of the felspar is clear and is plagioclase (labradorite), but secondary minerals are developed.

Nos. 10 and 19 are mottled greenish and grey, with small patches which are jade-like in appearance. The former specimen is bounded by joint-planes, the second has a sand-worn surface.—*Microsc.* In both, the mineral constituents are replaced, but in 19, where the grains are larger and clearer, actinolite is grouped in curving sheaves, suggesting the possibility of pressure-effects. In 10 two or three isolated, fairly large crystals of a brownish dichroic mineral (pale to cinnamon-brown) with bluish dusty centre, probably are tourmaline. They terminate irregularly, enclose foreign substances, and appear to be a late formation, and to have grown across the hornblende-zoisite aggregate, almost eating it up, as the mica described by Prof. Bonney across a schist.<sup>1</sup> The form, however, would be unusual for tourmaline in a rock of this kind, and it may be not only secondary but also pseudomorphic.

(b) *Diabasic Rocks with Lustre-mottled Hornblende.*—16 (Murrat) is from the Southern, and 1 (Tilat Abda) & 33 are from the Eastern region. In all, well-cleaved blackish or dark-green lustre-mottled hornblende is associated with felspar, which is greenish-white saussuritic-looking in 1 or an opaque white in 16.—*Microsc.* The felspar is replaced by a micaceous or kaolin aggregate with flaky yellowish viridite, or pseudophite, and granular epidote, some oligoclase remaining in 1. The hornblende is dichroic,<sup>2</sup> has colourless and other patches, and where the differences are most marked, as in 33, the varieties apparently pass into each other by secondary change. It encloses grains of felspar often altered; also in 1 some pyroxenic grains and some of granular calcite, but there appear to be gradations between these, as if the pyroxene might be a lime-pyroxene—a malacolite—such as occurred in the pierite of St. David's described by Prof. Bonney.<sup>3</sup> Clustered epidote and scattered actinolite are abundant. In 33 iron-oxide, a few zircons, apatite, and epidote occur, and a quartz-vein. Much of this slide consists of dusty felspars, broadly oblong, closely set in a ground of coarse quartz.<sup>4</sup>

<sup>1</sup> 'On a Secondary Development of Biotite and of Hornblende.....,' *Quart. Journ. Geol. Soc.* vol. xlix. (1893) p. 104.

<sup>2</sup> In 1 **c**, pale brown; **b**, dull olive-green; **a**, reddish brown to green.

<sup>3</sup> *Quart. Journ. Geol. Soc.* vol. xli. (1885) p. 519.

<sup>4</sup> I incline to the view that the rock is akin to the diorites, notwithstanding the form of the felspars; and from the character of the hornblende, it seems best described here. Compare also Nos. 4, 30, 27, *infra*, pp. 366, 367.

(c) *Other Hornblende-diabases.*—(4, 20, 9, 13, 2, 14, 17, 5, 25.) In one specimen from the west (4: Jebel Raft, west side) and in five specimens from the south (Murrat: 20, 9, 13, 2, 14), where minerals are recognizable, feldspar and hornblende in various stages of alteration are the chief components, and on the weathered surfaces the latter may be etched out (4, 2).—*Microsc.* The feldspar exhibits plagioclase structure either in the interior or as a rim; and in most of the rocks interstitial clear quartz or secondary feldspar is present, some of which may be traced in No. 4 originating at the exterior of certain crystals, and even connected with a kind of micropegmatitic structure.<sup>1</sup> The hornblende in some cases is markedly idiomorphic, and exhibits a change from the brown to a green variety,<sup>2</sup> as in the mottled crystals in 20 and 13. In 9 the large idiomorphic hornblende is entirely replaced by streaky serpentinous or chloritic mineral with small included crystals; in 4 it is partially replaced by filmy viridite. In the former rock some of the enclosures are iron-oxide; but the most interesting are very numerous prisms of rutile (and perhaps pseudobrookite), which sometimes are related in their position to the principal cleavages of the hornblende.<sup>3</sup> In 20 a light-coloured part beyond a sharp straight boundary of the hornblende-crystal is probably an added growth.<sup>4</sup> Specimen 2, somewhat bounded by joint-planes, greyish-green, and externally brownish, shows under the microscope aggregates of chlorite apparently replacing pyroxenic crystals, and yellowish, slightly dichroic flakes, probably altered biotite, and some approaching viridite in character. In the microlithic groundmass are granular epidote, calcite, and iron-oxide. Clustered rutile seems to have formed within ilmenite which is now replaced by leucoxene, or within sphene, and in 13 sphene is apparently derived from ilmenite. No. 14 is an iron-stained, compact rock which exhibits (microscopically) a very irregular mosaic of plagioclase, quartz, colourless chlorite, and a high-refracting mineral giving a peculiar blue with crossed nicols. It includes grains small and large (some  $\frac{1}{24}$  inch in diameter) of a carbonate with a green rim, and of hæmatite or limonite. Corroded remains of larger plagioclase-feldspars occur. These two rocks have undergone much change, and 14 is somewhat crushed, but they were probably felspathic dolerites or diorites.

Two rocks also from the Southern region (5, 17: Murrat) are fine-grained and are difficult to identify. No. 5 is a dark-grey rock, with an interrupted silky look due to minute crystals, and with small brownish projections on the surfaces smoothed and pitted by sand-action.—*Microsc.* The knobs consist of a quartz-mosaic coloured by a brownish carbonate. The cryptocrystalline sericitic groundmass

<sup>1</sup> The rock reminds me somewhat of specimens examined from the Nile Valley and from West Africa. See also Geol. Mag. 1893, p. 436; compare Nos. 27 & 30, *infra*, p. 367.

<sup>2</sup> Like the change in certain picrites. See T. G. Bonney, Quart. Journ. Geol. Soc. vol. xli. (1885) p. 520.

<sup>3</sup> Compare the rutile within serpentinized olivine, 'On the ..... Rauenthal Serpentine,' Quart. Journ. Geol. Soc. vol. liii. (1897) p. 253.

<sup>4</sup> See Whitman Cross, Am. Journ. Sci. ser. 3, vol. xxxix. (1890) p. 360.

might be derived from a felspathic substance, and numerous brown-stained, greenish, dichroic flakes or prisms occur. The rock has rather the aspect of a mica-trap, but some of the last-named constituent seems to have an oblique extinction, as if it were hornblende rather than biotite. No. 17 has a modified felspathic ground somewhat similar to 5 (with calcite, quartz, limonite, and minute ? kyanite); but it is penetrated by strings of small hornblende, and encloses large porphyritic feldspars, and probably altered representatives of others. These form whitish oblongs in the pale greenish hand-specimen, which exhibits a platy structure, and the rock might be called a hornblende-schist, but is probably a modified diorite.

In 25 (Tilat Abda) from the Eastern area, we return rather nearer to the type of 2 or 14. It is a greyish rock crowded with small, white, irregular feldspars.—*Microsc.* These are dusty-looking, and other crystals, doubtless pyroxenic, consist partly of yellowish, generally isotropic substance. As in 2, an interstitial clear mineral, granular epidote, calcite, and iron-oxide are present.

From the Eastern area also come four other specimens of rather different types (29, 26, 30, 27).

(d) *Porphyritic Diabase* (29).—A dull greenish rock, sand-polished and somewhat crushed.—*Microsc.* The porphyritic crystals are large, lath-shaped, rich green, and irregularly terminated. They are replaced by chlorite, epidote, granular secondary feldspar, sometimes deposited as if along cleavage-planes; if these were feldspar originally, they have developed an exceptional amount of chlorite. The groundmass is almost completely masked by granular epidote.

(e) *Diabase with remains of Augite* (26).—Only one rock in the collection exhibits augite partially unaltered occurring as porphyritic crystals, and even here hornblende forms the ferromagnesian constituent of the groundmass. Doubtless in many of the rocks augite was originally present, the hornblende being secondary. This specimen is dark greenish-grey, slightly speckled, containing narrow, white, porphyritic feldspars, sometimes in radiating clusters, and some iron pyrites.—*Microsc.* The feldspar is kaolinized; the augite sometimes well-preserved, occasionally twinned along 100; but generally the crystals are changed—along the borders or completely—to fibrous hornblende. Clusters of similar actinolite with a carbonate and iron-oxide are found. The groundmass includes labradorite, and gummy brown mica-like hornblende passing into green actinolite. The rock, originally a minutely crystalline dolerite, now is rather a hornblendic diabase.

#### (iv) Quartz-diorite.

In 30 the quartz is not, perhaps, in sufficient amount to justify this term, but it leads up to the better-marked type (27). The former consists of flesh-coloured or greenish feldspar and of blackish hornblende with a little quartz.—*Microsc.* The plagioclase-feldspar is intercrystallized with a mosaic, the grains exhibiting a kind of

micropegmatitic structure. This may show finger-like divisions radiating in tufts, or two sets of them at right angles forming a kind of basket-work, but usually the structure is less regular.<sup>1</sup> The hornblende is dichroic (myrtle-green to pale greenish-yellow), not idiomorphic or fresh-looking, associated with some altered biotite. Iron-oxide, epidote, ?apatite, besides quartz, are present. The rock originally may have been a diorite.

No. 27 is a pinkish-white fine-grained rock.—*Microsc.* The felspar is plagioclase; the quartz forms a mosaic, containing lines of cavities and acicular microliths which extend through adjacent grains. The rich green dichroic hornblende,<sup>2</sup> with twinning along 100, encloses grains of quartz or felspar. Iron-oxide (? ilmenite), epidote, and impure-looking sphene occur. The constituents are all rather irregular, and the rock appears to have been somewhat affected by pressure followed by reconstitution.

#### (v) Granite.

One specimen from the Western area (3: Jebel Raft, west side, by Wadi Tonaidba) consists of quartz (projecting on weathered surfaces), of much pinkish felspar, and of a reddish-black iron-oxide.—*Microsc.* The felspars are idiomorphic, kaolinized, but at places apparently plagioclase. In the interstitial quartz are lines of enclosures. Veins also occur which are in mineral continuity with the quartz where they pass through it. The hæmatite or limonite replaces fairly large crystals which are posterior to the felspar, but resemble pyroxene, and are similar to the replaced pyroxene (?) in rocks, probably doleritic, from Abu Seir and West Africa.<sup>3</sup>

#### (vi) Felstones.

Two rocks from the Eastern area appear to be cryptocrystalline forms of an intermediate or acid type. No. 31 is jointed, with rather polished surfaces. The rock is brown and flinty-looking, speckled with white porphyritic felspar-crystals, partly corroded.—*Microsc.* A second generation of small felspars helps to form the ground-mass, which includes small green, dichroic, micaceous, or chloritic flakes and black iron-oxide. The rock probably is a compact quartz-felsite.

No. 32 is pale grey, with numerous whitish porphyritic felspars, often idiomorphic, like orthoclase in shape, but altered, with various enclosures—micaceous, pyroxenic, and others. A vein filled with a carbonate occurs. The devitrified groundmass, abundantly microlithic, has a fluxional look, and the rock is a felsite probably slightly affected by pressure.

<sup>1</sup> Although a similar formation in other rocks may be original, this suggests a secondary deposition along cleavage-planes, resembling the 'quartz de corrosion' of Fouqué & Lévy, 'Min. Micr.' (Mém. Carte géol. France, 1879) p. 193.

<sup>2</sup> a, myrtle-green; b, olive-green; c, pale brownish-green.

<sup>3</sup> Geol. Mag. 1893, p. 441.

## (vii) Rocks of Igneous Character, but Uncertain Origin.

('Schistose' area: 21, 24, 23.)

(21) Wadi Om Nabadi; (24) Jebel Banat Raft. Two rocks from different parts of the southern schistose area bear some resemblance to each other. Both are pale greenish, with fine-grained structure developed, probably by wind-erosion, on the weathered surface. They have a slight appearance of schistosity; and one rock (24) exhibits apparent fragments separated by vein-like parts rich in epidote.—*Microsc.* Both rocks include worn and sometimes rounded plagioclase-crystals; the intermediate part being much masked by epidote and other secondary minerals. In all the constituents microlithic enclosures have formed, often of small flakes of chlorite, of which mineral larger crystals also occur in the slide (dichroic, changing from green to yellowish). Much scattered iron-oxide is found. While some of the microscopic fragmental appearance is probably due to subsequent disturbance or crushing, some of it is probably original. The rock (21) seems certainly a diabase-grit or ash, with inclusion possibly of some andesitic or felsitic fragments; while 24, although it may have been also originally elastic, has more resemblance to a true igneous rock. The sp. gr. of 24 is 2.77.

(23: Om Nabadi) is a dull greenish-drab, finely-speckled schistose rock, in which the plagioclase-crystals are broken and corroded. The felsitic groundmass contains greenish microliths (more abundant along iron-stained streaks), a carbonate, limonite, ? chalybite, ? epidote, and black iron-oxide. The brown mica includes small scales changing to green, and larger, clearer flakes, transverse to the foliation, which thus appear to be secondary, like those described by Prof. Bonney in an Alpine schist.<sup>1</sup> Green dichroic flakes occur, probably derived from certain of these larger mica-crystals. The clearer areas, enclosed within greenish stringy lines, appear, on microscopic examination, to be like normal felsite, and the rock, which looks finely fragmental, may owe this appearance to crushing, and may be a squeezed porphyrite. The sp. gr. of one fragment was found to be 2.71, which would agree very well with this identification.

## (viii) Sedimentary Fragmental Rocks.

One rock from the Southern area is an impure limestone (6: Murrat, S.). A strong, compact, dark grey rock, with a somewhat foliated look, containing small, elongated, slightly irregular, silvery flakes, very definitely orientated. The rock effervesces briskly with hydrochloric acid, is a quartzose or gritty limestone, indurated, and from the flaky laminae has the appearance of being pressure-modified, but this character cannot be well recognized in the microscope-slide. One surface is sand-worn.—*Microsc.* Calcite, the chief constituent, is dusty with opacite (? carbonaceous), and is interrupted by nests of impure limonite. The included fragments consist of quartz, of

<sup>1</sup> Quart. Journ. Geol. Soc. vol. xlix. (1893) p. 104.

plagioclase, some of (?) felsite. Minute flakes of white mica are scattered within or around the fragments, or form wavy patches, the silvery scales being seen macroscopically.

This specimen, brought from the area of 'crystalline' rocks, has more affinity with those of the 'schistose' region, and resembles certain squeezed muddy limestones of the Alps, which probably are Jurassic in age.

#### (ix) (?) Phyllites.

(21,\* 22: Wadi Om Nabadi. From the 'Schistose' area.) These two specimens are schistose rocks with silvery-sheen surfaces, somewhat iron-stained, partly in connexion with rusty cubic crystals.—*Microsc.* The fine-grained clear mosaic is crowded with pale green micaceous (?) microliths, often orientated, and sometimes matted along wavy lines. In 21\* one rather large crystal, now limonite, has a border of coarsely crystalline quartz, almost cubic in outline. Fine-grained quartz-veins traverse the slide. It is not easy to decide whether these two specimens are crushed, somewhat gritty phyllites, or much-cleaved schist, like certain Alpine rocks. Although in the slice from 22 a crystalline character seems slightly more evident, the rocks which have been crushed were more probably not true schists. The two specimens might well come from the same rock, and scarcely represent even different bands.

A quantity of cubes of a rich brown colour were collected on the hill of Kageritbar, where it was crossed by Capt. Lyons's route. The mineral is limonite, but is no doubt a pseudomorph. The crystals are generally from  $\frac{1}{4}$  to  $\frac{3}{8}$  inch across, and they were probably formed *in situ*, since in an accompanying fragment of rock are similar cubes, but much smaller (about  $\frac{1}{16}$  inch). These crystals often have closely-fitting quartz, which builds up a regular partially cubic form, as if it were a vein-like growth similar to that described in slide 21,\* and at one part like 'faser-quartz.' The loose cubes often exhibit associated quartz. Thus it seems as if the formation of the cubes may have induced crystallization and deposition of silica around them. In the slice of this rock, micaceous microliths are not recognizable, but the fine granular mosaic of the groundmass seems to be similar to that in the preceding specimens, although here it is very much masked by patchy limonite. By the kindness of Prof. Bonney, I have looked for comparison at slides of the Obermittweida rocks,<sup>1</sup> which exhibit a micromineralogical change far more marked, but apparently of the same type.

#### (x) Vein-quartz.

(8, 12: Abu Sinaiyat.) Two specimens from the Southern area are hard, compact, sand-worn rock, speckled with minute metallic grains, and weathering brown. They have a brecciated look, the fragments, black in colour, tinged violet in places, being separated by whitish veins of composite quartz, larger in 12.—*Microsc.* Fragments of the original vein-quartz are large, irregular, but

<sup>1</sup> See Quart. Journ. Geol. Soc. vol. xlv. (1888) p. 25.

elongated and orientated. In these the opaque metallic hæmatite (?) is disseminated in fine particles, but it is aggregated as crystals or thicker streaks among the cementing secondary quartz. In 12 the grains of the mosaic are larger, more sharply defined, more crystal-shaped, and freer from opacite.

#### SUMMARY.

### 1. Classes of Rocks.

With the exception of two or three felstones, the igneous rocks are holocrystalline. One is apparently granitic, and one gneiss may be a modification of an igneous rock, but the great majority belong to a rather basic or to an intermediate type, and are generally much altered; they are diorites, diabases, dolerites, or gabbros. Of none of the rocks can we say with certainty that it originated as a lava-flow, only a slight indication of fluxional structure being found in one felstone, and certain specimens (such as the gabbro and the granite) doubtless can only be from intrusive masses; the mode of occurrence of others must be decided by field evidence.

The few fragmental rocks come from the 'Schistose' area, except one gritty limestone apparently caught in among igneous masses. Two are much crushed, probably phyllites; and one at least consists chiefly of igneous materials, but probably originated from the denudation of doleritic or diabasic rocks, and not as tuff or agglomerate.

### 2. Mineral Changes.

The rock-constituents afford evidence of many and various alterations. These are especially illustrated in the numerous specimens belonging to the doleritic or allied groups.

*Felspar.*—In nearly all cases the felspars are much changed, in some completely so. Examples occur of the common dusty alteration, while much of the felspar has developed flakes or films, either scattered or massed together, of a minute mica-like mineral which may be sometimes a hydrous mica, sometimes kaolin. Epidote occurs in crystals, or often as a granular aggregate; but some of the felspars are replaced by zoisite or by a mixture of zoisite and epidote, and other groups of these minerals probably are similarly derived. Occasionally a small amount of a greenish mineral resembling a serpentinous product is present, and in one slide a quantity of chlorite is found within crystals which probably are felspar, a less usual alteration, and one which is only possible by the interchange of constituents.<sup>1</sup>

*Pyroxenic Minerals.*—In only one slide is there any ordinary unchanged augite, and even there many of the crystals are either partially or completely altered to an aggregate mostly of an actinolitic character. Several of the rocks contain common, brown, well-cleaved hornblende, nearly always exhibiting alteration to a mottled and pale green or colourless variety or to actinolite. The lustre-mottling of the crystals is interesting; they sometimes

<sup>1</sup> See T. G. Bonney, 'On some Schistose Greenstones, etc.,' *Quart. Journ. Geol. Soc.* vol. xlix. (1893) p. 103.

include grains of felspar, sometimes probably a lime-pyroxene like the picrite of St. David's.<sup>1</sup> Apparently an added growth occurs in one or two cases.<sup>2</sup> In several specimens an actinolitic aggregate is the only representative of the pyroxenic constituent, especially in what seem to have been originally gabbros, although the diallage structure is rarely recognizable in them. This actinolitic development is not necessarily connected with any dynamo-metamorphism, and may be considered to be probably an example of the second class of alteration suggested by Prof. Bonney.<sup>3</sup> The rocks exhibit other secondary minerals, the most interesting of which, perhaps, is rutile, richly developed in one case within crystals idiomorphic in form, but now consisting of an actinolitic aggregate, like the development within serpentine in certain altered peridotites where the outline of the original olivine-grain is retained.<sup>4</sup> In another rock, rutile apparently is formed from ilmenite, now replaced by leucoxene. In more than one case, mica has developed apparently across structure-planes, as in the rocks described by Prof. Bonney.<sup>5</sup>

### 3. Pressure-effects.

The area described by Capt. Lyons as consisting of 'schistose' rocks, and so marked on the accompanying map (Pl. XXVI), is illustrated in this collection by only five specimens. Judging from these, the rocks all show effects of pressure, which in the probable phyllites are very strongly marked.

A crushed and brecciated vein-quartz is interesting as exhibiting a separation of the quartz, and of the minute disseminated iron-oxide. In this, however, as in so many other examples, doubtless the crushed material facilitated the percolation of water, through the action of which separation and recrystallization probably were caused. The fragmental rocks have undergone pressure-modification, as in one gritty limestone, and doubtless several of the basic rocks (altered gabbros and diabase), but these would offer much resistance and would not easily exhibit effects from this cause.

### 4. Meteorological Action.

One phenomenon of which there is clear evidence is the erosion by wind and desert-sand, and the formation of a weathered coating. The worn faces of the rocks usually are lumpy or irregular, but with projections and depressions, smoothed or polished. In many of the crystalline rocks the pyroxenic constituent is slightly hollowed out on the weathered surface, and apparently is the part first to acquire the brown coating described by Walther and other observers.<sup>6</sup> Whatever be the origin of this layer, the peculiar polish which accompanies it is almost certainly due to the wind-action noticed above.

<sup>1</sup> T. G. Bonney, *Quart. Journ. Geol. Soc.* vol. xli. (1885) p. 519.

<sup>2</sup> See also Whitman Cross, *Am. Journ. Sci.* ser. 3, vol. xxxix. (1890) p. 360.

<sup>3</sup> *Quart. Journ. Geol. Soc.* vol. xlix. (1893) p. 102.

<sup>4</sup> *Ibid.* vol. liii. (1897) pp. 253, 262.

<sup>5</sup> *Ibid.* vol. xlix. (1893) p. 104.

<sup>6</sup> 'Die Denudation in der Wüste,' J. Walther, 1891, pp. 109-117.

## 5. Relative Age of the Rocks, and Comparison with other Localities.

While the coarse gneissic and granitoid rocks of the Nile Valley near Assuan are poorly represented, some likeness to those of a more basic or intermediate type from Wadi Halfa is exhibited.<sup>1</sup> The rocks which appeared to belong to an ancient series from that part of the Nile Valley were, however, generally dioritic. The more modified types in this collection from east of the Nile are usually coarser, and are altered gabbro rather than diorite. Much of the hornblende is similar to that in the less-altered diorites of the valley, although in the latter the plagioclase is often somewhat fresher in appearance. In one rock from the Second Cataract unchanged augite occurred, as in No. 26 in this collection (p. 367).

The altered gabbros with remains of diallage, occasionally still recognizable, rather resemble the well-known euphotide (Alpine gabbro),<sup>2</sup> and this type has not been noticed, so far as I am aware, from Upper Egypt. The almost pure hornblendite seems not to be represented nearer than Pangani or Southern Abyssinia. The rarity of these types in this southerly region can be seen by referring to the exhaustive list given by A. Rosiwal.<sup>3</sup> Notwithstanding specific or varietal differences, however, the conclusions arrived at as regards this area are similar to those suggested by examination of specimens from parts of the Nile Valley; and even similar in the difficulty, sometimes, of identifying with certainty all the members of the ancient Archæan series.<sup>4</sup>

It seems clear that the complex in this district east of the Nile exhibits the old floor of crystalline rocks of which Capt. Lyons has already noticed indications in the country west of the river (for example, the gneiss of Jebel Abu Bayan). It is interesting to find these basement-rocks exposed along what Capt. Lyons had suggested may be an anticlinal axis.<sup>5</sup> The resemblances also to rocks which have been described from near Wadi Halfa render this coincidence the more striking, since it is by way of this locality that the suggested anticlinal would cross the Nile Valley.

<sup>1</sup> Geol. Mag. 1893, p. 437. I have to thank Mr. L. Fletcher, M.A., F.R.S., Keeper of Mineralogy at the British Museum of Natural History, for kindly allowing me to re-examine the specimens described, as the rocks and slides have been deposited in that collection.

<sup>2</sup> 'Petrological Notes on the Euphotide or Saussurite-smaragdite Gabbro of the Saasthal,' T. G. Bonney, Phil. Mag. ser. 5, vol. xxxiii. (1892) p. 237; 'On some Specimens of Gabbro from the Pennine Alps,' T. G. Bonney, Min. Mag. vol. ii. (1878) p. 5.

<sup>3</sup> Denkschr. der Kais. Akad. der Wiss. Wien, vol. lviii. (1891): 'Beitr. zur geol. Kenntniss des östlichen Afrika,' pt. ii. pp. 531-548.

<sup>4</sup> Geol. Mag. 1893, p. 436.

<sup>5</sup> Quart. Journ. Geol. Soc. vol. 1. (1894) p. 539.

## III. WATER ANALYSES.

By Miss E. ASTON, B.Sc.

The water was collected from wells in the Nubian Desert in December 1894 by Capt. H. G. Lyons, R.E., who has sent with each specimen the following description :—

## 1. Murrat Wells.

Water-surface 10 feet from the ground ; depth 2 feet 6 inches. If the water is all used up by a caravan, the well refills in a few hours, trickling in at the sides. Last fall of rain in November 1891, except for two or three showers. No vegetation within half a mile of the wells, which are sunk in the sand-and-gravel detritus filling the valley. The supply of water is said by the Arabs to be unlimited. Wells from 1 to 8 in number, open at various times.

## 2. Bir Tilat Abda.

Called by the Arabs a 'bitter' well. Water 20 feet from the surface ; well sunk in sand-and-gravel detritus. Considerable vegetation around it. Last rain in November 1891.

## 3. Bir Ab Araga.

Water 20 feet from the surface. A moderate number of trees and shrubs in the vicinity. Last rain fell in November 1891. Used by the Arabs who live in the neighbourhood.

The tables (p. 375) give the analyses of the waters. In the first table the figures are the actual amounts of the substances found ; the second table gives the approximate constitution. The wells are numbered as above :—1 = Murrat, 2 = Bir Tilat Abda, 3 = Bir Ab Araga.

Quantities are tabulated in grains per gallon. The 'total solid matter' was found by direct evaporation. The ammonia is expressed, in the usual manner, in parts per million.

## PLATE XXVI.

Geological sketch-map of a portion of the Nubian Desert south-east of Korosko, on the scale of 16 miles to 1 inch.

## DISCUSSION.

Prof. HULL was glad to find that Capt. Lyons was continuing his geological observations up the Valley of the Nile. He presumed that those described were the result of a reconnaissance made in advance of the Geological Survey of Egypt, and they seemed to show that the relations of the various formations above the First Cataract were similar to those about Assuan. The old Archæan metamorphic rocks were found peering up through the nearly horizontal

TABLE I.

	Well 1.	Well 2.	Well 3.
'Total solid matter' .....	410.5	359.5	253.5
SiO <sub>2</sub> .....	1.28	3.36	2.48
Fe <sub>2</sub> O <sub>3</sub> + Al <sub>2</sub> O <sub>3</sub> .....	0.26	4.36	0.96
Ca .....	37.76	31.19	37.95
Mg .....	5.81	6.74	6.89
Na .....	61.38	63.88	21.91
K .....	32.08	30.41	11.18
SO <sub>4</sub> .....	175.23	182.52	142.47
Cl .....	61.79	21.42	28.05
NO <sub>3</sub> .....	1.86	1.88	trace.
	377.45	345.76	251.89
Free ammonia .....	0.378	0.105	0.199
Albuminoid ammonia .....	0.185	0.173	0.260

TABLE II.

	Well 1.	Well 2.	Well 3.
SiO <sub>2</sub> .....	1.28	3.36	2.48
Fe <sub>2</sub> O <sub>3</sub> + Al <sub>2</sub> O <sub>3</sub> .....	0.26	4.36	0.96
KCl .....	34.18	10.73	1.45
NaCl .....	15.81	41.71	17.29
Na <sub>2</sub> SO <sub>4</sub> .....	170.25	146.49	46.45
K <sub>2</sub> SO <sub>4</sub> .....	21.27	—	—
MgSO <sub>4</sub> .....	28.15	32.65	33.35
KNO <sub>3</sub> .....	3.03	3.06	2.26
CaSO <sub>4</sub> .....	59.50	81.87	120.13
CaCO <sub>3</sub> } .....	82.04	28.79	10.56
H <sub>2</sub> CO <sub>3</sub> }			
	415.77	353.62	234.93

beds of the Nubian Sandstone—probably along the axes of low saddles—and throwing off the stratified deposits on all sides. He noticed the suggestion that possibly there were two divisions of the Nubian beds—namely, the conglomerates and varied strata in the lower part, and the more solid sandstones in the upper (from which the building-stones of the great temples had been derived); but the question whether all these deposits were merely variations of one great lacustrine (or estuarine) formation, or were distinct formations, could be determined only by a detailed survey. Regarding the igneous rocks which occur as dykes traversing the old rocks, it was clear that they belong to some period intermediate between the Archæan and the Cretaceous—possibly Upper Palæozoic. He thought that when the waters of the old wells became saturated with salts, the best plan would be to sink new wells close by in favourable positions, in which the waters would probably be found less saline.

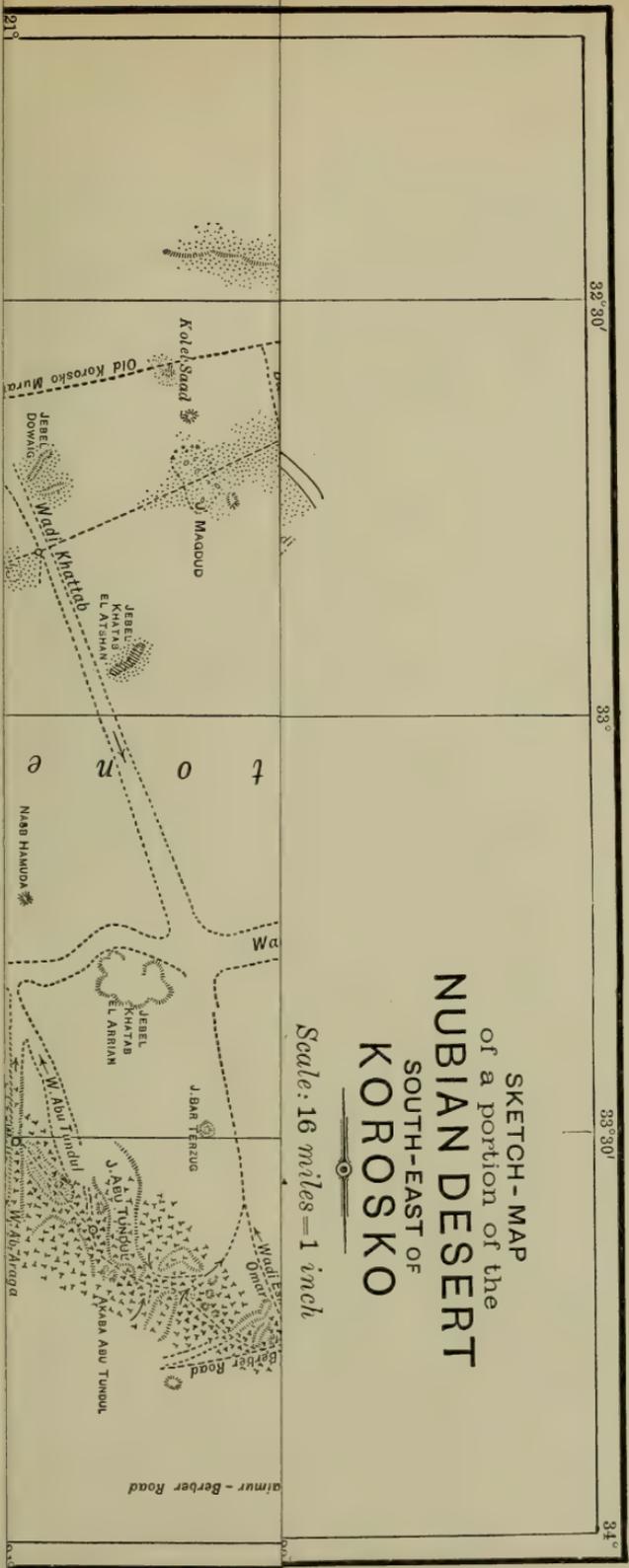
The Rev. J. F. BLAKE thought that geologists seemed rather too ready to suppose comparatively recent changes of climate to account for phenomena which they could not otherwise explain. In the present case the depressions in the river-beds called 'potholes' are thus accounted for. In Cutch, however, there were numerous similar depressions filled with water all the year round, while the remainder of the stream-course was dry sand, and yet there was evidence that the general conditions of climate had been constant for a long time. It was possible, therefore, that in the case of the district described a varying intensity of rainfall, or the diversion of the water falling on higher reaches of the streams into other courses, owing to physical changes beyond the district in question, might account for the present lack of water, without any very serious alteration of the climatic conditions.

Prof. BONNEY said that it had occurred to him that possibly the lower conglomerate mentioned by Capt. Lyons might be pre-Cretaceous, like those described by Prof. Hull. He did not think that much good would come from sinking fresh wells. As regards the origin of the wadis and rounded stones, he did not see how these phenomena could possibly be explained without a heavier rainfall, and that climate had changed was a geological commonplace. He thought that the wells were in detritus.

Quart. Journ. Geol. Soc. Vol. LIII. Pl. XXVI.

SKETCH-MAP  
of a portion of the  
**NUBIAN DESERT**  
SOUTH-EAST OF  
**KOROSKO**

Scale: 16 miles = 1 inch









28. *The MOLLUSCA of the CHALK ROCK: PART II.* By HENRY WOODS, M.A., F.G.S. (Read May 12th, 1897.)

## [PLATES XXVII. &amp; XXVIII.]

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## I. INTRODUCTION.

THE first part of this paper, dealing with the Cephalopoda, Gastropoda, and Scaphopoda, appeared in the preceding volume of this Journal.<sup>1</sup> In the present communication I propose to consider the Lamellibranchia, and to discuss the relations and distribution of the fauna of the Chalk Rock and the conditions under which that fauna lived.

The Lamellibranchs are represented by a larger number of species than either the Cephalopoda or the Gastropoda, but, on account of the imperfect manner in which their remains are preserved, greater difficulty has been found in studying them than was the case with the groups considered in Part I. Again, there is evidence of the existence of forms other than those herein described, but the specimens now at my disposal are not sufficiently good for determination. I shall hope, after more collecting has been done, to be able to supplement this work, and shall be grateful for any opportunity of examining specimens from this zone.

For further assistance I must again thank the gentlemen mentioned in Part I., particularly Mr. Jukes-Browne, Mr. E. T. Newton, Mr. G. C. Crick, and Mr. R. M. Brydone.

## II. Class LAMELLIBRANCHIA.

## Family Nuculanidæ, Stoliczka.

## Genus NUCULANA, Link, 1807

[= *Leda*, Schumacher, 1817].

## NUCULANA cf. SILIQUA (Goldfuss).

1837. *Nucula siliqua*, A. Goldfuss, 'Petref. Germ.' vol. ii. p. 156, pl. cxxv. f. 13;  
1846. A. E. Reuss, 'Die Verstein. der böhm. Kreideformat.' pt. ii. p. 7, pl. xxxiv.

<sup>1</sup> Vol. lii. (1896) pp. 68-98 & pls. ii-iv. Correction to be noted there:—pp. 88 *et seq.*, for *Trochus berocscirensis* read *Trochus berocscirensis*.

f. 11; 1889. O. Griepenkerl, 'Die Verstein. der Senon. Kreide von Königsutter,' Paläont. Abhandl. vol. iv. p. 57.

1850. *Leda siliqua*, A. d'Orbigny, 'Prodr. de Pal.' vol. ii. p. 236; 1877. A. Fritsch, 'Stud. im Gebiete der böhm. Kreideformat. II. Die Weissenberger u. Malnitzer Schichten,' p. 117, f. 81; 1889. E. Holzapfel, 'Die Mollusken der Aachener Kreide,' Paläontographica, vol. xxxv. p. 203; 1893. A. Fritsch, 'Stud. im Gebiete der böhm. Kreideformat. V. Priesener Schichten,' p. 92; 1895. F. Vogel, 'Die holländ. Kreide,' p. 37.

1885. *Nuculana siliqua*, F. Nötling, 'Die Fauna d. baltisch. Cenoman-Geschiebe,' Paläont. Abhandl. vol. ii. pt. iv. p. 27, pl. iv. f. 15.

[Non *Nucula siliqua*, H. B. Geinitz, 'Char. d. Schichten u. Petref. d. sächs.-böhm. Kreidegeb.' pt. iii. (1842) p. 77, pl. xx. f. 28 & 29.]

*Remarks.*—There are two specimens in the Montagu Smith Collection which agree well with the figures given by Goldfuss and Reuss, but since, like the figured specimens, they are in the form of casts, it is difficult to be sure of their identity. The approximate size of one of the specimens is:—length=16 mm.; height=6 mm. The type of the species comes from the Aachen Greensand (Lower Senonian).

*Distribution.*—*England*: Chalk Rock of Cuckhamsley. *North-western Germany*: Maestrichtian of Konrath near Aachen; Hervien of Aachen. *Bohemia*: Weissenberg and Priesen Beds.

### Family Nuculidæ, Gray.

Genus *NUCULA*, Lamarck, 1799.

*NUCULA* sp. (Pl. XXVII. figs. 1 & 2.)

*Remarks.*—A species of *Nucula* is represented in the Montagu Smith Collection by eleven specimens; it approaches closely in form d'Orbigny's *N. Renauviana*<sup>1</sup> found in the Turonian of Uchaux, but, unfortunately, all the specimens are internal casts, so that an exact determination is impossible. Size of an average specimen: length=13 mm.; height=10 mm.

*Distribution.*—Chalk Rock of Cuckhamsley.

### Family Arcidæ, Lamarck.

Genus *ARCA*, Linnæus, 1766.

*ARCA* sp., cf. *GALLIENNEI*, d'Orbigny. (Pl. XXVII. fig. 3.)

There are two casts from Cuckhamsley in the Montagu Smith Collection which agree with *A. Galliennei*, d'Orbigny,<sup>2</sup> from the Cenomanian of Le Mans, Rouen, etc., except that they are rather shorter. Size of a specimen: length=33 mm.; height=19 mm.

*ARCA* (*BARBATIA*) sp., cf. *GEINITZI*, Reuss, 1844. (Pl. XXVII. figs. 5 & 6.)

[See especially, Reuss, 'Geogn. Skizzen,' vol. ii. (1844) p. 192, and 'Die Verstein. der böhm. Kreideformat.' pt. ii. (1846) p. 11, pl. xxxiv. f. 31; Geinitz, 'Das

<sup>1</sup> 'Pal. Franç. Terr. Crét.' vol. iii. (1843-47) p. 179 & pl. ccciv. figs. 7-9. This is regarded by Pictet & Campiche, 'Foss. Terr. Crét. Ste. Croix,' pt. iii. (1866) p. 418, as a synonym of *N. impressa*, Sowerby.

<sup>2</sup> *Op. supra cit.* p. 218 & pl. ccciv.

Elbthalgeb. in Sachsen,' pt. ii. (1873) p. 55, pl. xvi. f. 78; Fritsch, 'Stud. im Gebiete der böhm. Kreideformat. IV. Die Teplitzer Schichten' (1889), p. 79, fig. 63; Favre, 'Moll. Foss. de la Craie des Envir. de Lemberg' (1869), p. 125, pl. xii. f. 15 & 16.]

*Remarks.*—A specimen, consisting of an internal, and part of an external mould, agrees with *A. Geinitzi* in form, but differs in possessing rather finer and more numerous ribs. It is probably the form figured by Sowerby as *Bysoarca marullensis*<sup>1</sup> from the Chalk of Kent. Size of specimen from Cuckhamsley: length (approximate)=23 mm.; height=11 mm.

*A. Geinitzi* occurs in the Pläner-Kalk of Strehlen (Saxony), in the Teplitz Beds of Bohemia, etc.

*Distribution.*—Chalk Rock of Cuckhamsley.

ARCA sp. (Pl. XXVII. fig. 4.)

*Description.*—Shell oblique, elongate, anteriorly very short and rounded. Posterior margin oblique, somewhat rounded. Umbones sharp. Surface with concentric lines of growth; and with radiating ribs extending from the umbo to the posterior margin. Size: length=13 mm.; height=6 mm.

*Remarks.*—This species is at present known by one specimen only. It resembles *Arca strehlensis*, Geinitz, from the Pläner-Kalk of Strehlen, but in that form the shell is less oblique, and the surface is generally smooth, except on the anterior part which is marked with radiating ribs.

*Distribution.*—Chalk Rock of Cuckhamsley (Montagu Smith Collection).

#### GENUS LIMOPSIS, Sassi, 1827.

LIMOPSIS sp. (Pl. XXVII. figs. 7 & 8.)

*Description.*—Shell small, oval, convex, a little oblique, wider than long; margins of valves not crenulate. Casts show fine radiating striæ, sometimes crossed by a few shallow concentric furrows. Size: length=8 mm., height=7 mm.

*Remarks.*—At present this species is known only from the casts, so that a complete description cannot yet be given; it seems, however, quite distinct from the other forms. I have not been able to make out the hinge-plate in a satisfactory manner, and it is possible that this species may really belong to *Axinœa*.

*Affinities.*—Römer's<sup>2</sup> *Pectunculus planus* is similar to this species, but the valves are flatter and the umbones less prominent.

*Distribution.*—Chalk Rock of Cuckhamsley.

<sup>1</sup> Sowerby (*non* d'Orbigny) in F. Dixon's 'Geol. Sussex' (1850), p. 355 & pl. xxviii. fig. 11. I have not been able to find the original of Sowerby's figure.

<sup>2</sup> 'Die Verstein. des norddeutsch. Kreidegeb.' 1841, p. 69 & pl. viii. fig. 24.

## Family Mytilidæ, Lamarck.

## Genus MODIOLA, Lamarck, 1799.

## MODIOLA COTTÆ, Römer, 1841. (Pl. XXVII. figs. 9–12.)

1840. *Modiola Cottæ*, H. B. Geinitz, 'Char. der Schicht. u. Petref. des sächs. Kreidegeb.' pt. ii. p. 56, pl. x. f. 5; 1873. H. B. Geinitz, 'Das Elbthälgebirge in Sachsen,' Palæontographica, vol. xx. pt. i. pl. xlvi. f. 4–8, p. 214.

1841. *Mytilus Cottæ*, F. A. Römer, 'Die Verstein. des norddeutsch. Kreidegeb.' p. 66, pl. viii. f. 18; 1843. H. B. Geinitz, 'Die Verstein. von Kieslingswalda,' p. 15; 1846. A. E. Reuss, 'Die Verstein. der böhm. Kreideformat.' pt. ii. p. 14, pl. xxxiii. f. 4; 1850. A. d'Orbigny, 'Prodr. de Pal.' vol. ii. p. 246; 1889. A. Fritsch, 'Stud. im Geb. der böhm. Kreideformat. IV. Die Teplitzer Schichten,' p. 79, f. 66.

1842. ? *Mytilus Cuvieri*, P. Matheron, 'Cat. méth. et descript. des Corps org. foss. du Dép. des Bouches-du-Rhône,' p. 179, pl. xxviii. f. 9 & 10.

1850. *Modiola quadrata*, J. de C. Sowerby, in F. Dixon's 'Geol. Sussex,' p. 347, pl. xxviii. f. 13 [p. 382, 2nd ed.]; 1854. J. Morris, 'Cat. Brit. Foss.' 2nd ed. p. 211.

*Remarks.*—This species was figured by J. de C. Sowerby as *Modiola quadrata*; but I have not been able to find the type, which was stated to come from the Lower Chalk, no locality being mentioned. The figures of *M. Cottæ* given by different authors vary considerably, but a careful comparison of the Chalk Rock specimens with the figures in Geinitz ('Das Elbthälgebirge in Sachsen') and Fritsch leaves practically no doubt that *M. quadrata* is identical with *M. Cottæ*. The type of the latter comes from the Cenomanian of Plauen, near Dresden. In England the species is not common.

*Distribution.*—*England*: Chalk Rock of Winchester, Cuckhamsley, Luton cutting, and Underwood Hall near Dullingham. Upper Chalk of Northfleet. *Saxony*: Cenomanian Pläner of Plauen; Lower Quader Sandstone (Cenomanian) of Golberoda, and Klein-Nauendorf; Pläner-Kalk of Strehlen. *Bohemia*: Teplitz Beds.

## Family Pernidæ, Zittel.

## Genus INOCERAMUS, Sowerby, 1819.

## INOCERAMUS BRONGNIARTI, Sowerby, 1823.

1823. *Inoceramus Brongniarti*, J. de C. Sowerby, 'Min. Conch.' vol. v. pl. ccccxli. f. 2 & 3, p. 60; 1854. J. Morris, 'Cat. Brit. Foss.' 2nd ed. p. 169.

[*Non I. Brongniarti*, G. A. Mantell, 'Foss. S. Downs' (1822), p. 214, pl. xxvii. f. 8.]

1822. *Inoceramus Lamarcki*, G. A. Mantell (*non Parkinson*), 'Foss. S. Downs,' p. 214, pl. xxvii. f. 1.

*Remarks.*—In the present paper I shall refrain from giving a full account of the synonymy and distribution of the species of *Inoceramus* which occur in the Chalk Rock, as I hope to deal at another time with all the species of this genus. The specimen figured by Mantell is different from Parkinson's species, and is probably identical with Sowerby's *Brongniarti*. Mantell's *Brongniarti* appears to be the same as Parkinson's. Sowerby's types (without locality) are preserved in the British Museum, and also the originals of Mantell's *I. Lamarcki*, from near Lewes, and of his *Brongniarti* from Sussex.

*Distribution.*—*England*: Chalk Rock of Cuckhamsley, Old-borough Castle, and Luton. Upper Chalk.

*INOCERAMUS STRIATUS*, Mantell, 1822. (Pl. XXVII, fig. 13.)

1822. *Inoceramus striatus*, G. A. Mantell, 'Foss. S. Downs,' p. 217, pl. xxvii. f. 5; 1828. J. de C. Sowerby, 'Min. Conch.' vol. vi. p. 160, pl. dlxxii. f. 2; 1854. J. Morris, 'Cat. Brit. Foss.' 2nd ed. p. 170; 1872-73. H. B. Geinitz, 'Das Elbthalgeb. in Sachsen,' Palæontographica, vol. xx. pt. i. p. 210, pl. xlvi. f. 9-13; pt. ii. p. 41 (?? pl. xliii. f. 1, 2, 9, 10).

*Remarks.*—The specimens found in the Chalk Rock differ from the types in being less rounded—they are higher than long. If this character be constant it may indicate a different species, but this cannot be determined until a much larger collection has been obtained. At present I have seen only three or four specimens from the Chalk Rock; they agree in form with some which were collected from the Upper Chalk of Newmarket. Size of Chalk Rock specimens:—(1) Length=24 mm.; height=33 mm. (2) Length=30 mm.; height=38 mm.

Both Mantell's and Sowerby's types are in the British Museum; the former was obtained at South Street, Lewes; the latter near Heytesbury (? Lower or Middle Chalk).

*Distribution.*—*England*: Chalk Rock of Roman Road (south-east of Calstone Willington) and Cuckhamsley. Lower, and perhaps also Middle and Upper, Chalk. *Ireland*: Hibernian Greensand—Chloritic Sandstone division (*vide* Tate).

*INOCERAMUS* sp. (Pl. XXVII, figs. 14-17.)

*Remarks.*—A small species, which is unlike any described form with which I am acquainted, but is at present represented by casts only, is moderately common in the Chalk Rock. The shell is rather convex, higher than long, with shallow concentric furrows and prominent pointed umbones.

*Distribution.*—Chalk Rock of Lichfield (Hants), Winchester, Roman Road south-east of Calstone Willington, Cuckhamsley, Luton cutting, Wallington near Baldock, and Underwood Hall near Dullingham.

Family *Ostreidæ*.

Genus *OSTREA*, Linnæus, 1766.

*OSTREA SEMIPLANA*?, Sowerby, 1825.

1825. *Ostrea semiplana*, J. de C. Sowerby, 'Min. Conch.' vol. v. pl. ccclxxxix. f. 3. p. 144.

*Remarks.*—The genus *Ostrea* is poorly represented in the Chalk Rock. The specimens which I believe to be referable to *O. semiplana* are rather small, and this probably accounts for the fact that the plications of the marginal part of the valves are only faintly indicated. Sowerby's types came from Norwich, and are now in the British Museum.

*Distribution.*—*England*: Upper and Middle Chalk; Chalk Rock of Cuckhamsley, and Underwood Hall near Dullingham. *Ireland*: Hibernian Greensand. *Northern France*: zone of *T. gracilis* in the Yonne and Aube, zone of *Epiaster brevis* at Thiernu, zone of *M. breviporus* at Cambrai, Senonian of the neighbourhood of Epernay and

Reims. *Aachen*: *Quadrata*- and *Mucronata*-beds. *North-western Germany*: Senonian of Salzberg, Cœsfeld, etc. *Saxony*: Cenomanian of Plauen, Pläner-Kalk of Strehlen and Weinböbla. *Silesia*: Cenomanian of Bladen. *Bohemia*: Weissenberg, Malnitz, Iser, Teplitz, and Priesen Beds. *Bavaria*: Kagerhöb Beds. *Galicia*: Chalk of Nagorzany and Lemberg.

Family Pectinidæ, Lamarck.

GENUS CHLAMYS, Bolten, 1798.

CHLAMYS TERNATA (Goldfuss), 1833.

1833. *Pecten ternatus*, A. Goldfuss, 'Petref. Germ.' vol. ii. p. 52, pl. xci. f. 13; 1841. F. A. Römer, 'Die Verstein. des norddeutsches. Kreidegeb.' p. 53; 1842. H. B. Geinitz, 'Char. d. Schichten u. Petref. des sächs.-böhm. Kreidegeb.' pt. iii. p. 83; 1850. A. d'Orbigny, Prodr. de Pal. vol. ii. p. 252; 1889. O. Griepenkerl, 'Die Verstein. der Senon. Kreide von Königslutter,' Paläont. Abhandl. vol. iv. p. 43.

1837. *Pecten septemplicatus*, F. Dujardin (*non* Nilsson), Mém. Soc. géol. France, vol. ii. p. 227, pl. xvi. f. 11.

1841. *Pecten Dujardini*, F. A. Römer, 'Die Verstein. des norddeutsches. Kreidegeb.' p. 53; 1843-47. A. d'Orbigny, 'Pal. Franç. Terr. Crét.' vol. ii. p. 615, pl. ccccxxxix. f. 5-11; 1846 ?? A. E. Reuss, 'Die Verstein. der böhm. Kreideformat.' pt. ii. p. 30, pl. xxxix. f. 17; 1850. J. de C. Sowerby, in F. Dixon's 'Geol. Sussex,' p. 356, pl. xxviii. f. 4; 1850. A. d'Orbigny, 'Prodr. de Pal.' vol. ii. p. 251; 1850. H. B. Geinitz, 'Das Quadersandsteingeb. oder Kreidegeb. in Deutschland,' p. 184; 1854. J. Morris, 'Cat. Brit. Foss.' 2nd ed. p. 176; 1870. F. Römer, 'Geol. von Oberschlesien, p. 340, pl. xxix. f. 2, pl. xxxvii. f. 5; 1870. F. J. Pictet & G. Campiche, 'Foss. du Terr. Crét. de Ste. Croix,' Matér. Pal. Suisse, ser. 5, pt. iv. p. 219; 1872. H. B. Geinitz, 'Das Elbthalgeb. in Sachsen,' Paläontographica, vol. xx. pt. ii. p. 36, pl. x. f. 10-12; 1877. A. Fritsch, 'Stud. im Gebiete der böhm. Kreideformat. II. Die Weissenberg. u. Malnitzer Schichten,' p. 136, f. 137; 1883. A. Fritsch, 'Stud. im Gebiete der böhm. Kreideformat. III. Die Iersschichten,' p. 116; 1889. Fritsch, *ibid.* IV. 'Die Teplitzer Schichten,' p. 85; 1893. Fritsch, *ibid.* V. 'Die Priesener Schichten,' p. 100; 1893. R. Michael, Zeitschr. d. Deutsch. geol. Gesellsch. vol. xlv. p. 242.

1842. ? *Pecten squamifer*, H. B. Geinitz, 'Char. d. Schichten u. Petref. des sächs.-böhm. Kreidegeb.' pt. iii. p. 83, pl. xxi. f. 5; 1850 ? Geinitz, 'Das Quadersandsteingeb. oder Kreidegeb. in Deutschland,' p. 184.

*Remarks.*—I have seen only two specimens of this form from the Chalk Rock. The species was founded by Goldfuss on a cast from the Quader Sandstone of Schandau. A specimen from Touraine was described by Dujardin as *P. septemplicatus*, Nilsson, but it was shown to be distinct from that species by Römer, who changed the name to *P. Dujardini*, by which it has since been generally known. Geinitz's *P. squamifer* and Reuss's *P. Dujardini* appear to be distinct from this species.

*Distribution.*—*England*: Chalk Rock of Winchester, and Clothall near Baldock. Upper Chalk of Sussex (*vide* Morris). *France*: zone of *Micraster breviporus* at Cambrai, zone of *Epiaster brevis* east of the Paris basin, zones of *Spondylus truncatus* and *Sp. spinosus* in Loir-et-Cher, zone of *Micraster cor-testudinarium* in the Nord, Upper Chalk of Tours (Indre-et-Loire). *Saxony*: Middle Quader Sandstone (*Inoceramus labiatus*-beds) of Rottwernsdorf and Gross-Cotta, Upper Pläner of Kritzschwitz near Pirna, Glauconitic Sandstone (*Brongniarti*-beds), and Pläner-Kalk of Strehlen and Weinböbla. *Silesia*: *Scaphites*-beds of Oppeln. *Bohemia*: Weissenberg, Malnitz, Iser, Teplitz, and Priesen Beds. *Bavaria*: Kagerhöb Beds.

## Family Limidæ, d'Orbigny.

## Genus LIMA, Chemnitz, 1784.

## LIMA GRANOSA, Sowerby, 1850.

1850. *Lima granosa*, J. de C. Sowerby in F. Dixon's 'Geol. Sussex,' p. 347, pl. xxviii. ff. 24 & 25 [p. 382, 2nd ed.]; 1854. J. Morris, 'Cat. Brit. Foss.' 2nd ed. p. 171.

*Remarks.*—Sowerby does not state from what locality his specimens came, and I have not been able to find the type. I have seen only two examples from the Chalk Rock.

*Distribution.*—*England*: Chalk Rock of Winchester (coll. R. M. Brydone). Chalk of Sussex. Upper Chalk of Norwich.

## Subgenus PLAGIOSTOMA, Sowerby, 1812.

## LIMA (PLAGIOSTOMA) HOPERI, Mantell, 1822.

1822. *Plagiostoma Hoperi*, G. A. Mantell, 'Foss. S. Downs,' p. 204, pl. xxvi. f. 2, 3, 15; 1822. J. Sowerby, 'Min. Conch.' vol. iv. p. 111, pl. cclclxxx; 1850. var., J. de C. Sowerby in F. Dixon's 'Geol. Sussex,' p. 345, pl. xxvii. f. 21 (p. 383, 2nd ed.).

1822. *Plagiostoma Mantelli*, A. Brongniart, 'Descr. géol. des Environs de Paris,' p. 600, pl. iv. f. 3; 1839. H. B. Geinitz, 'Char. d. Schichten u. Petref. des sächs. Kreidegeb.' p. 24.

1836. *Lima Mantelli*, A. Goldfuss, 'Petref. Germ.' vol. ii. p. 92, pl. civ. f. 9; 1841. F. A. Römer, 'Die Verstein. des norddeutsch. Kreidegeb.' p. 58; 1846. H. B. Geinitz, 'Grundriss der Verstein.' p. 472, pl. xx. fig. 13; 1847. R. Kner, 'Verstein. des Kreidemerg. v. Lemberg,' Haidinger's Naturwiss. Abhandl. vol. iii. pt. ii. p. 29. 1877? A. Fritsch, 'Stud. im Gebiete der böhm. Kreideformat. II. Die Weissenb. u. Malnitzer Schichten,' p. 134, f. 122.

1825. *Pachyostoma Hoperi*, DeFrance, 'Dict. des Sci. naturelles,' vol. xxxvii. p. 207.

1827. *Plagiostoma punctatum*, S. Nilsson, 'Petref. Suecana,' p. 24, pl. ix. f. 1; 1837. W. Hisinger, 'Lethæa Suecica,' p. 54, pl. xv. f. 3.

1830. *Lima Hoperi*, G. P. Deshayes, 'Encycl. méth., Hist. nat. des Vers,' vol. ii. p. 349; 1836. A. Goldfuss, 'Petref. Germ.' vol. ii. p. 91, pl. civ. f. 8; 1836. G. P. Deshayes & H. Milne-Edwards, 'Hist. nat. des Animaux sans Vert.' (Lamarck, 2nd ed.) vol. vii. p. 120; 1838. H. G. Bronn, 'Lethæa Geogn.' 2nd ed. vol. ii. p. 682, pl. xxxii. f. 8; 1839. H. B. Geinitz, 'Char. der Schicht. u. Petref. des sächs. Kreidegeb.' p. 24; 1841. F. A. Römer, 'Die Verstein. des norddeutsch. Kreidegeb.' p. 58; 1846. H. B. Geinitz, 'Grundriss der Verstein.' p. 473, pl. xx. f. 14; 1846. A. E. Reuss, 'Die Verstein. der böhm. Kreideformat.' pt. ii. p. 34, pl. xxxviii. f. 11 (? 12); 1850. A. Alth, 'Geogn.-pal. Beschreib. der nächst. Umgeb. von Lemberg,' Haidinger's Naturwiss. Abhandl. vol. iii. pt. ii. p. 240; 1850. H. B. Geinitz, 'Das Quaderstandst. oder Kreidegeb. in Deutschland,' p. 192; 1854. J. Morris, 'Cat. Brit. Foss.' 2nd ed. p. 171; 1863. A. v. Strombeck, 'Zeitschr. d. Deutsch. geol. Gesellsch. vol. xv. p. 148; 1863. R. Drescher, *ibid.* vol. xv. p. 355; 1869. E. Favre, 'Descr. des Moll. Foss. de la Craie des Envir. de Lemberg,' p. 137, pl. xii. f. 19; 1870. F. Römer, 'Geol. von Oberschles.' p. 315, pl. xxxiv. f. 10; 1870. F. J. Pictet & G. Campiche, 'Foss. du Terr. Crét. de Ste. Croix,' ser. 5, pt. iv. Matér. Paléont. Suisse, pp. 171, 173; 1872. H. B. Geinitz, 'Das Elbthalgeb. in Sachsen,' Palæontographica, vol. xx. pt. ii. p. 40, pl. ix. f. 11 & 12; 1877. A. Fritsch, 'Stud. im Gebiete der böhm. Kreideformat. II. Die Weissenb. u. Malnitzer Schichten,' p. 134, f. 121; 1882. H. Schröder, 'Zeitschr. d. Deutsch. geol. Gesellsch. vol. xxxiv. p. 263; 1887. A. Peron, 'Notes pour servir à l'Hist. du Terr. de Craie,' Bull. Soc. des Sci. hist. et nat. de l'Yonne, ser. 3, vol. xii. p. 149; 1889. E. Holzapfel, 'Die Mollusken der Aachen. Kreide,' Palæontographica, vol. xxxv. p. 240, pl. xxvii. f. 5; 1889. A. Fritsch, 'Stud. im Gebiete der böhm. Kreideformat. IV. Die Teplitzer Schichten,' p. 84, f. 78; 1893. A. Fritsch, *ibid.* V. 'Die Priesener Schichten,' p. 100; 1895. B. Lundgren, 'Molluskfauna i Mammillatus- och Mucronata-zonerna i nordöstra Skåne,' K. Svenska Vet.-Akad. Handl. n. f. xxvi. no. 6, p. 62. [Non 1843-47. *Lima Hoperi*, A. d'Orbigny, 'Pal. Franç. Terr. Crét.' vol. iii. p. 564, pl. ccccxxiv. f. 10-13.]

1893. ? *Lima* sp., cf. *Hoperi*, R. Michael, 'Zeitschr. d. Deutsch. geol. Gesellsch. vol. xlv. p. 234.

1850. *Lima Sowerbyi*, H. B. Geinitz, 'Das Quadersandst. oder Kreidegeb. in Deutschland,' p. 192; 1851. J. Müller, 'Mon. der Petrefact. der Aachener Kreideformat.' pt. ii. p. 67; 1851-52. H. G. Bronn, 'Lethæa Geogn.' 3rd ed. vol. ii. p. 278, pl. xxxii. f. 8; 1870. F. J. Pictet & G. Campiche, 'Foss. du Terr. Crét. de Ste. Croix,' ser. 5, pt. iv., Matér. Paléont. Suisse, p. 173; 1872. H. B. Geinitz, 'Das Elbthalgeb. in Sachsen,' Palæontographica, vol. xx. pt. ii. p. 41, pl. ix. f. 13 & 14; 1883. A. Fritsch, 'Stud. im Gebiete der böhm. Kreideformat. III. Die Iserschichten,' p. 115, f. 87.

1841. *Lima Nilssoni*, F. A. Römer 'Die Verstein. des norddeutsch. Kreidegeb.' p. 57.

1842. *Lima Goldfussi*, F. v. Hagenow, Leonhard's Neues Jahrb. p. 555.

1892. *Lima (Plagiostoma) Hoperi*, E. Stolley, 'Die Kreide Schleswig-Holsteins,' Mitth. aus dem Min. Inst. Univ. Kiel, vol. i. p. 237; 1888. O. Griepenkerl, 'Die Verstein. der Senon. Kreide von Königsutter,' Paläont. Abhandl. vol. iv. p. 40.

*Remarks.*—The ornamentation varies considerably in this species. In some examples the shell is almost smooth, except near the anterior and posterior margins; in others the whole surface is marked with pitted grooves, which, however, are usually less distinct near the centre than on the anterior and posterior parts of the shell. There is every gradation between these two extremes; in some cases the differences are due to imperfect preservation. Some specimens show the ornamentation near the umbo, but not on the rest of the shell.

Geinitz considers that Sowerby's *L. Hoperi* is distinct from Mantell's; the former (which he names *L. Sowerbyi*) is for the most part smooth; the latter possesses grooves over the whole surface. These differences, as I have pointed out above, are not of specific value; there can be no doubt whatever that Mantell's fig. 2 is the same species as Sowerby's, and moreover Sowerby received his specimens from Mantell. The examples figured by both authors came from Lewes: Sowerby's specimens are in the British Museum, but I have not seen Mantell's.

The species described by Brongniart as *Plagiostoma Mantelli* was considered by Mantell<sup>1</sup> to be identical with *L. Hoperi*.

Different specimens of *L. Hoperi* show a considerable amount of variation in the relative proportions of the length and height, some being higher than long, others longer than high.

*Distribution.*—*England*: Chalk Rock and Upper Chalk—*not* common in the former. Chalk Rock of Luton cutting, Westley Waterless, and Underwood Hall near Dullingham. *Ireland*: White Limestone. *France*: zone of *Micraster breviporus* at Cambrai; zone of *Epiaster brevis* at St. Clément and Guise; zone of *M. coranguinum* at Banogne and Lezennes. *Belgium*: Senonian of Limbourg. *Aachen*: *Mucronata*-beds of Vaals and Henry-Chapelle. *Westphalia*: Senonian of Cöesfeld; *Mucronata*-beds of Haldem, etc.; *Quadrata*-beds of Ilsenburg; *Scaphites*-beds of Quedlinburg; and *Inoceramus Brongniarti*-Pläner. *Brunswick*: Upper Senonian of Königsutter. *Saxony*: Pläner-Kalk of Strehlen and Weinböhl. *Silesia*: *Scaphites*-beds of Oppeln. *Schleswig-Holstein*: *Quadrata*-beds of Lägerdorf. *Bohemia*: Weissenberg, Malnitz, Teplitz, and Priesen Beds. *Bavaria*: Grossberg Beds. *Galicia*: Chalk of Nagorzany (Lemberg). *Scania*: *Mammillatus*-zone of Ignaberga, etc.

<sup>1</sup> Trans. Geol. Soc. ser. 2, vol. iii. (1835) p. 206.

Subgenus *ACESTA*, Adams, 1855.*LIMA* (*ACESTA*?) *SUBABRUPTA*, d'Orbigny, 1850.

1845. *Lima abrupta*, A. d'Orbigny (*non* Goldfuss), 'Pal. Franç. Terr. Crét.' vol. iii. p. 559, pl. cccxxxiii. f. 6-9.

1850. *Lima subabrupta*, A. d'Orbigny, 'Prodr. de Pal.' vol. ii. p. 167; 1870. F. J. Pictet & G. Campiche, 'Foss. du Terr. Crét. de Ste. Croix,' Matér. Pal. Suisse, ser. 5, pt. iv. p. 169.

*Remarks.*—I have seen only two imperfect specimens of this species; it has not been previously recorded in England.

*Distribution.*—*England*: Chalk Rock of Winchester. *Northern France*: in the zones of *Scaphites æqualis*, *Pachydiscus peramplus*, and *Spondylus truncatus* of Loir-et-Cher.

## Family Spondylidæ, Gray.

Genus *SPONDYLUS*, Linnæus, 1766.*SPONDYLUS SPINOSUS* (Sowerby), 1814.

1814. *Plagiostoma spinosa*, J. Sowerby, 'Min. Conch.' vol. i. p. 177, pl. lxxviii. f. 1-3; 1822. G. A. Mantell, 'Foss. S. Downs,' p. 203, pl. xxvi. f. 10; 1822. A. Brongniart, Descr. géol. des Envir. de Paris,' pp. 251, 320, pl. iv. f. 2.

1827. *Plagiostoma spinosum*, S. Nilsson, 'Petrif. Suecica,' p. 25; 1833? (young), S. Woodward, 'Geol. Norfolk,' p. 40, pl. v. f. 25; 1837. W. Hisinger 'Lethæa Suecica,' p. 54, pl. xv. f. 4.

1819. ? *Spondylus podopsideus*, J. B. de Lamarck, 'Animaux sans Vert.' vol. vi. p. 194.

1819. ? *Plagiostoma sulcata*, J. B. de Lamarck, 'Animaux sans Vert.' vol. vi. p. 161.

1820. *Pectinites aculeatus*, E. T. v. Schlotheim, 'Die Petrefactenkunde,' p. 228.

1822. ? *Plagiostoma brightonensis*, G. A. Mantell, 'Foss. S. Downs,' p. 204, pl. xxv. f. 15.

1825. *Pachyotus spinosus*, Defrance, 'Dict. des Sciences nat.' vol. xxxvii. p. 207, pl. lxxviii. f. 2, pl. lxxix. f. 1.

1825. ? *Pachyotus striatus*, Defrance, 'Dict. des Sciences nat.' vol. xxxvii. p. 207.

1836. *Spondylus spinosus*, A. Goldfuss, 'Petref. Germ.' vol. ii. p. 95, pl. cv. f. 5;

1838. H. G. Bronn, 'Lethæa Geogn.' p. 684, 2nd ed. (p. 280, vol. ii. 3rd ed.), pl. xxxii. f. 6; 1839. H. B. Geinitz, 'Char. d. Schicht. u. Petref. des sächs. Kreidegeb.' pt. i. p. 24; 1841. F. A. Römer, 'Die Verstein. des norddeutsch. Kreidegeb.' p. 58;

1843-47. A. d'Orbigny, 'Pal. Franç. Terr. Crét.' vol. iii. p. 673, pl. cccclxi. f. 1-4; 1846. H. B. Geinitz, 'Grundriss der Verstein.' p. 474; 1846. A. E. Reuss, 'Die Verstein. der böhm. Kreideformat.' pt. ii. p. 36; 1849. H. B. Geinitz, 'Das Quadersandst. in Deutschl.' p. 196; 1850. A. d'Orbigny, 'Prodr. de Pal.' vol. ii. p. 254;

1850? A. Alth, 'Geogn.-pal. Beschreib. der nächst. Umgeb. von Lemberg,' Haidinger's Naturwiss. Abhandl. vol. iii. pt. ii. p. 250; 1854. J. Morris, 'Cat. Brit. Foss.' 2nd ed. p. 182; 1869? E. Favre, 'Moll. Foss. de la Craie des Envir. de Lemberg,' p. 158; 1870. F. Römer, 'Geol. von Oberschlesien,' p. 315, pl. xxiv. f. 11; 1872.

H. B. Geinitz, 'Das Elbthalgeb. in Sachsen,' Palæontographica, vol. xx. pt. ii. p. 31, pl. ix. f. 1-3; 1889. A. Fritsch, 'Stud. im Gebiete der böhm. Kreideformat.' IV. Die Teplitzer Schichten,' p. 85, f. 81; 1889. E. Holzappel, 'Die Mollusken der Aachener Kreide,' Palæontographica, vol. xxxv. p. 243, pl. xxvii. f. 12 & 13.

1836. *Spondylus duplicatus*, A. Goldfuss, 'Petref. Germ.' vol. ii. p. 95, pl. cv. f. 6

1839. H. B. Geinitz, 'Char. d. Schicht. u. Petref. des sächs. Kreidegeb.' pt. i. p. 25

1841. F. A. Römer, 'Die Verstein. des norddeutsch. Kreidegeb.' p. 58.

1854. ? *Spondylus brightonensis*, J. Morris, 'Cat. Brit. Foss.' 2nd ed. p. 182.

1877. *Spondylus spinosus* var. *duplicatus*, A. Fritsch, 'Stud. im Gebiete der böhm. Kreideformat. II. Die Weissenberger u. Malnitzer Schichten,' p. 138, f. 132.

1881. *Lima spinosa*, R. Etheridge, in Penning & Jukes-Browne's 'Geol. neighb. of Cambridge,' Mem. Geol. Surv. pp. 65, 69 & 72.

*Remarks.*—This species is fairly common in the Chalk Rock. In Westphalia it is a characteristic fossil of the *Reussianum*-zone, and in Saxony of the *Scaphites*-beds. Sowerby's types are preserved in the British Museum, but I have not been able to trace the specimens figured by Mantell. Judging from the figure alone, I think it probable that Mantell's *Plagiostoma brightonensis* will prove to be identical with this species. *Sp. spinosus* shows considerable variation in proportions and in the number of spines, but there is a perfect gradation between the different forms.

In various Memoirs of the Geological Survey of England (for example, nos. 15, 17, 21, 25, & 31 of the bibliographic list given on p. 71 of Part I. of this paper) this species has been referred to the genus *Lima*, but I do not know on what grounds, since it differs from *Lima* in the inequality of the valves, the absence of the area on the right valve, and the character of the ornamentation. As long ago as 1828 it was clearly shown by Deshayes<sup>1</sup> that this and other Cretaceous species on which the genera *Dianchora*, Sowerby,<sup>2</sup> *Podopsis*, Lamarck,<sup>3</sup> and *Pachytos*, DeFrance,<sup>4</sup> were founded, differ from *Spondylus* only in the fact that certain parts of the shell have been removed by water in solution. Deshayes states that the shell in existing species is formed of an outer thin layer and an inner thick layer, and that the former is absent on the area. The inner layer has been removed from the Chalk specimens, and this accounts for the thinness of their shells, and the absence of the muscular impression and area. The greater solubility of the inner layer is due to the fact that it consists of aragonite,<sup>5</sup> whereas the outer layer is calcite. The triangular opening under the umbo, which results from the removal of the area, was regarded by Sowerby as having served for the passage of the byssus; but, since these forms were attached by the left valve, an organ of fixation would have been useless. In no case have I seen the teeth of *Sp. spinosus*, but certain casts, which probably belong to this species, give indications of them. Since the area is missing, the teeth would obviously not be found on the left valve; a specimen of the right valve in the Wiltshire Collection (Woodwardian Museum) shows distinctly the interior of the shell and the hinge-line, but there are no teeth visible; another specimen which I cleaned out agrees with this one. The absence of teeth is explained by the circumstance that they consist entirely of aragonite: a section of *Sp. aurantius*, Lamk., which I have had prepared shows this clearly. The section is cut perpendicular to the hinge-line, and passes through a tooth, the area, and the umbo. The thin outer layer referred to by Deshayes consists of fine prisms arranged obliquely and rather irregularly; it does not pass beyond the umbo. The inner layer

<sup>1</sup> Ann. Sci. Nat. vol. xv. (1828) p. 427; also 'Coq. Foss. des Envir. de Paris,' vol. i. (1830) p. 318.

<sup>2</sup> 'Min. Conch.' vol. i. (1815) p. 183.

<sup>3</sup> 'Hist. nat. des Animaux sans Vert.' vol. vi. pt. i. (1819) p. 194.

<sup>4</sup> 'Dict. Sci. Nat.' vol. xxxvii. (1825) p. 207.

<sup>5</sup> Sorby, Pres. Addr., Quart. Journ. Geol. Soc. vol. xxxv. (1879) Proc. p. 60.

near the middle of the valve is about three times the thickness of the outer layer; it possesses an indistinct and irregular prismatic structure, but a high power shows two sets of fibres crossing each other obliquely; this layer is traversed by numerous parallel tubes placed at right angles to the surface, but at the umbo, where the shell is thicker, they radiate outward so as to become perpendicular to the outside of the shell. This layer thins out on the area towards the hinge-line. The teeth and the main part of the area are formed of large distinct prisms placed more or less parallel to the surface, but bending inward, and they are crossed obliquely by tubules. On the outer surface of the area is a thin layer which tapers in passing from the hinge-line, and is absent in the neighbourhood of the umbo; this layer has a finer structure, and under a high power appears to be fibrous; it is not traversed by tubules.

*Distribution.*—*England*: in the upper part of the Middle Chalk (namely: zones of *Terebratulina gracilis*, *Holaster planus*, & *Heteroceras Reussianum*), and throughout the Upper Chalk. Chalk Rock (*Reussianum*-zone) of Shalcombe and Brixton (Isle of Wight), Winchester, Cuckhamsley, Bledlow, Wycombe, Princes Risborough, Boxmoor, Luton, Reed, Barkway, Great Chesterford, Westley Waterless, and Underwood Hall near Dullingham. *Ireland*: Hibernian Greensand (Chloritic Sandstone division) and White Limestone. *France*: zone of *Inoceramus labiatus* at Joigny (Yonne), etc.; zone of *Terebratulina gracilis* at Hauteville, Cyosing, in the Yonne and Aube, etc. zone of *Micraster breviporus* of Cambrai, and at Partout (Yonne). zone of *Holaster planus*, east of the Paris basin; zone of *Epiaster brevis* at Guise, etc.; zones of *Spondylus spinosus* and *Sp. truncatus* in Loir-et-Cher; zone of *Micraster cor-anguinum* at Lezennes. *Belgium*: Hervien of Limbourg. *North-western Germany*: zone of *Heteroceras Reussianum* in Westphalia. *Saxony*: Pläner-Kalk of Strehlen, Weinböbla, etc.; *Brongniarti*-Pläner of Cottauer Berge; and the Glauconitic Marl and Pläner. *Silesia*: *Scaphites*-beds of Oppeln. *Bohemia*: Weissenberg, Malnitz, and Teplitz Beds. *Bavaria*: Kagerhöh Beds.

### SPONDYLUS LATUS (Sowerby), 1815.

1815. *Dianchora lata*, J. Sowerby, 'Min. Conch.' vol. i. p. 184, pl. lxxx. f. 2; 1822. G. A. Mantell, 'Foss. S. Downs,' p. 205, pl. xxvi. f. 21.

1822. ? *Dianchora obliqua*, G. A. Mantell, 'Foss. S. Downs,' p. 206, pl. xxv. f. 1 & pl. xxvi. f. 12.

1836. *Spondylus lineatus*, A. Goldfuss, 'Petref. Germ.' vol. ii. pl. cvi. f. 3, p. 97; 1839. H. B. Geinitz, 'Char. d. Schichten u. Petref. des sächs. Kreidegeb.' pt. i. p. 25 (pl. xx. f. 39?); 1841. F. A. Römer, 'Die Verstein. des norddeusch. Kreidegeb.' p. 59; 1846. A. E. Reuss, 'Die Verstein. der böhm. Kreideformat.' pt. ii. p. 36, pl. xl. f. 7-9; 1847. J. Müller, 'Petref. der Aachener Kreideformat.' pt. i. p. 34; 1850. H. B. Geinitz, 'Das Quadersandsteingeb. in Deutschl.' p. 194 (*partim*); 1850. A. d'Orbigny, 'Prodr. de Pal.' vol. ii. p. 254; 1850? A. Alth, 'Geogn.-pal. Beschreib. der nächst. Umgeb. von Lemberg,' Haidinger's Naturwiss. Abhandl. vol. iii. pt. ii. p. 250; 1869? E. Favre, 'Moll. Foss. de la Craie des Envir. de Lemberg,' p. 158.

1841. *Spondylus latus*, F. A. Römer, 'Die Verstein. des norddeusch. Kreidegeb. p. 59; 1842. H. B. Geinitz, 'Char. d. Schichten u. Petref. des sächs.-böhm. Kreidegeb. pt. iii. p. 82; 1850. J. de C. Sowerby in F. Dixon's 'Geol. Sussex,' p. 356, pl. xxviii. f. 30 & 31; 1854. J. Morris, 'Cat. Brit. Foss.' 2nd ed. p. 182; 1872. H. B. Geinitz, 'Das Elbthalegeb. in Sachsen,' Paläontographica, vol. xx. pt. i. p. 187, pl. xlii. f. 4-6

& pt. ii. p. 32, pl. viii. f. 18-21; 1877. A. Fritsch, 'Stud. im Gebiete der böhm. Kreideformat. II. Die Weissenberger u. Malnitzer Schichten,' p. 138; 1889. Fritsch, *ibid.* IV. 'Die Teplitzer Schichten,' p. 86, f. 82; 1889. E. Holzappel, 'Die Mollusken der Aachener Kreide,' *Palæontographica*, vol. xxxv. p. 244, pl. xxvii. f. 11, 14; 1892. E. Stolley, 'Die Kreide Schleswig-Holsteins,' *Mitth. a. d. mineralog. Institut der Univ. Kiel*, vol. i. p. 236.

1842. *Spondylus obliquus*, H. B. Geinitz, 'Char. d. Schichten u. Petref. des sächs.-böhm. Kreidegeb.' pt. iii. p. 82; 1846. A. E. Reuss, 'Die Verstein. der böhm. Kreideformat.' p. 36, pl. xl. f. 4; 1850. H. B. Geinitz, 'Das Quadersandsteingeb. in Deutschl.' p. 194 (*partim*).

1870. *Spondylus striatus*, F. Römer, 'Geol. von Oberschlesien,' p. 315, pl. xxxvii. f. 3 & 4.

*Remarks.*—This species is much less common in the Chalk Rock than is *Sp. spinosus*. Sowerby's type came from the Chalk of Lewes, and is now in the British Museum, as is also the specimen figured by Dixon. Mantell's *Dianchora obliqua* (from near Lewes and Brighton) is probably identical with this species, but I have not been able to find the type.

*Affinities.*—*Sp. latus* is related to *Sp. striatus*, Sowerby, the type of which comes from the Warminster Greensand (Rye Hill Sand<sup>1</sup>); but its length is proportionately greater, it is more oval, and the ribs are finer and more numerous.

*Distribution.*—*England*: Lower and Middle Chalk (zones of *Terebratulina gracilis*, *Holaster planus*, & *Heteroceras Reussianum*), and Upper Chalk. Chalk Rock of Brixton, Winchester, Cuckhamsley, Thickthorn Hill (Bledlow), Boxmoor. *France*: zone of *Terebratulina gracilis*, at Voulpaix, in the Yonne and Aube, etc.; zone of *Micraster cor-anguinum* at Lezennes. *North-western Germany*: in the zone of *Heteroceras Reussianum*. *Aachen*: *Mucronata*-beds of Schneeberg. *Saxony*: Unter-Pläner (Upper Cenomanian) of Gross-Sedlitz near Pirna; Pläner-Kalk of Strehlen and Weinböhla. *Silesia*: *Scaphites*-beds of Oppeln. *Schleswig-Holstein*: *Quadrata*-beds (Senonian) of Lägerdorf. *Bohemia*: Teplitz Beds.

### Genus Plicatula, Lamarck, 1801.

Plicatula BARROISI, Peron, 1887. (Pl. XXVII. figs. 18 & 19.)

1846. *Plicatula pectinoides*, A. E. Reuss (*non* Sowerby), 'Die Verstein. der böhm. Kreideformat.' pt. ii. p. 37, pl. xxxi. f. 16 & 17.

1872. *Plicatula nodosa*, H. B. Geinitz (*non* Dujardin), 'Das Elbthalgeb. in Sachsen,' *Palæontographica*, vol. xx. pt. ii. p. 32, pl. ix. f. 5; 1878. C. Barrois, 'Terr. Crét. des Ardennes,' *Ann. Soc. géol. Nord*, vol. v. p. 391; 1889. A. Fritsch, 'Stud. im Gebiete der böhm. Kreideformat. IV. Die Teplitzer Schichten,' p. 86, f. 83; 1895. *Plicatula cf. nodosa*, B. Lundgren, 'Molluskfaunan i Mammill.- och *Mucron.*-zonerna i nordöstra Skåne,' *K. Svenska Vet.-Akad. Handl. n. s.* vol. xxvi. no. 6, p. 41.

1887. *Plicatula Barroisi*, A. Peron, 'Notes pour servir à l'Hist. du Terr. de Craie,' *Bull. Soc. Sci. hist. nat. de l'Yonne*, ser. 3, vol. xii. p. 167, pl. ii. f. 5-7.

*Remarks.*—D'Orbigny<sup>2</sup> considered that this species (which was figured by Reuss as *P. pectinoides*) was identical with *P. nodosa*, Dujardin,<sup>3</sup> and this view has been adopted by Geinitz and Fritsch. Barrois pointed out that the species under consideration differs considerably from *P. nodosa*, and Peron has since described it under

<sup>1</sup> See Jukes-Browne, *Geol. Mag.* 1896, p. 261.

<sup>2</sup> 'Prodr. de Pal.' vol. ii. (1850) p. 254.

<sup>3</sup> *Mém. Soc. géol. France*, vol. ii. (1837) p. 228 & pl. xv. f. 14.

the name of *P. Barroisi*. The only English specimens that I have seen were collected by Mr. R. M. Brydone. *P. nodosa* itself comes from Touraine.

*Affinities*.—*P. nodosa*, Dujardin, differs from *P. Barroisi* in being about four times larger, more elongated, and ornamented with large, simple, widely-separated ribs.

*Distribution*.—*England*: Chalk Rock of Winchester. *France*: zones of *Belemnitella plena*, *Inoceramus labiatus*, *Terebratulina gracilis*, *Epiaster brevis*, & *Belemnitella quadrata*, north and east of the Paris basin. *Savony*: Pläner-Kalk of Strehlen. *Bohemia*: Reuss's specimens came from the Pläner-Kalk and Pyrope-Sand of Triziblit, and the Pläner-Mergel of Weberschan. Fritsch's examples are from the Teplitz Beds.

### Family Cardiidæ, Lamarck.

#### Genus CARDIUM, Linnæus, 1758.

#### CARDIUM TURONIENSE, sp. nov. (Pl. XXVII. figs. 20–22.)

*Description*.—Shell small, oblique, oval, inflated, higher than long; umbones prominent. Ornamented with plain ribs, separated by furrows of about the same width; with indistinct pits in the furrows. About ten ribs in a space of 3 mm. Size of a specimen: length=6 mm.; height=7 mm.

*Affinities*.—The ornamentation is coarser and the shell more oblique than in *C. lineolatum*, Reuss. The ornamentation is somewhat similar to that in *C. cenomanense*, d'Orbigny, but the ribs are less numerous than in that species, and the form of the shell is quite different.

*Remarks*.—This is a rare species; the only forms seen are in the Montagu Smith Collection.

*Distribution*.—Chalk Rock of Cuckhamsley.

#### CARDIUM sp., cf. CENOMANENSE, d'Orb. (Pl. XXVII. figs. 23 & 24.)

1843–47. A. d'Orbigny, 'Pal. Franç. Terr. Crét.' vol. iii. p. 37 & pl. ccxlix. f. 5–9.

*Remarks*.—A species of *Cardium*, agreeing in form with *C. cenomanense*, is represented by several specimens from Cuckhamsley, but all are in the condition of internal casts, so that their determination must remain doubtful for the present. Size of a specimen: length=9 mm.; height=9 mm.; thickness=8 mm.

*Distribution*.—Chalk Rock of Cuckhamsley (Montagu Smith Collection.)

#### CARDIUM sp., cf. MAILLEANUM, d'Orbigny.

1843–47. A. d'Orbigny, 'Pal. Franç. Terr. Crét.' vol. iii. p. 40 & pl. ccxvi. f. 7–12.

*Remarks*.—There is one specimen in the Montagu Smith Collection which probably belongs to this species, but only a small portion of the shell on the posterior part of the right valve is preserved.

*Distribution*.—Chalk Rock of Cuckhamsley. D'Orbigny obtained specimens from the Lower Chalk of Rouen, etc.

## Family Astartidæ, Gray.

Genus *CARDITA*, Bruguière, 1789.*CARDITA CANCELLATA*, sp. nov. (Pl. XXVIII. figs. 2-5.)

Cf. *C. tenuicosta*, F. Nötling (*non* Sowerby), 'Die Fauna der baltisch. Cenoman-Geschiebe,' Paläont. Abhandl. vol. ii. (1885) p. 29 & pl. v. f. 4; and Geinitz, 'Das Elbthalgelände in Sachsen,' Paläontographica, vol. xx. pt. ii. pl. xvii. f. 11-13.

*Description.*—Shell oval, somewhat inflated, with the part from the umbo to the posterior margin slightly depressed; a little longer than high. Anterior side shorter and smaller than the posterior. Ventral margin curved. Ornamentation cancellated, consisting of numerous concentric and radiating ribs—the two sets being of about equal size. Size of an average specimen: length=16 mm.; height=14 mm.

*Remarks.*—This is a fairly common species at Cuckhamsley, but seems to be rare in other places.

*Affinities.*—This species is related to *C. tenuicosta*, Sowerby, found in the Gault, but that form has a more quadrangular and compressed shell, and its ornamentation consists of radiating ribs only, crossed by growth-lines.

*Distribution.*—Chalk Rock of Cuckhamsley, Thickethorn Hill (Bledlow), and Luton.

## Family Arcticidæ, Newton.

Genus *ARCTICA*, Schumacher, 1817.*ARCTICA QUADRATA* (d'Orbigny), 1843. (Pl. XXVII. fig. 25; Pl. XXVIII. fig. 1.)

1840. *Isocardia cretacea*, H. B. Geinitz, 'Char. d. Schicht. u. Petref. des sächs. Kreidegeb.' pt. ii. p. 53, pl. xi. f. 6 & 7.

1843. *Cyprina quadrata*, A. d'Orbigny, 'Pal. Franç. Terr. Crét.' vol. iii. p. 104, pl. cclxxvi.; 1850. A. d'Orbigny, 'Prodr. de Pal.' p. 161; 1850. H. B. Geinitz, 'Das Quadersandst. oder Kreidegeb. in Deutschland,' p. 156; 1869. F. J. Pictet & G. Campiche, 'Foss. des Terr. Crét. de Ste. Croix,' Matér. Pal. Suisse, ser. 5, pt. iii. p. 225, pl. cxv. f. 3-5; 1877? A. Fritsch, 'Stud. im Gebiete der böhm. Kreideformat. II. Die Weissenberger u. Malnitzer Schichten,' p. 116, f. 76; 1873. H. B. Geinitz, 'Das Elbthalgel. in Sachsen,' Paläontographica, vol. xx. pt. ii. p. 62, pl. xvii. f. 14-16; 1883. A. Fritsch, 'Stud. im Gebiete der böhm. Kreideformat. III. Die Iserschichten,' p. 100, f. 65; 1895. E. Tiessen, Zeitschr. der Deutsch. geol. Gesellsch. vol. xlvii. p. 486.

*Remarks.*—This species was founded by d'Orbigny on casts from the French Cenomanian. Mr. Jukes-Browne has sent me specimens from the Chloritic Marl of Chard, one of which has the shell preserved. I have seen only four specimens from the Chalk Rock; one (fig. 25) is in the form of an internal mould of both valves, but the others have a considerable portion of the shell present. The latter agree with the Chard specimen, and the internal mould is like d'Orbigny's figure.

*Affinities.*—Geinitz considers that d'Orbigny's *Cyprina ligeriensis* and *C. Noueliana* are identical with this species. *C. Noueliana* was founded on a cast. D'Orbigny considered that his *C. quadrata* was

distinguished from *C. ligeriensis* by its more quadrate form, the short anterior part of the shell, and the larger posterior part. The type of *quadrata* is a more convex shell than *ligeriensis*.

The species under consideration differs from *C. regularis* in the umbones being more oblique and the posterior margin more truncated.

*Distribution.*—*England*: Chloritic Marl of Chard; Chalk Rock of Morgan's Hill near Devizes, Cuckhamsley, and Luton cutting. *France*: Cenomanian of Rouen; zone of *Pecten asper* at Savigny; zone of *Ammonites laticlavus* at Blanc-Nez. *Switzerland*: 'Grès vert supérieur' of Ste. Croix. *Saxony*: Cenomanian Pläner of Plauen; *Brongniarti* Quader Sandstone of Posta, etc.; Pläner-Kalk of Strehlen and Weinböhl. *Bohemia*: Weissenberg, Malnitz, and Iser Beds.—*Bavaria*: Regensburg Beds.

ARCTICA? *EQUISULCATA*, sp. nov. (Pl. XXVIII. figs. 6–8.)

*Description.*—Shell moderately convex, subquadrate, oblique; umbones pointed, rather anterior. Shell rather thick, ornamented with numerous regular, parallel, concentric grooves—about 15 in 10 mm. Hinge unknown. Adductor-impressions well marked. Approximate size: length=32 mm.; height=29 mm.

*Remarks.*—This species is imperfectly known at present, but since the ornamentation appears to be quite distinct I have ventured to give it a specific name. There are seven examples of it in the Montagu Smith Collection, six being internal casts.

*Distribution.*—Chalk Rock of Cuckhamsley.

Genus *TRAPEZIUM*, Megerle v. Mühlfeldt, 1811.

*TRAPEZIUM TRAPEZOIDALE* (Römer), 1841. (Pl. XXVIII. figs. 9 & 10.)

1841. *Crassatella trapezoidalis*, F. A. Römer, 'Die Verstein. des norddeutsch. Kreidegeb.' p. 74, pl. ix, f. 22; 1846. A. d'Archiac, Mém. Soc. géol. France, ser. 2, vol. ii. p. 302.

1849. *Cyprina trapezoidalis*, H. B. Geinitz, 'Das Quadersandst. in Deutschl.' p. 158 (*partim*); 1873. H. B. Geinitz, 'Das Elbthalgebirge in Sachsen,' Paläontographica, vol. xx. pt. i. p. 229, pl. 1. f. 6 (? f. 5).

1850. *Cypricardia trapezoidalis*, A. d'Orbigny, 'Prodr. de Pal.' vol. ii. p. 240; 1889? E. Holzappel, 'Die Mollusken der Aachener Kreide,' Paläontographica, vol. xxxv. p. 179.

*Description.*—Shell inflated, trapezoidal, anteriorly short and rounded, posteriorly elongate and angular. Ventral margin slightly curved, nearly parallel to the hinge-line. Posterior margin nearly straight, forming an obtuse angle with the hinge-margin. Umbones much curved, reaching almost to the end of the hinge-line. A sharp carina, gently curved, extends from the umbo to the posterior angle, and cuts off a slightly concave and triangular area. Surface with concentric lines.

*Remarks.*—This is a very rare species in the Chalk Rock; all the specimens seen are casts, but one shows a small fragment of shell. The type is stated by Römer to have come from the Pläner-Kalk of Strehlen; but Geinitz has never found the species in that locality.

*Affinities.*—The shell in *Cypricardia galiciana*, E. Favre<sup>1</sup> (from near Lemberg), is relatively shorter, more ovoid, and the umbones less recurved. *Crassatella tricarinata*, Römer,<sup>2</sup> is also more ovoid than *trapezoidalis*, and the umbones are less anterior in position.

*Distribution.*—*England*: Chalk Rock of Cuckhamsley, Princes Risborough, Thickthorn Hill (Bledlow), and Luton cutting. *Ireland*: White Limestone. *Saxony*: Cenomanian of Plauen (*vide* Geinitz); Pläner-Kalk of Strehlen (*vide* Römer). *Bavaria*: Kagerhöh Beds of Kagerhöh.

TRAPEZIUM RECTANGULARE, sp. nov. (Pl. XXVIII. figs. 11 & 12.)

*Description.*—Shell oblong, moderately convex, anteriorly short and rounded, posteriorly elongate. Hinge-margin and the ventral margin nearly straight and parallel. Posterior margin nearly straight, and almost at right angles to the hinge-margin. Umbones not prominent. Carina obtuse, extending in a curve from the umbo to the posterior angle, and cutting off a triangular and slightly convex area. In the interior a septum extends from the umbo towards the anterior-ventral margin. Size of a specimen: length = 19 mm.; height = 11 mm.

*Affinities.*—The shell in this species is flatter than in *T. trapezoidale*, the umbones are less prominent, and the posterior margin forms a right angle with the hinge-margin. It differs from *T. parallelum*, Alth.,<sup>3</sup> in being relatively shorter, in the anterior part being very short, and in the ventral margin being nearly straight.

*Distribution.*—I have seen only four examples of this species, all of which come from Cuckhamsley, and are in the Montagu Smith Collection. A small piece of shell is preserved on one specimen, and is almost smooth.

### Family Lucinidæ, Deshayes.

#### Genus CORBIS, Cuvier, 1817.

CORBIS? MORISONI, sp. nov. (Pl. XXVIII. figs. 13 & 14.)

*Description.*—Shell much inflated, rounded, inequilateral, slightly longer than wide. Umbones moderately prominent, close together, curved anteriorly. Surface with well-marked lines of growth. Hinge unknown. Size of a specimen: length = 14 mm.; height = 13 mm.

*Remarks.*—I have seen only two specimens of this species; one is a cast of the left valve, the other is a right valve with a portion of the shell preserved. With this limited material at my disposal it is impossible to give a full description of the characters of this species.

*Distribution.*—Chalk Rock of Cuckhamsley.

<sup>1</sup> 'Descr. Moll. Foss. de la Craie des Envir. de Lemberg en Galicie,' 1869, p. 109 & pl. xii. f. 3.

<sup>2</sup> 'Die Verstein. des norddeutsch. Kreidegeb.' (1841) p. 74 & pl. ix. f. 23.

<sup>3</sup> 'Geogn.-pal. Beschreib. der nächst. Umgeb. v. Lemberg,' Haidinger's Naturwiss. Abhandl. vol. iii. pt. ii. (1850) p. 229 & pl. xii. f. 8.

## Family Pholadidæ, Leach.

Genus *MARTESIA*, Leach, 1824.

*MARTESIA*? *ROTUNDA* (Sowerby), 1850. (Pl. XXVIII. figs. 15–18.)

1850. ? *Teredo rotundus*, J. de C. Sowerby in F. Dixon's 'Geol. Sussex,' p. 346, pl. xxviii. f. 27 & 28.

*Description.*—Umbonal groove well marked, only a little oblique; in front of it the surface is ornamented with strong radiating ribs crossed by finer and closer concentric ribs; just behind the groove are two radiating ribs and on the rest of the shell concentric grooves only are seen.

The cast of the interior is oval in form, narrowing posteriorly, rounded in front and apparently also behind; it shows that the large anterior gape was closed by a callus; behind the umbonal groove is a cast of a ridge or process extending towards the posterior margin. Size of the cast: length=7 mm.; height=5.5 mm.

*Remarks.*—I have seen only one specimen of this, consisting of a perfect internal cast and a mould of a portion of the exterior; it is not sufficiently perfect to enable me to determine the genus with certainty; but I think that, on the whole, it is more likely to be *Martesia* than *Pholadidea*. Sowerby figured, under the name of *Teredo rotundus*, a fragment from the Chalk of Kent showing the ornamentation, and also a cast; from the former, I believe it is probable that the Chalk Rock specimen belongs to the same species, but I have not been able to confirm this view by an examination of the type, which appears to have been lost.

*Distribution.*—Chalk Rock of Cuckhamsley.

## Family Cuspidariidæ, Fischer.

Genus *CUSPIDARIA*, Nardo, 1840.

*CUSPIDARIA CAUDATA* (Nilsson), 1827. (Pl. XXVIII. figs. 19 & 20.)

1827. *Corbula caudata*, S. Nilsson, 'Petref. Suecana,' p. 18, pl. iii. f. 13; 1837. W. Hisinger, 'Lethæa Suecica,' p. 66, pl. xix. f. 12; 1840. A. Goldfuss, 'Petref. Germ.' vol. ii. p. 251, pl. cli. f. 17; 1846. A. E. Reuss, 'Die Verstein. der böhm. Kreideformat.' pt. ii. p. 20, pl. xxxvi. f. 23; 1847. R. Kner, 'Verstein. Kreidemerg. von Lemberg,' Haidinger's Naturwiss. Abhandl. vol. iii. pt. ii. p. 25, pl. v. f. 3; 1850. H. B. Geinitz, 'Das Quadersandsteingeb. in Deutschl.' p. 150; 1850. A. d'Orbigny, 'Prodr. de Pal.' vol. ii. p. 238; 1850? var., A. Alth, 'Geogn.-pal. Beschreib. der nächst. Umgeb. v. Lemberg,' Haidinger's Naturwiss. Abhandl. vol. iii. p. 237, pl. xii. f. 22; 1863. A. v. Strombeck, Zeitschr. Deutsch. geol. Gesellsch. vol. xv. p. 147; 1873. H. B. Geinitz, 'Das Elbthalgeb. in Sachsen,' Palæontographica, vol. xx. pt. ii. p. 67, pl. xxiii. f. 19; 1877? A. Fritsch, 'Stud. im Gebiete der böhm. Kreideformat. II. Die Weissenberger u. Malnitzer Schichten,' p. 125, f. 107; 1882. H. Schröder, Zeitschr. Deutsch. geol. Gesellsch. vol. xxxiv. p. 275; 1889. Fritsch, 'Stud. im Gebiete der böhm. Kreideformat. IV. Die Teplitzer Schichten,' p. 81; 1893. Fritsch, *ibid.*, 'V. Die Priesener Schichten,' p. 96.

1839–53. *Neæra caudata*, G. P. Deshayes, 'Traité Élément. de Conchyliol.' vol. i. p. 192; 1864. F. J. Pictet & G. Campiche, 'Foss. du Terr. Crét. des Envir. de Ste. Croix' (Pal. Suisse, ser. ix.), p. 42; 1869. E. Favre, 'Moll. Foss. de la Craie des Envir. de Lemberg,' p. 102, pl. xi. f. 8; 1885. F. Nötling, 'Die Fauna der baltischen Cenoman-Geschiebe,' Palæont. Abhandl. vol. ii. p. 35, pl. vi. f. 7; 1889. O. Griepenkerl, 'Die Verstein. d. Senon. Kreide v. Königslutter,' Palæont. Abhandl. vol. iv. p. 69.

1850. *Leda pulchra*, J. de C. Sowerby, in F. Dixon's 'Geol. Sussex,' p. 346 (p. 382, 2nd ed.), pl. xxviii. f. 10; 1854. *Leda*? *pulchra*, J. Morris, 'Cat. Brit. Foss.' 2nd ed. p. 205.

*Remarks.*—I have seen only one example of this from the Chalk Rock, which is in the Montagu Smith Collection; it shows the concentric ribs, although the shell is not preserved. This specimen agrees perfectly with Sowerby's figure of *Leda pulchra*, but I have not succeeded in tracing the type of that species; it is stated to have come from the 'Chalk of Kent.' The English specimens, and also the figures given by Goldfuss and Reuss, differ from the type in having the posterior part of the shell much shorter; this, however, is probably due to the preservation of the shell in Nilsson's original specimen.

*Affinities.*—Stoliczka<sup>1</sup> states that this species is closely allied to his *Neera detecta* (from the Ootatoor Group), 'but it has the posterior end still narrower and longer, and the beaks incurved in a direction perpendicular to the longitudinal axis of the shell.'

*Distribution.*—Chalk of Kent (horizon unknown). Chalk Rock of Cuckhamsley. *Westphalia*: zone of *Ammonites caesfeldensis* (Upper Senonian) of Cæsfeld. *Saxony*: Pläner-Kalk of Strehlen. *Bohemia*: in the Weissenberg, Malnitz, and Teplitz Beds (*vide* Fritsch). *Bavaria*: Grossberg Beds of Marterberg near Passau. *Galicja*: Nagorzany, near Lemberg (*vide* Favre).

#### IV. DISTRIBUTION AND RELATIONS OF THE FAUNA.

I have already pointed out that the fauna of the *Reussianum*-zone has a wide range in Europe; it can be recognized, although showing differences in passing from one region to another, in Northern France, North-western Germany (Westphalia, Brunswick), Saxony, Upper Silesia, Bohemia, and Bavaria. But, though traceable in countries so distant as England and Bohemia, it is, I believe, absent from the Belgian area; this is probably to be accounted for by the very different conditions under which the Cretaceous Series was deposited in Belgium. I hope, however, to recur to this point after I have had further opportunities of studying the rocks of that country.

The area over which the *Reussianum*-zone can be traced undoubtedly formed part of one life-province in the Cretaceous seas; this province seems to have remained fairly constant throughout the Chalk period; it included what Munier-Chalmas<sup>2</sup> has termed the second or temperate zone, which he considers to have been especially characterized, in Senonian and Upper Turonian times, by the great development of the echinoids *Micraster* and *Echinocorys*.

Just as is the case in so many formations, the cephalopoda of the *Reussianum*-zone have a much wider geographical range than the gasteropoda and lamellibranchia; this is no doubt accounted for by their more active mode of life. Of the 10 species of cephalopods present in the *Reussianum*-zone in this country, 7 occur in Saxony and 6 in Bohemia; but of the 16 gasteropods only 2 (or perhaps 3) are found in Saxony and 2 in Bohemia; of the 29 species of lamellibranchs about half have been recognized in Saxony and 11

<sup>1</sup> 'Cret. Fauna S. India,' Pal. Indica, vol. iii. (1870) p. 46, pl. iii. f. 7 & pl. xvi. f. 15.

<sup>2</sup> Comptes Rendus, vol. cxiv. (1892) p. 851.









or 12 in Bohemia. So far as I know, no species of cephalopod, with the exception of *Nautilus sublevigatus*, d'Orb., is common to the Chalk Rock and the Belgian Cretaceous beds.

The palæontological characters of the *Reussianum*-zone as seen in England are well maintained in the 'Zone of *Heteroceras Reussianum* and *Spondylus spinosus*' (Schlüter) of North-western Germany. This is especially true as regards the cephalopoda, which have been so carefully described by Prof. Schlüter; the gasteropoda and lamellibranchia, however, are not so abundant nor so well preserved, and have not yet been studied in detail.

In Saxony, the Pläner-Kalk of Strehlen (near Dresden) contains the fauna we are now considering, with, perhaps, that of part of a lower zone also. That rock can no longer be studied at Strehlen, the site of the old exposure having been built over. The fossils, however, have been fully described and figured in Geinitz's great work, 'Das Elbthalgebirge in Sachsen,' and the originals are preserved in the Dresden Museum. Even allowing for the possibility that the Pläner-Kalk includes a little more than the *Reussianum*-zone, the number of species in that part of it is still considerably greater than in the same zone in England. This is indeed what we should expect from the fact that the Upper Cretaceous rocks of Saxony were deposited in shallower water and much nearer the shore-line than were those of the same age in England. The greater richness of the fauna is seen particularly in the Lamellibranchia, Gasteropoda, and Fishes; of these three groups Geinitz describes about 50, 30, and 28 species respectively. There is no important difference in the number of forms of Cephalopoda, Brachiopoda, Echinoidea, and Actinozoa in the two countries; but in the Pläner-Kalk the Asteroidea, Crinoidea, and Reptilia, which, so far as I know (with the exception of a single specimen of *Pentacrinus*), are not found in the Chalk Rock at all, are each represented by one or two species.

The genera of gasteropods and lamellibranchs which are present in the Pläner-Kalk, but unknown in the Chalk Rock, are:—

<i>Patella.</i>	<i>Anomia.</i>	<i>Crassatella.</i>
<i>Rissoa.</i>	<i>Glycimeris.</i>	<i>Venus.</i>
<i>Turritella.</i>	<i>Pinna.</i>	<i>Isocardia.</i>
<i>Acteon.</i>	<i>Gervillia.</i>	<i>Eriphyla.</i>

The species which are found in the Chalk Rock, but not in the Pläner-Kalk of Strehlen, are:—

<i>Ptychoceras Smithi</i> , Woods.	<i>Dentalium turoniense</i> , Woods.
<i>Heteroceras</i> sp.	<i>Arca</i> cf. <i>Galliennei</i> , d'Orb.
<i>Emarginula Sanctæ-Catharinæ</i> , Passy.	<i>Limopsis</i> , sp.
"    aff. <i>divisiensis</i> , Gard.	<i>Lima granosa</i> , Sow.
<i>Trochus Schlüteri</i> , Woods.	"    ( <i>Acesta?</i> ) <i>subabrupta</i> , d'Orb.
" <i>berocscirensis</i> , Woods.	<i>Cardium turoniense</i> , Woods.
<i>Turbo gemmatus</i> , Sow.	"    cf. <i>cenomanense</i> , d'Orb.
" <i>Geinitzi</i> , Woods.	"    cf. <i>Mailleanum</i> , d'Orb.
<i>Cerithium cuckhamiense</i> , Woods.	<i>Cardita cancellata</i> , Woods.
" <i>Saundersi</i> , Woods.	<i>Arctica?</i> <i>equisulcata</i> , Woods.
<i>Aporrhais (Lispedesthes) Mantelli</i> , Gard.	<i>Trapezium rectangulare</i> , Woods.
<i>Lampusia?</i> sp.	<i>Corbis?</i> <i>Morisoni</i> , Woods.
<i>Avellana</i> cf. <i>Humboldti</i> , Müll.	<i>Martesia?</i> <i>rotunda</i> (Sow.).

The fauna of the *Reussianum*-zone in Bohemia is apparently also richer than in our own country, but at present it is not possible in all cases to say definitely which species come from that zone. In the Tables showing the range of the mollusca (facing p. 394, and Part I. pp. 92, 93), it will be noticed that some species, which in other areas have a very limited range, pass through all or nearly all the divisions in Bohemia. I believe that these divisions ('Weissenberg Beds' etc.) are, to a large extent, geographical, rather than zonal, in character.<sup>1</sup>

It would be interesting to compare the English fauna with the Bavarian; but in this case too we meet with a difficulty, since, from the available sources of information, it is not possible to separate all the species found in the Pulverthurm Beds from those of the other divisions of the Kagerh h Beds.

As might be expected, there is no important difference between the fauna of the *Reussianum*-zone in England and in Northern France.

I believe that few, if any, of the species which occur in the *Reussianum*-zone have been identified, without doubt, as occurring in extra-European areas, although some have certainly 'representative forms' elsewhere.

Turning now to our own country, we find that the feature which has struck everyone who has studied this zone is the general resemblance of its fauna to that of the Chalk Marl.—First: ammonoids, gasteropods, and certain groups of lamellibranchs are abundant at both horizons, whereas they are rare or absent in the intervening beds. Secondly: some species are common to the *Reussianum*-zone and the Cenomanian, namely:—

*Nautilus sublævigatus*, d'Orb.

*Crioceras ellipticum* (Mant.).

*Emarginula Sanctæ-Catharinæ*, Passy.

*Pleurotomaria perspectiva* (Mant.).

*Turbo gemmatus*, Sow.

*Aporrhais (Lispodesthes) Mantelli*, Gard.

(?) *Inoceramus striatus*, Mant.

*Spondylus latus* (Sow.).

*Arctica quadrata* (d'Orb.).

Thirdly: allied forms occur at the two horizons, e. g. *Baculites bohemicus*, Fritsch, *Scaphites Geinitzi*, d'Orb., and *Holaster planus* (Mant.) of the higher zone, are closely related to *B. baculoides*, Mant., *S. obliquus*, Sow., and *H. trecensis*, Leym., of the lower zone.

In England, the following species of mollusca are, so far as is known at present, confined to the *Reussianum*-zone:—

*Ptychoceras Smithi*, Woods.

*Heteroceras Reussianum*, d'Orb.

sp.

*Baculites bohemicus*, Fritsch.

*Prionocyclus Neptuni* (Gein.).

*Turbo Geinitzi*, Woods.

*Trochus Schli teri*, Woods.

„ *berocscirensis*, Woods.

*Natica (Naticina) vulgaris*, Reuss.

*Cerithium cuckhamiense*, Woods.

„ *Saundersi*, Woods.

*Avellana* cf. *Humboldti*, M ll.

*Dentalium turoniense*, Woods.

*Nuculana* cf. *siliqua* (Goldf.).

*Arca* cf. *Galliennei*, d'Orb.

„ (*Barbatia*) cf. *Geinitzi*, Reuss.

*Lima (Acesta?) subabrupta*, d'Orb.

*Plicatula Barroisi*, Peron.

*Cardium turoniense*, Woods.

„ cf. *cenomanense*, d'Orb.

„ cf. *Mailleanum*, d'Orb.

*Cardita cancellata*, Woods.

*Arctica? equisulcata*, Woods.

*Trapezium trapezoidale* (R m.).

„ *rectangulare*, Woods.

*Corbis? Morisoni*, Woods.

*Martesia? rotunda* (Sow.).

*Cuspidaria caudata* (Nilss.).

<sup>1</sup> On this subject see J. J. Jahn, 'Einige Beitr ge zur Kenntniss der b hm. Kreideformat.' Jahrb. d. k.-k. geol. Reichsanst. vol. xlv. (1895) p. 125.

One of the most noteworthy points in the mollusca of the *Reussianum*-zone, as compared with those of the Cenomanian, is the rarity in the former, of the three families Ostreidæ, Pectinidæ, and Limidæ. All three are very important in the Lower Chalk.

Whether the *Reussianum*-zone should be regarded as the lowest zone of the Senonian or the highest of the Turonian appears to me to be a point of no great importance. The forms which seem to show that its relations are with the lower rather than the higher division are *Pachydiscus peramplus*, *Crioceras ellipticum*, *Turbo gemmatus*, *Arctica quadrata*, and *Holaster planus*. Others, however—such as *Spondylus spinosus*, *Lima (Plagiostoma) Hoperi*, and the species of *Micraster*, *Cardiaster*, and *Echinocorys*,—link it to the Senonian. Probably the species of *Inoceramus*, when fully worked out, may furnish some evidence of importance on this point. On the whole, I am inclined to think that the affinities of the fauna are closer to the Turonian than to the Senonian.

The absence of crustacea in the Chalk Rock, with the exception of a few specimens of *Pollicipes*, is somewhat remarkable, but the rarity of this class of animals in deposits now forming was noticed by the *Challenger Expedition*,<sup>1</sup> and is attributed to the areolar structure of the exoskeleton, 'which admits of relatively rapid solution after the death of the animal.'

It may be convenient for reference to give here a list of the fossils, other than the mollusca, which are found in the Chalk Rock:—

## PISCES.

- Oxyrhina Mantelli*, Ag.<sup>2</sup>  
*Corax falcatus*, Ag.  
*Ptychodus latissimus*, Ag.  
 „ *mammillaris*, Ag.

## CIRRIPEDIA.

- Pollicipes* sp.

## CHLÆTOPODA.

- Serpula ampullacea*, Sow.  
 „ *plexus*, Sow.  
 „ sp.

## BRACHIOPODA.

- Rhynchonella Cuvieri*, d'Orb.<sup>3</sup>  
 „ *plicatilis* (Sow.).  
 „ „ var. *Woodwardi*,  
 Dav.  
 „ „ var. *octoplicata*  
 (Sow.).  
 „ *reedensis*, Eth.

## BRACHIOPODA (cont.).

- Terebratula carnea*, Sow.  
 „ *semiglobosa*, Sow.  
*Terebratulina striata* (Wahl).  
*Trigonosemus incerta*, ? Dav. (? young specimen).<sup>3</sup>

## CRINOIDEA.

- Pentacrinus Agassizi*, v. Hagen.

## ECHINOIDEA.

- Cardiaster ananchytis* (Leske); elevated variety.  
*Cidaris* sp.  
*Cyphosoma radiatum*, Sorig.  
 „ *spatuliferum*?, Forbes.  
*Echinoconus conicus*, Breyn.  
*Echinocorys vulgaris*, Breyn., var. *gibbus* (Lam.).  
*Holaster planus* (Mant.).  
*Micraster breviporus*, Ag.  
 „ *cor-bovis*, Forbes.

<sup>1</sup> Murray & Renard, *Challenger Rep.* 'Deep-Sea Deposits' (1891), p. 264.

<sup>2</sup> For the determination of this species I am indebted to Mr. A. Smith Woodward, F.G.S.

<sup>3</sup> I am indebted to Mr. J. F. Walker for the determination of these species.

ACTINOZOA.	PORIFERA ( <i>cont.</i> ).
<i>Parasmilia centralis</i> (Mant.).	<i>Placotrema cretaceum</i> , Hinde.
	<i>Plinthosella squamosa</i> , Zitt. <sup>1</sup>
PORIFERA.	<i>Plocoscyphia convoluta</i> (Smith).
<i>Camerospongia campanulata</i> (Smith).	" <i>flexuosa</i> (Mant.).
" <i>subrotunda</i> (Mant.).	<i>Ventriculites alcyonoides</i> , Mant.
<i>Coscinopora infundibuliformis</i> , Goldf.	" <i>angustatus</i> , Röm.
<i>Cystispongia subglobosa</i> , Römer.	" <i>decurrens</i> , Smith.
<i>Guetardia stellata</i> , Mich.	" <i>impressus</i> , Smith.
<i>Leptophragma Murchisoni</i> (Goldf.). <sup>1</sup>	" <i>mammillaris</i> , Smith.
	<i>Verrucocelia tubulata</i> ? (Smith).

#### V. CONDITIONS UNDER WHICH THE CHALK ROCK WAS DEPOSITED.

To endeavour to determine the depth at which a fauna, composed (with the exception of some of the foraminifera) of extinct species, lived, may at first sight appear to be quite hopeless, since we know that at the present day different species of a genus have often very diverse ranges. I believe, however, that by a study of the predominating forms in a fauna, and their association, together with the relative numbers of individuals and species, some conclusions of a trustworthy nature may be arrived at.

That the fauna of the *Reussianum*-zone lived in water of less depth than the faunas of the other Turonian and Senonian zones will, I think, scarcely be disputed. The Chalk Rock is very thin generally, yet fossils are more numerous specifically and far more abundant individually than in the other zones. It is well known that at the present day we find a similar difference in passing from comparatively shallow water to greater depths: the number of species, as well as the number of individuals, living on the sea-bottom, diminishes considerably. In water of no great depth, the nature of the materials forming the sea-bottom has a greater influence on the character of the fauna than has the actual depth of the water.<sup>2</sup> The relative richness of the fauna of the *Reussianum*-zone certainly cannot be accounted for by any difference in the nature of the sea-bottom, since in its original soft state the Chalk-ooze must have been, so far as animal life was concerned, uniform in character throughout the Chalk period. We can, therefore, only conclude that the change in the fauna was caused by a decrease in depth; and, since the change is so marked, the decrease was probably considerable.

The presence of glauconite-grains, which is one of the distinguishing features of this zone, also lends support to the view just stated. The *Challenger* Expedition<sup>3</sup> found that glauconite was 'almost exclusively limited to terrigenous deposits in more or less close proximity to the continental masses of land, while it was relatively

<sup>1</sup> These species are here recorded from information supplied by Mr. Jukes-Browne, whose specimens were determined by Dr. G. J. Hinde, F.R.S.

<sup>2</sup> See especially remarks by W. A. Herdman, Proc. Liverpool Geol. Soc. vol. vii. pt. ii. (1894) p. 171; also Address, Rep. Brit. Assoc. (Ipswich) 1895, p. 698.

<sup>3</sup> Murray & Renard, *Challenger* Rep. 'Deep-Sea Deposits' (1891), p. 382.

rare or wholly absent from pelagic deposits situated towards the centres of great ocean basins. . . . It is also present in samples of *Globigerina*-ooze situated at no great distance from the continents.' 'Glauconite may therefore be regarded as having been formed in deep water not far from the coasts, or in shallow water where no large quantity of continental débris was deposited.' Further, at the present day glauconite is generally associated with phosphate of lime; this is what we find too in the Chalk Rock—it is a nodular phosphatic deposit, containing glauconite.

The rarity or absence of aragonite-organisms, even in the form of casts, in the Upper Chalk, is considered by Mr. P. F. Kendall<sup>1</sup> to be due to the fact that they were, like the shells of pteropods, which form the main part of the modern Pteropod-ooze, dissolved at a particular depth—not less than 1500 fathoms; for if these organisms had remained for a short time on the floor of the Chalk sea, some of them would have left traces of their existence in the form of casts, since the soft Chalk-ooze would easily have filled up the interiors of the shells. If this explanation be correct, then I think we may safely take the abundance of casts of aragonite-organisms (ammonoids, *Nautilus*, etc.) in the *Reussianum*-zone as an indication that it was formed in water of less depth than the Upper Chalk, since the aragonite shells must have become covered up with sediment and were not dissolved until some time afterwards.

We can scarcely doubt that the Chalk Rock was formed beyond the limits of terrigenous deposits, and therefore presumably at a depth of greater than about 100 fathoms. Both palæontological and lithological evidence are entirely in favour of this. The Benthos within the 100-fathom line would have been much richer in species than is our *Reussianum*-zone; just as the fauna of the Pläner-Kalk of Strehlen—particularly the gasteropoda and lamelli-branchia—is more varied than that of the Chalk Rock. If we remember the extremely minute quantity of detrital material which is present in the Chalk Rock, and if we compare a section of that rock with sections of some samples of hardened *Globigerina*-ooze, we can hardly doubt that the two deposits have been formed in the same way.

That the *Reussianum*-zone was not laid down in very deep water is shown by the character of its fauna; not only does it contain a considerable variety of forms, but the number of individuals of any species is, even in the same block of stone, often very large. This is contrary to what is met with in abyssal regions at the present day; thus in the deep-sea Benthos the number of specimens of a species, as well as the number of species, decreases with increasing depth, and, apart from depth, a similar diminution in numbers is noticed in tropical and subtropical regions as the distance from the shore becomes greater. Another point is the large number of gasteropods with thick shells, often of large size (such as *Turbo*, *Pleurotomaria*), in the *Reussianum*-zone; at the present day most

<sup>1</sup> Rep. Brit. Assoc. (Liverpool) 1896, p. 791.

deep-sea animals are characterized by the possession of thin shells, usually of rather small size. It might indeed be urged that the occurrence of thick shells in the Chalk Rock can be explained by the existence of a higher temperature than is found in the deep sea at the present time, since Murray and Irvine<sup>1</sup> have shown that the secretion of carbonate of lime by organisms is directly related to the temperature of the water; but I know of no evidence in favour of the Cretaceous temperature having been high enough to cause any great change at abyssal depths.

In discussing the question of depth from the evidence supplied by the genera of Mollusca which have living representatives we must consider three main points:—(1) the genera which have a limited bathymetrical range; (2) the depths at which the other genera are most numerous; (3) the relative abundance of the genera in the *Reussianum*-zone itself.

So far as their range in depth is concerned, we may conveniently divide the genera into five groups:—

1. The first includes *Crepidula*, *Emarginula*, *Martesia*, *Ostrea*, *Plicatula*, and *Trapezium*, all of which are shallow-water forms and, so far as I know, do not live at a greater depth than 50 fathoms. These genera are all rare, and some of them very rare, in the *Reussianum*-zone, and we cannot therefore take them as a proof that the deposit was formed in such shallow water.<sup>2</sup>
2. *Pleurotomaria*, *Cardita*, and *Arctica* do not live below a depth of 200 fathoms.

*Pleurotomaria* is one of the commonest gasteropods in the *Reussianum*-zone, and its evidence should therefore be of considerable importance. Only four living species are known; they were dredged at various depths between 73 and 200 fathoms. Two species—*P. Adansonia* and *P. Beyrichi*, both of large size—have been found at the greater depth. It is, of course, possible that the range of the genus may have been more extended in Mesozoic times when the number of species reached its maximum; we know, at any rate, that it is very common in several Jurassic formations which are undoubtedly of shallow-water origin.

*Cardita* and *Arctica* are not common in the Chalk Rock; the former extends from the Littoral zone to 150 fathoms, and is found mainly in shallow water; the latter ranges from the Laminarian zone down to about 180 fathoms.

<sup>1</sup> Proc. Roy. Soc. Edin. vol. xvii. (1891) p. 79; J. Murray, 'Summary of Scientific Results (*Challenger* Exped.),' pt. ii. (1895) p. 1456.

<sup>2</sup> With regard to genera which appear to be limited to shallow water, we shall do well to bear in mind the warning given by Starkie Gardner:—'When we reflect that, for one cast of the dredge in abyssal depths, a thousand have perhaps been made in the littoral zone, we must hesitate to pronounce definitely that any genus is without deep-sea species' (Geol. Mag. 1884, p. 497).

3. *Turbo*, *Chlamys*, *Spondylus*, and *Cardium* are not found below the 600-fathom line.

*Turbo* is very common in the *Reussianum*-zone, and one of the species is of considerable size. At the present day the genus extends from the Littoral zone down to 565 fathoms, but, being phytophagous, it is of course most abundant in shallow water.

*Chlamys* is very rare, and *Cardium* not common, in the *Reussianum*-zone; both are abundant in fairly shallow water.

*Spondylus* is rather common, particularly *Sp. spinosus*. The existing species live in warm seas, mainly in the Littoral zone, or at no great depth, but one form, which is, however, quite small, has been found at a depth of 520 fathoms.

4. *Natica* is found down to about 1000 fathoms, but is abundant only at less than 100 fathoms; it is moderately common in the *Reussianum*-zone.

*Modiola* extends down to 800 fathoms, but is not common below 100 fathoms; it is moderately rare in the *Reussianum*-zone.

5. Ten genera—namely, *Trochus*, *Aporrhais*, *Cerithium*, *Dentalium*, *Limopsis*, *Nucula*, *Arca*, *Cuspidaria*, *Nuculana* (= *Leda*), and *Lima*—have species which live at 1000 fathoms or greater depths, but in every case these genera have a great bathymetric range; all occur in shallow water, and nearly all are found in depths of only a few (1 to 5) fathoms.

The living forms of *Trochus*<sup>1</sup> are abundant in the Littoral and Laminarian zones, but the genus is not uncommon in fairly deep water; indeed, Agassiz<sup>2</sup> speaks of the Trochidæ as being well represented in deep water. *Trochus* is, I believe, the commonest gasteropod in the *Reussianum*-zone, nevertheless it is represented by only two species; in water of less than 100 fathoms there would almost certainly have been a larger number of species.

*Aporrhais* is also very common. Existing species are most numerous within the 100-fathom line, and are not common beyond it.

*Cerithium*: there are two species in the Chalk Rock, one being very common. The genus is abundant in the Littoral zone or at no great depth, and rare beyond 100 fathoms.

*Dentalium*: the Dentaliidæ are characteristic of deep water, but also occur in shallow regions. The genus is somewhat rare in the *Reussianum*-zone.

*Nucula* and *Arca* are common in the Chalk Rock; they

<sup>1</sup> Dr. W. F. Hume, 'Nat. Sci.' vol. vii. (1895) p. 391, has stated that the 'presence of *Trochus*, *Turbo*, and *Solarium* in the Chalk Rock is paralleled at the present day by the same association found at Culebra Island at a depth of 390 fathoms.' *Solarium* does not occur in the Chalk Rock, and the association of *Trochus* and *Turbo* proves nothing, since they both occur in the Littoral zone as well as at various greater depths.

<sup>2</sup> 'Three Cruises of the *Blake*,' vol. ii. (1888) p. 67.

are widely distributed in rather shallow water, and have also some abyssal species.

*Cuspidaria* is found in all seas and at all depths, but the species are most abundant in deep water and abyssal regions; since, however, only one specimen has been seen in the Chalk Rock, we cannot take it as evidence of very deep water.

*Nuculana* (= *Leda*) also occurs at all depths, but is rather a characteristic deep-water form.<sup>1</sup> Only two specimens have been found in the Chalk Rock.

To sum up the preceding evidence furnished by the Mollusca, we see that we have in the *Reussianum*-zone some genera (*Cuspidaria*, *Nuculana*, *Dentalium*) which are characteristic of deep water, but are not confined to it; others which are limited to shallow water (0 to 50 fathoms). But neither group forms the predominating element in the *Reussianum*-fauna; we may therefore consider that this zone was not laid down either in shallow or in very deep water. The commonest genera, although at the present day most abundant in shallow or rather shallow water, do occur fairly often in water of moderate depth (say from 100 to 500 fathoms), but these genera, numerous in the *Reussianum*-zone as the individuals may be, are there represented by only one or two species in each case, whereas in shallow water they would almost certainly have been represented by a larger number. I think, therefore, that it is unlikely that the *Reussianum*-zone was formed at a depth greater than about 500 fathoms; this is further supported by the fact that in dredging beyond this depth a marked decrease is noticed in the number of individuals as well as species of both lamellibranchia<sup>2</sup> and brachiopoda.<sup>3</sup>

I consider, then, that the Chalk Rock was laid down between the depths of about 100 and 500 fathoms. From the number of species found in it, several of which belong to genera common in fairly shallow water, I think it was probably deposited somewhat nearer the former than the latter limit, although the depth must necessarily have varied in different places. The absence of the Chalk Rock in Lincolnshire is most likely due to the greater depth of water which existed in that region.

I have not studied in detail the other groups of fossils found in the *Reussianum*-zone. I may, however, mention that the Hexactinellid sponges are well represented, and therefore strongly favour the view that the lower limit was not less than about 100 fathoms,

<sup>1</sup> The occurrence of the genera *Cuspidaria* (= *Neæra*), *Nuculana* (= *Leda*), and *Dentalium* is noteworthy, since Dr. Gwyn Jeffreys and many later writers have regarded the absence of these forms in the Upper Chalk as evidence in favour of its shallow-water origin. On this subject see J. G. Jeffreys, Rep. Brit. Assoc. for 1877 (1878), p. 86; J. S. Gardner, Geol. Mag. 1884, pp. 496-506; A. R. Wallace, 'Island Life,' 2nd ed. (1892) p. 89.

<sup>2</sup> E. A. Smith, 'Report on the Lamellibranchiata,' *Challenger* Exped. (1885) p. 6.

<sup>3</sup> T. Davidson, 'Report on the Brachiopoda,' *Challenger* Exped. (1880) pp. 3, 4.

since they do not live in water of less than 95 fathoms in depth; they are abundant between 95 and 200 fathoms, and also from 301 to 700 fathoms.<sup>1</sup>

#### EXPLANATION OF PLATES XXVII. & XXVIII.

All the specimens figured come from the Chalk Rock, and, unless otherwise stated, are preserved in the Woodwardian Museum (Montagu Smith Collection). The figures are of the natural size, except where otherwise stated.

##### PLATE XXVII.

- Figs. 1 & 2. *Nucula* sp. Internal moulds.  
 Fig. 3. *Arca* sp., cf. *Galliennei*, d'Orbigny. Internal mould.  
 4. *Arca* sp. Internal mould.  
 Figs. 5 & 6. *Arca* (*Barbatia*) sp., cf. *Geinitzi*, Reuss. 5. Wax mould of exterior showing ornamentation. 5a. Portion of same,  $\times 5$ . 6. Internal mould.  
 Figs. 7 & 8. *Limopsis* sp. Internal moulds.  $\times 1\frac{1}{2}$ .  
 Figs. 9-12. *Modiola Cottæ*, Römer. 9, 10. From Winchester (coll. R. M. Brydone). 11. Part of a larger specimen from Luton (collected by the Author). 11a. Portion of shell of the same enlarged, showing the character of the ornamentation,  $\times 6$ . 12. Outline of section of valve of the same specimen.  
 Fig. 13. *Inoceramus striatus*, Mantell.  
 Figs. 14-17. *Inoceramus* sp. Internal moulds. 15. Posterior view of 14.  
 Figs. 18 & 19. *Plicatula Barroisi*, Peron, from Winchester (coll. R. M. Brydone).  $\times 2$ .  
 Figs. 20-22. *Cardium turoniense*, sp. nov. 20. Wax mould,  $\times 1\frac{1}{2}$ . 20a. Portion of same further enlarged, showing the character of the ornamentation,  $\times 5$ . 21. Natural mould,  $\times 1\frac{1}{2}$ . 22. Anterior view of the same,  $\times 1\frac{1}{2}$ .  
 Figs. 23 & 24. *Cardium*, cf. *cenomanense*, d'Orbigny. Internal mould. 24. Anterior view.  
 Fig. 25. *Arctica quadrata* (d'Orbigny). Anterior view of natural mould. Morgan's Hill, near Devizes (coll. A. J. Jukes-Browne).

##### PLATE XXVIII.

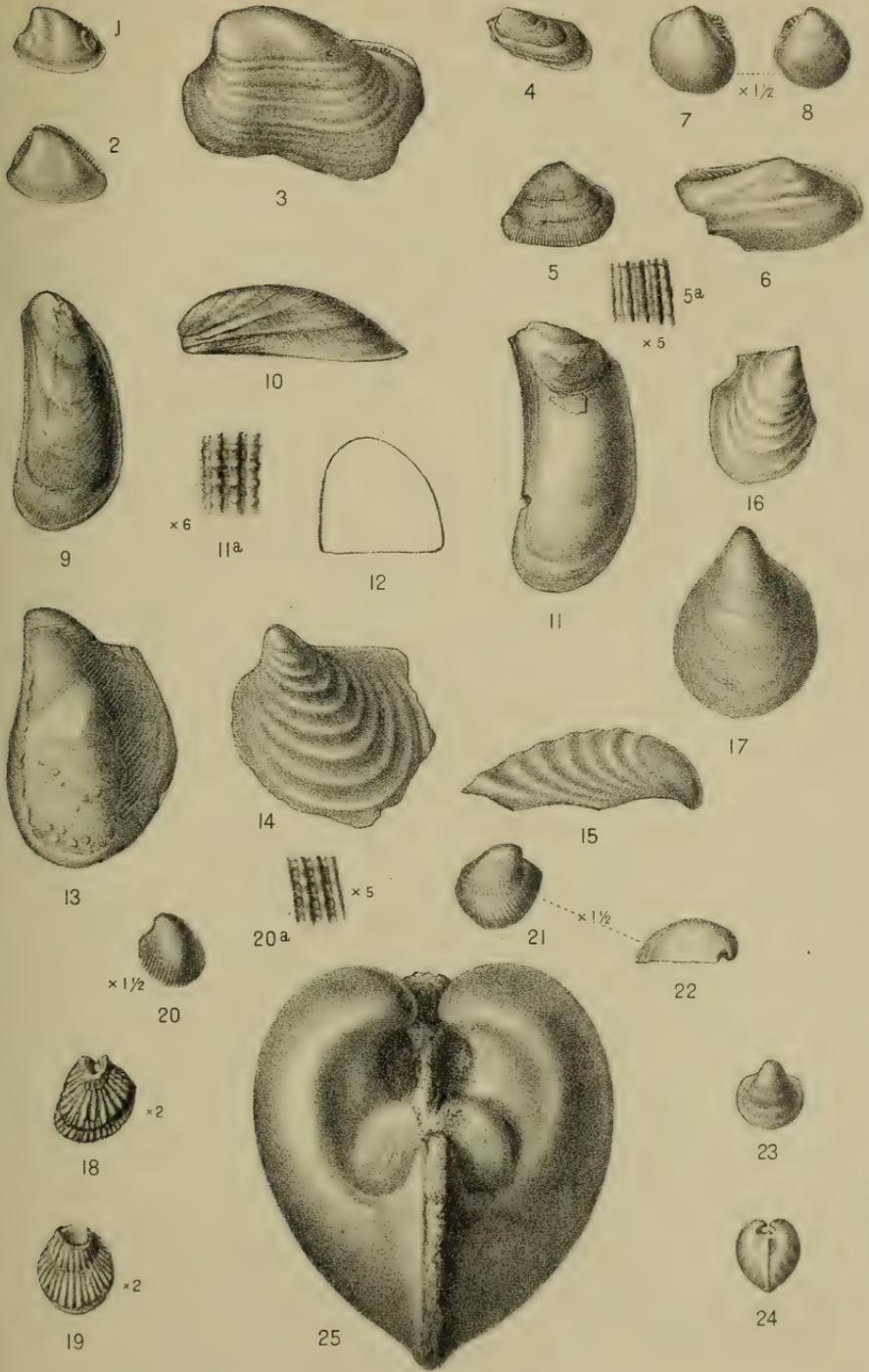
- Fig. 1. *Arctica quadrata* (d'Orbigny). Right valve.  
 Figs. 2-5. *Cardita cancellata*, sp. nov. 2. Wax mould. 3. Portion of same,  $\times 5$ . 4, 5. Natural mould. 4. Anterior view. 5. Left valve.  
 Figs. 6-8. *Arctica?* *equisulcata*, sp. nov. 6. Dorsal view of natural mould. 7. Right valve of same. 8. Left valve, with part of shell preserved. 8a. Portion of same enlarged,  $\times 3$ .  
 Figs. 9 & 10. *Trapezium trapezoidale* (Römer). 9. Left valve. 10. Dorsal surface of the two valves.  
 Figs. 11 & 12. *Trapezium rectangulare*, sp. nov. Internal moulds. 11. Left valve. 12. Dorsal surface of the two valves.  
 Figs. 13 & 14. *Corbis?* *Morisoni*, sp. nov. 13. Right valve. 14. Anterior end.  
 Figs. 15-18. *Martesia?* *rotunda* (Sowerby). 15-17. Internal casts,  $\times 2$ . 15. Dorsal view. 16. Right valve. 17. Anterior end. 18. Wax mould of exterior of right valve,  $\times 2\frac{1}{2}$ .  
 Figs. 19 & 20. *Cuspidaria caudata* (Nilsson). Internal cast. 19. Left valve. 20. Dorsal surface.

<sup>1</sup> F. E. Schultze, 'Report on Hexactinellida,' *Challenger* Exped. (1887) pp. 453-467.

## DISCUSSION.

Dr. W. F. HUME congratulated the Author on the completion of this detailed contribution to our knowledge of the Chalk Rock fauna, and referred to the interest of the records of *Chlamys* and *Arctica* at this horizon. That the nodular condition characteristic of this lithological feature had been formed at some depth was an hypothesis now being generally accepted; but the Author, in discussing the question of the depth at which the deposit had been formed, scarcely seemed to lay sufficient stress on the action of currents, which to the speaker appeared of essential value in the formation of the nodular rock. Analyses carried out recently show that the glauconitic material is generally present only in small quantity, the carbonate of lime in most cases exceeding 90 per cent.; so that the higher bathymetric limit assigned by the Author appears to be the more probable. The repetition of a lower or Cenomanian fauna in the Chalk Rock, to which the Author has again called attention, is one of great interest, and the beds containing these forms should be considered as the true upper limit of the Middle Chalk, all the more arbitrary boundaries adopted having completely broken down.

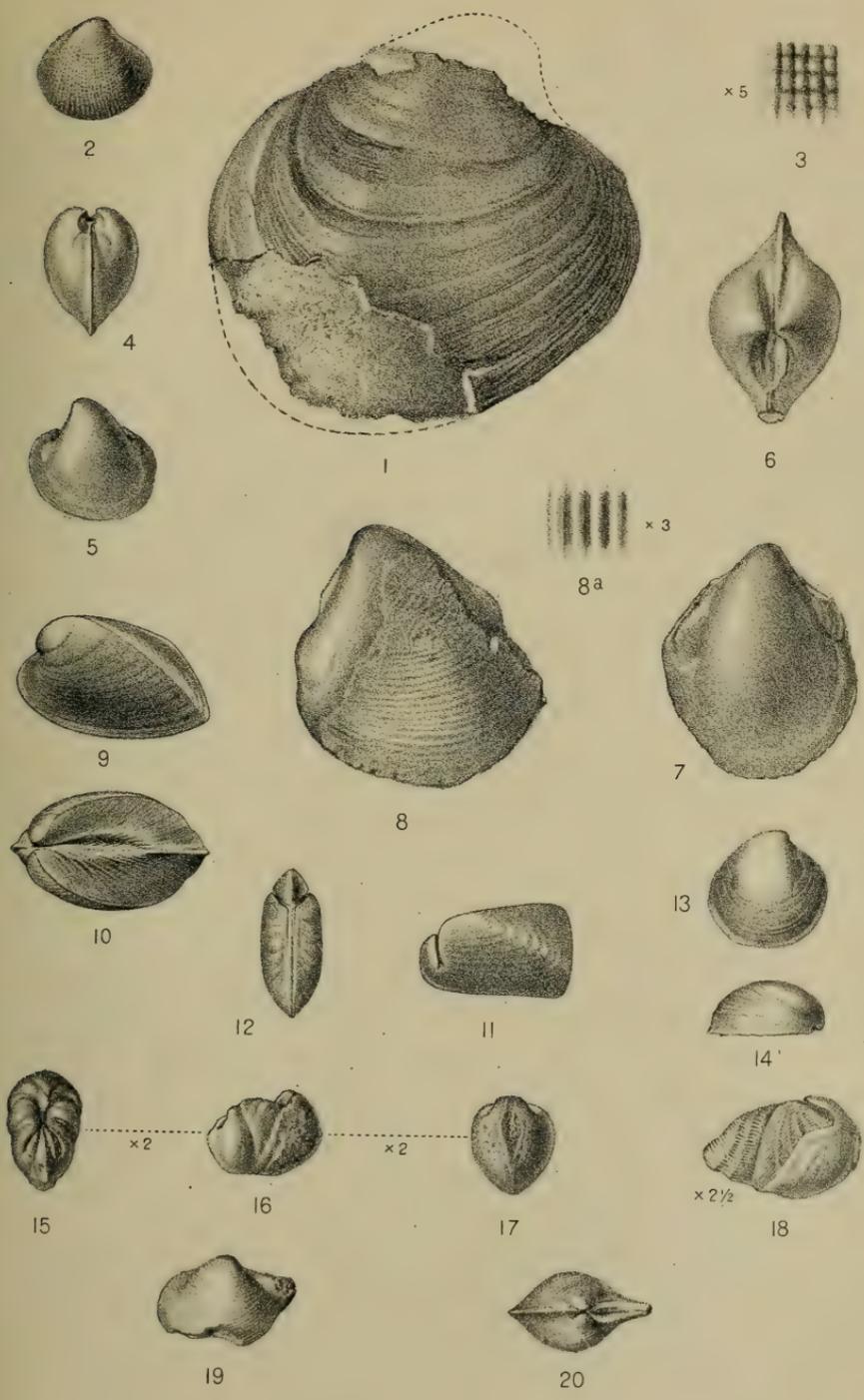
Mr. W. WHITAKER also spoke.



Edwin Wilson, Cambridge

CHALK ROCK MOLLUSCA.





Edwin Wilson, Cambridge.

CHALK ROCK MOLLUSCA.



29. *On AUGITE-DIORITES with MICROPEGMATITE in SOUTHERN INDIA.*  
By THOMAS H. HOLLAND, Esq., A.R.C.S., F.G.S., Officiating  
Superintendent, Geological Survey of India. (Read May 26th,  
1897.)

## [PLATE XXIX.]

## CONTENTS.

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## I. INTRODUCTION.

PRIOR to the great outburst of Deccan trap at the close of the Cretaceous period, there were two principal periods of volcanic activity in Peninsular India. One of these is indicated by the contemporaneous traps of the Dharwars—the oldest of our recognized Transition systems—and the other by the lava-flows of the Cuddapah system, whose precise position in the stratigraphical succession remains, on account of the complete absence of fossils, still undetermined. As a result of the great earth-movements which affected the strata of Peninsular India previous to the deposition of the Cuddapah system, the igneous rocks of Dharwar age have been greatly metamorphosed, and in this respect they stand in striking contrast to the Cuddapah traps, since the eruption of which the Peninsula of India has been remarkably free from geological disturbances. It is evidently in consequence of this remarkable freedom, both from extreme changes of level and the crushing effects of earth-movements, that rocks as old as the Cuddapahs have their original delicate structures, and primary constituents so susceptible as olivine and augite, preserved with striking freshness.

The numerous dykes of basic igneous rocks which break through the 'pyroxene-granulites' and gneisses of the Madras Presidency, and which, for reasons that need not now be stated, are regarded as the dyke-representatives of the Cuddapah lava-flows,<sup>1</sup> vary in composition from very basic olivine-augite norites approaching saxonites, through augite-norites, to augite-diorites with micropegmatite. Detailed descriptions of these and the peculiar hemi-crystalline and vitreous varieties, which form the selvages of the larger masses, or occur as narrow apophyses, are published in the Records of the Geological Survey of India (vol. xxx. pt. i. 1897). It is only with the interesting features displayed by the rocks which I have grouped under Prof. Cole's very convenient term augite-diorite that the present paper is intended to deal.

The augite-diorite dykes occur in various parts of the Madras

<sup>1</sup> 'Manual of the Geology of India,' 2nd ed. (1893) p. 40.

Presidency, but are particularly well-developed in the districts of Chingelput and South Arcot, on the Coromandel coast, where they break through the acid members of the 'pyroxene-granulite' series, and are often traceable for many miles, showing their actual contacts with the older crystallines, or projecting as lines of black hummocks through the alluvium and soil of the 'paddy' fields.

The facts revealed by the microscopic study of these Indian rocks have, it seems to me, the most interesting bearing on the questions raised by the distinguished petrographers who have examined the well-known associations of micropegmatite with basic rocks near Penmaenmawr,<sup>1</sup> in the Charnwood Forest,<sup>2</sup> the Whin Sill,<sup>3</sup> the Cheviot district,<sup>4</sup> Carrock Fell,<sup>5</sup> Carlingford,<sup>6</sup> and Skye.<sup>7</sup>

## II. PETROLOGICAL CHARACTERS OF THE ROCKS.

The central masses of the large dykes are tough, black, even-grained rocks, in which the crystals seldom exceed 5 mm. in length. The specific gravity is remarkably uniform, varying between 3.00 and 3.09. Towards the margins of the dykes the rocks are finer in grain, while the selvages, so far as their microscopic characters are concerned, could not be distinguished from augite-andesites, having a fine-grained, pilotaxitic, and sometimes distinctly hyalopilitic groundmass, through which irregular, glomero-porphyrific groups of augite and plagioclase are scattered.

*Mineral Composition.*—The rocks are composed essentially of augite, plagioclase, and micropegmatite. Enstatite is often present in small quantities, forming the cores of the pyroxene-crystals. Opaque, black iron-ores, hornblende, and biotite in small quantities, and either wholly or in part secondary in origin, present a constant and peculiar relation to the augite and micropegmatite, the significance of which is pointed out below.

*Order of Crystallization of the Constituents.*—Although in the more basic dykes associated with these rocks, and in which enstatite is a prominent constituent, the consolidation of the plagioclase must have been completed invariably after that of the pyroxene, in the augite-diorites now under consideration there is no such distinct difference between the periods of the consolidation of these two minerals. They are intergrown with a want of regularity which indicates an average simultaneous crystallization, and this conclusion is confirmed also by the intergrowths exhibited in the glomero-porphyrific groups of augite- and plagioclase-phenocrysts in the hemicrystalline varieties forming the selvages of the dykes.

<sup>1</sup> J. A. Phillips, *Quart. Journ. Geol. Soc.* vol. xxxiii. (1877) p. 423; Waller, *Midland Naturalist*, 1885, p. 4.

<sup>2</sup> Hill & Bonney, *Quart. Journ. Geol. Soc.* vol. xxxiv. (1878) p. 199.

<sup>3</sup> Teall, *Quart. Journ. Geol. Soc.* vol. xl. (1884) p. 640.

<sup>4</sup> *Id.*, 'British Petrography' (1888), p. 272.

<sup>5</sup> *Ibid.* p. 179; Harker, *Quart. Journ. Geol. Soc.* vol. 1. (1894) p. 311 & vol. li. (1895) p. 125.

<sup>6</sup> Sollas, *Trans. Roy. Irish Acad.* vol. xxx. (1894) p. 477.

<sup>7</sup> Harker, *Quart. Journ. Geol. Soc.* vol. lii. (1896) p. 320.

The micropegmatite, however, is distinctly later in origin, being never older than the 'water-clear' outer margins of the felspar-crystals. But although distinctly the last-formed original constituent, there is no reason for regarding it as other than the result of one continuous process, and the final stage in the consolidation of the magma which gave rise to the rock.<sup>1</sup>

The order of the crystallization of the constituents is, then, the following:—

- (1) Augite and plagioclase together forming the main mass of the rock, and
- (2) Micropegmatite, playing the part of groundmass.

The augite is pale brown in colour, sometimes distinctly pleochroic, frequently twinned according to the common law, and, so far as its original microscopic characters are concerned, calls for no further remark. An analysis of material carefully separated from the dyke at the Seven Pagodas, Chingelput district, whose bulk-analysis is given below, shows the close resemblance between the monoclinic pyroxene of this rock and that of the petrologically similar Whin Sill analysed by Mr. Teall.

	I.	II.
SiO <sub>2</sub> .....	50.02	49.03
Al <sub>2</sub> O <sub>3</sub> .....	5.61	5.46
Fe <sub>2</sub> O <sub>3</sub> .....	15.61	15.57
MnO .....	trace	0.22
CaO .....	14.84	15.34
MgO .....	12.01	11.66
Na <sub>2</sub> O & K <sub>2</sub> O .....	0.96	1.24
Loss on ignition .....	0.76	0.81
	99.81	99.33

I. Monoclinic pyroxene in augite-diorite dyke, Seven Pagodas, Chingelput district, Madras Presidency.

II. Monoclinic pyroxene from the Whin Sill, Teall, Quart. Journ. Geol. Soc. vol. xl. (1884) p. 648.

The central portions of the plagioclase-crystals give the extinction-angles of varieties approaching labradorite in composition. But as the margins of the crystals are approached the well-known zoning by change of chemical composition is well displayed. The central portions of the crystals are pale-brown in colour through innumerable original inclusions, a feature which is also well shown by the phenocrysts of the hemicrystalline varieties. But in the holocrystalline, coarser-grained types, the plagioclase-crystals become paler in colour near the margins and finally 'water-clear' in their outermost zones.

The micropegmatite generally fills in the angles between the felspars and pyroxenes, and is composed of the usual intergrowth of quartz with felspar, which is sometimes microcline, but generally plagioclase. When the intergrown felspar is plagioclase its

<sup>1</sup> The evidence, upon which the conclusion as to the primary origin of the micropegmatite is based, is detailed below and on p. 409.

crystallographic continuity with an adjacent normal, and unquestionably original, plagioclase can generally be demonstrated between crossed nicols. The quartz and felspar of the micropegmatite both contain numerous colourless, or very pale-green, acicular crystals, which, being thinner than the sections of doubly-refracting minerals in which they lie, cannot be determined with certainty. On account of the almost constant presence of these acicular crystals and on account of the constantly 'water-clear,' limpid appearance of the quartz and felspar in which they lie, the patches of micropegmatite can easily be detected in ordinary light.

As noticed by Teall in connexion with the Whin Sill,<sup>1</sup> the coarseness of the micropegmatitic patches varies with that of the remaining constituents of the rock, and in the finer-grained varieties the separation of the constituents becomes less and less pronounced, until the quartz- and felspar-individuals, becoming narrower than the thickness of the section, are indistinguishable one from another in polarized light, thus passing into the structure to which Harker has given the name cryptographic.<sup>2</sup> This interesting character strongly supports the conclusion that the micropegmatite is primary in origin.

The minerals which are wholly, or in part, secondary in origin are opaque iron-ores, hornblende, and biotite. In the larger number of dykes these minerals are comparatively small in quantity, and are almost always situated on the margins of the augite which abut directly against the micropegmatite, while the faces of the same mineral abutting directly against the ordinary plagioclase-crystals are more often quite free of any such signs of secondary change. The secondary changes in the augites are thus facilitated by proximity to the micropegmatite, and in the few dykes in which hydrous decomposition has appreciably advanced these peculiar circumstances are still more marked. In such cases the felspars of the micropegmatite itself have been completely decomposed and converted into an aggregate of minute chlorite-flakes, sometimes clear green and sometimes coloured by rusty stains. The felspars around the micropegmatitic patches are at the same time kaolinized to varying extents, accompanied by the deposition of secondary quartz in crystallographic continuity with that forming part of the micropegmatite: while the augites are, on the faces exposed to the micropegmatite, corroded by the formation of hornblende, biotite, and iron-ores (see Pl. XXIX. fig. 1). The significance of these phenomena is indicated farther on (p. 413).

### III. CHEMICAL COMPOSITION OF THE ROCKS.

For the purposes of chemical analysis, I have selected the dyke exposed near the rock-hewn Seven Pagodas, in the Chingelput district, as an example of the well-crystallized types comparatively free from enstatite; and the selvage of a dyke near Perumbakam, in the South Arcot district, as the most typical of the fine-grained

<sup>1</sup> Quart. Journ. Geol. Soc. vol. xl. (1884) p. 644.

<sup>2</sup> 'Petrology for Students' (1895), p. 92.

types approaching augite-andesite in structure. Sections of both these rocks are figured in Pl. XXIX. figs. 1 & 3. For the analysis of the rock from the Seven Pagodas I am indebted to Mr. P. Brühl, Professor of Physics in the Civil Engineering College, Sibpur.

	I. Augite-diorite with Micropegmatite.	II. Augite-andesite.
SiO <sub>2</sub> .....	51·15	50·86
TiO <sub>2</sub> .....	0·44	0·63
P <sub>2</sub> O <sub>5</sub> .....	0·06	trace
Al <sub>2</sub> O <sub>3</sub> .....	15·92	15·65
Fe <sub>2</sub> O <sub>3</sub> .....	9·34	} 10·85
FeO .....	2·87	
MnO .....	0·09	trace
CaO .....	10·40	11·76
MgO .....	6·48	6·03
Na <sub>2</sub> O .....	1·19	2·01
K <sub>2</sub> O .....	1·61	1·56
H <sub>2</sub> O .....	0·11	0·20
	99·66	99·55
Sp. gr. ....	3·19	3·01

Both these analyses recall the composition given by Mr. Teall for the Whin Sill, with which these rocks agree so strikingly in petrological characters.<sup>1</sup> The comparatively high percentage of potash among the alkalis indicates the probable presence of a potash-felspar as a constituent of the micropegmatite, and this is confirmed by the detection of microcline in several of the dykes.

If the silica, alumina, and alkalis due to the micropegmatite, which possesses a silica-percentage near that of Bunsen's 'normal trachytic magma' (76·67 SiO<sub>2</sub>), were deducted from the bulk-analysis of the rock, the remainder would agree fairly closely in composition with the 'normal pyroxenic magma' to which Bunsen gave the hypothetical composition:—SiO<sub>2</sub>, 48·47; Al<sub>2</sub>O<sub>3</sub>, 14·78; CaO, 11·87; MgO, 6·89; FeO, 15·38; alkalis, 2·61. It is an interesting circumstance that the numerous associations of gabbro with granophyre which have been recorded should so closely approach in composition Bunsen's hypothetical normal pyroxenic and normal trachytic magmas, and the similar association of these two types on a microscopic scale in the South Indian dykes suggests the derivation of these two distinct rocks by segregative consolidation from an originally common magma.

#### IV. EXPLANATION OF THE STRUCTURE OF THE DYKE-ROCKS.

As already pointed out, the augite-diorite dyke-rocks of Southern India are composed principally of augite and plagioclase, with subordinate quantities of micropegmatite. The relations of the

<sup>1</sup> See Teall, *Quart. Journ. Geol. Soc.* vol. xl. (1884) p. 654.

augite and plagioclase show that these two constituents consolidated approximately simultaneously, while there is no doubt that the micropegmatite was formed subsequently. The principal question to decide is whether the micropegmatite was formed—

(a) During the primary consolidation of the magma which was injected to form the dykes ;

(b) By secondary changes induced in the rock ; or

(c) By subsequent intrusion of granophyric material into the augite-plagioclase rock.

The complete absence of granitic intrusions, and for that matter of intrusions of any sort, into the very large number of basic dykes which have been carefully examined in Southern India puts the third consideration out of the question. The remarkable freshness of the rocks—their escape from crushing movements, as well as their freedom from the signs of subaerial hydration—precludes the possibility of explaining the presence of the micropegmatite as the result of secondary changes. But besides the removal of alternative explanations by very complete and satisfactory negative evidence in so large a number of instances in which these points of evidence have been tested, the first explanation offered—namely, that the micropegmatite is primary in origin—is supported uniformly by

(1) The crystallographic continuity of its felspar with that of the normal plagioclase of the rock.

(2) Its occurrence filling in the angles and spaces between the augite and plagioclase, thus playing the part of groundmass ; and

(3) Its variation in coarseness of grain agreeing with that of the remaining two constituents of the rock. In the centres of the large dykes the separation of the quartz from felspar in the micropegmatitic patches can easily be seen with low powers ; in the fine-grained portions nearer the margins, and in the smaller dykes, the intergrowth of these two minerals is on so minute a scale that even with high powers their individualization is not evident. Had the micropegmatite been introduced into the rock by subsequent intrusion, or had it been caused by secondary changes, such a relation between its structure and that of the rock would have been merely fortuitous, and therefore never an uniform rule.

The formation of the micropegmatite is, therefore, dependent directly upon the processes by which consolidation of the magma has been accomplished, and represents the final stage of that consolidation.

The consolidation of the rock may thus be divided into two distinct, though perfectly continuous, processes :—

(1) The crystallization of the augite and plagioclase, which make up the principal mass of the rock, to form a strong framework.

(2) The formation of micropegmatite from the residual mother-liquor filling the angular spaces and interstices in the framework of augite and plagioclase.

As the crystallization of the mother-liquor filling in the inter-crystal lacunæ and their ramifying connexions would be attended with the usual reduction in volume, and as the framework of augite

and plagioclase would be sufficiently strong to prevent the collapse of the rock under any but extreme pressure, the micropegmatitic patches would be less compact than the rest of the rock; they should in fact be miarolitic on a very small scale—to save words, micromiarolitic. That this actually is the case is confirmed by a very interesting feature displayed by all the rocks in which hydrous decomposition has commenced. In these it is seen that the decomposition has invariably developed around the micropegmatitic patches, the feldspars in the immediate neighbourhood of the patches being kaolinized, the secondary biotite and hornblende changed to chloritic products, and the iron-ores rusted. The greatest change of all has been effected in the feldspars which originally formed part of the micropegmatite; these have, as a rule, completely lost their original characters, and their places are now occupied by chloritic products, which have been manufactured from their remains with the aid of iron, magnesia, and other compounds derived from the adjoining biotite and iron-ores. Not the least interesting among the changes brought about by the introduction of water is the formation, in the adjoining kaolinized feldspars, of secondary quartz in crystallographic continuity with that forming an original constituent of the micropegmatite, and thus becoming a secondary extension of the structure. These unmistakable signs of hydrous decomposition limited to the neighbourhood of the micropegmatite show that the water is distributed through the rock by this means. The intercommunicating lacunæ once occupied by the residual mother-liquor, and subsequently filled loosely by the quartz and feldspar into which it crystallized, now evidently form a most intricate arterial system for water-communication.

#### V. COMPARISON WITH SO-CALLED GRANOPHYRIC GABBROS.

In his interesting memoir 'On the Relation of the Granite to the Gabbro of Barnavave, Carlingford,' Prof. Sollas has brought together a great assemblage of facts to show that the micropegmatite in the gabbro had been produced by minute intrusions of 'granophytic' material in a state of great fluidity, subsequent to the consolidation and even jointing of the older gabbro. In comparing the Carlingford case with the similar instances of micropegmatite occurring in basic rocks in Great Britain, Prof. Sollas pointed out the association of granophytic massive rocks with the well-known enstatite-diorite of Penmaenmawr and with the gabbro (augite-diorite) of Carrock Fell. For want of evidence, however, concerning the presence of granophytic intrusions in connexion with the Whin Sill, Prof. Sollas was unable to extend his explanation to that well-known instance; at the same time he remarked that 'till minute veins or dykes of granophyre have been specially searched for in this dyke without success, it will be impossible, in the light of our recent observations, not to feel some suspicion as to the real nature of the granophytic inclusions.'<sup>1</sup>

<sup>1</sup> Trans. Roy. Irish Acad. vol. xxx. (1894) p. 477.

The Madras dykes afford a fairly complete answer to Prof. Sollas's difficulty. The cases of augite-diorite dykes containing micropegmatite, which have been carefully examined by several members of the Geological Survey of India, are not one or two, but several scores; and not a single instance has been recorded of a dyke crossed by a later igneous intrusion of any sort, granitic or otherwise. The basic dykes, as recently remarked by my colleague Mr. C. S. Middlemiss, who, with Mr. F. H. Smith and myself, has during the last season kept this question specially in view, 'show nothing to suggest a veining by any other rock. They are well-defined, weather out into well-marked boulders, exfoliate concentrically, ring like metal under the hammer, and completely suggest a homogeneous composition.' It would, therefore, be quite contrary to the evidence to consider the micropegmatite to be the result of a later and separate intrusion, while for regarding it as derived from the magma which gave rise to the augite and plagioclase there is abundant evidence, both positive and negative.

In extending his explanation of the relations between the granite and gabbro of Carlingford to the peculiar structure of the Whin Sill, Prof. Sollas has given us a precedent for, *per contra*, extending the explanation which accounts for the intimate association on a microscopic scale of granophyric material with augite-diorite to the frequent instances which have been recorded of larger masses of granophyric acid rocks occurring in intimate association with basic masses. The association of pyroxene-diorite with granophyre in such well-known instances as the Stanner Rock, at Penmaenmawr, Carrock Fell, Carlingford, and the Western Isles of Scotland are sufficiently numerous within the limited area of the British Isles to suggest some sort of genetic relationship between two rocks that are found so often together, and with such a constancy in the peculiarities of their relations one to the other.

In the case of the Madras dykes I have attempted to show that the structure of the rocks indicates the formation of a strong framework of augite and plagioclase before the consolidation of the more acid residual mother-liquor in the interstices. Such an occurrence would be possible where, as is the case with these rocks, the augite and plagioclase together far exceed in quantity the micropegmatite, and where also the pressure to be withstood by the framework so formed is limited. But where the basic minerals are in subordinate quantity, and where, as would most certainly be the case in large bosses, the pressure is much greater, it would be only natural to expect that the formation of a loose framework of the older minerals would be impossible, and there would as a consequence be a more complete separation into distinct masses of the two divisions of the magma, the first-formed giving rise to an augite-diorite, while the second phase of consolidation would be represented by the formation of an acid rock. In his detailed examination of the gabbro and granophyre of Carrock Fell, Harker approaches a similar conclusion in stating that the interval between the consolidation of the two rocks was probably a short one, the

acid magma being intruded among rocks already hot.<sup>1</sup> Such a conclusion accounts for the coarseness of grain which has been so frequently, almost invariably, observed in the granophyric rocks at the junctions with their basic associates.<sup>2</sup>

But still more interesting are the secondary changes induced in the gabbro at its junction with the granophyre. Harker has noticed that near the granophyre the augites of the gabbros (augite-diorite) are largely replaced by green hornblende, and biotite sometimes occurs.<sup>3</sup> I have already referred to precisely similar changes in the augites of the Madras dykes where they come into contact with the micropegmatite, while the same augite-crystal where it abuts cleanly against a plagioclase is often quite fresh and unchanged (*supra*, p. 408). The explanation of these phenomena which agrees most nearly with the facts seems to me to be somewhat as follows:—The water originally contained in the molten magma would become, by the separation of the anhydrous minerals, augite and plagioclase, excluded to the final stages of consolidation, before the completion of which there must have been a more perfect condition of what has been frequently described as aquo-igneous fusion. The separation of the silica and alumino-alkaline silicate, as quartz and felspar respectively, from this aquo-igneous melt would leave the miarolitic channels filled with heated vapours, which would be free to attack the susceptible ferromagnesian silicate, and bring about the excretion of magnetite and formation of biotite by alteration of the highly ferriferous, and almost non-aluminous, augite.<sup>4</sup>

Although more limited in extent, the secondary changes shown by the augites where they come into contact with the micropegmatite are precisely similar in kind to those described by Prof. Sollas<sup>5</sup> as brought about by the action of the granophyre on the pyroxenic xenocrysts obtained from the gabbro of Barnavave—the assumption of a green colour, the excretion of magnetite, and the formation of biotite and hornblende referred to by Prof. Sollas as results of the transformation of diallage-xenocrysts, being phenomena constantly observed wherever the augite-crystals come into contact with micropegmatite in the Madras dykes. Although these facts suggest the likelihood of a similarity of physical conditions during the consolidation of the Barnavave granophyre and the micropegmatite in the Madras basic dykes, there is no escaping the conclusion that in the latter instance the acid material was formed after, and in direct succession to, the consolidation of the augite and felspar, and was thus formed at probably a lower temperature. If this conclusion be the correct one, it follows that the change of

<sup>1</sup> Quart. Journ. Geol. Soc. vol. li. (1895) p. 133.

<sup>2</sup> *Ibid.* p. 148.

<sup>3</sup> *Ibid.* pp. 133, 134, & 135.

<sup>4</sup> That water existed in the original molten material is more than likely, and that its presence would result in a suspension of consolidation will, in view of the researches which all point to the conclusion first indicated by Scheerer in 1846, be now generally conceded.

<sup>5</sup> Trans. Roy. Irish Acad. vol. xxx. (1894) pp. 493, 494.

augite to hornblende and biotite with concomitant separation of magnetite does not necessarily indicate that the augite-diorite has been altered by a subsequent and distinct igneous intrusion at a high temperature,

If the separation of the acid from the basic portions of a magma on a large scale, such as may have occurred in the instances quoted above, be really analogous to that which has taken place on a microscopic scale in the Whin Sill and the Madras dykes, we should naturally expect to find that the acid rock is later than its basic associate in completing its consolidation. At the same time, the close agreement in the ages of the two rocks might very well give rise to apparently contradictory phenomena along their junction-lines (especially if earth-movements disturbed them during, or subsequent to, consolidation), and so produce isolation of injected portions of the granophyre, or even local re-fusion of the rocks from the heat produced by mechanical movements.

In the minute intercrystal channels and lacunæ filled with micromiarolitic micropegmatite in the Madras augite-diorite, we have the equivalents of what the older geologists understood by the term 'contemporaneous veins,' veins which, though formed after sufficient consolidation of the rock in which they occur, are yet derived from the same magma and form part of one geological unit. Although there is no doubt that the augite and plagioclase were separated before the micropegmatite, the two groups of minerals have been separated from the same magma, and are as much 'contemporaneous' as are two twins, which for obvious reasons are not born simultaneously. Such was the view taken by Waller in describing the augitic acid veins penetrating the enstatite-diorite of Penmaenmawr, and such apparently was the idea in Macculloch's mind when, in discussing the difficulties of settling the relative ages of the similar rocks in the Western Isles of Scotland, he concluded that the 'trap' and the 'syenite' had a common origin.<sup>1</sup> Haughton, in describing the granite of Barnavave, has also classed the granophyric veins penetrating the gabbros as 'contemporaneous.'<sup>2</sup>

## VI. SUMMARY.

In the Madras Presidency the pyroxene-granulites and the ordinary gneisses are penetrated by a very large number of basic dykes, which are regarded as the underground representatives of the Cuddapah lava-flows. Since the intrusion of these rocks the Indian peninsula has been remarkably free from earth-movements, and the structures of the dykes are beautifully preserved.

Many of these rocks are augite-diorite with micropegmatite. They consist mainly of augite, approaching hedenbergite, and plagioclase, approaching labradorite in composition. The crystallization of these two minerals has been approximately simultaneous,

<sup>1</sup> 'Description of the Western Isles of Scotland,' vol. i. (1819) p. 363, vol. ii. pp. 57 & 345.

<sup>2</sup> See also Sollas, *Trans. Roy. Irish Acad.* vol. xxx. (1894) p. 478.

constituting the first phase in the consolidation of the magma, while micropegmatite—subsequently formed and representing the final stage in the consolidation of the magma—fills in the angles between the augite and plagioclase, and so plays the part of ground-mass.

The augite and plagioclase being in excess, their simultaneous separation from the magma resulted in the production of a strong solid framework, the angles and interstices of which were filled in with more acid mother-liquor, which ultimately gave rise to the micropegmatite. As the crystallization of the mother-liquor filling these intercrystal lacunæ and their ramifying connexions would be attended with the usual reduction in volume due to crystallization, and as the framework of augite and plagioclase previously formed would be strong enough to resist any but extreme pressure, the micropegmatite would be less compact than the rest of the rock, and would be miarolitic on a small scale (micromiarolitic). Hence the lacunæ and channels, loosely filled with micropegmatite, would form an intricate arterial system throughout the rock for, first of all, the passage of the liberated hot vapours, and finally for water. As a consequence of this fact, we find that the portions of the augites abutting directly against the micropegmatite are almost invariably attacked in the freshest of the rocks, while in those wherein hydrous decomposition has appreciably commenced the micropegmatitic patches are always the centres of very marked changes, the feldspars in their immediate neighbourhood being kaolinized, the biotites converted into chloritic products, and the iron-ores rusted.

In these augite-diorite dykes the coarseness of the micropegmatite varies with that of the other constituents; in the coarser-grained varieties the quartz and feldspars are easily distinguished between crossed nicols, while in the finer-grained varieties, forming the margins of large masses or constituting smaller dykes, the intergrowth of the constituents of the micropegmatite is as minute as that in the structure to which Harker has given the name 'cryptographic.' The feldspar of the micropegmatite is sometimes microcline, but more often plagioclase: when the latter, it is generally in crystallographic continuity with the outer zone of an adjoining and unquestionably original plagioclase. For these reasons, principally, the micropegmatite is regarded as primary in origin. The rocks being, as a rule, remarkably fresh and unaltered, there is no reason for considering the micropegmatite to be secondary in origin. As the numerous augite-diorite dykes are never found to be crossed by veins of granite or by subsequent intrusions of any sort, the explanation applied by Prof. Sollas to the 'granophyric gabbro' of Carlingford, and suggested by the same author for similar cases of augite-diorites with micropegmatite in Great Britain, is not applicable to any of the numerous dykes which have been very carefully examined in Southern India.

Where the augite and plagioclase far exceed the micropegmatite in quantity, and where the pressure is not too great, the formation of a strong solid framework by the simultaneous crystallization of

these two minerals would naturally precede the crystallization of the more acid residual mother-liquor. But in large boss-like masses, where the pressure is greater, and especially in cases where the basic material is not in great excess, such a framework would be impossible, and as a consequence there would be a more complete separation into distinct masses of the two divisions of the magma, the first crystallized giving rise to an augite-diorite, while the second phase of consolidation would be represented by the formation of an acid rock.

The suggestion is thus offered that the gabbros (augite-diorites) are genetically related to the granites (granophyres) with which they are found associated in the British instances quoted in the Introduction (p. 406). If this be so, we should expect, as the micropegmatite is consolidated after the augite and plagioclase in the dyke-rocks, so the granophyric rock will, as a rule, be later than its basic associate in completing its crystallization. We should expect, consequently, to find evidence—and such has been given by Harker and others—to show that the basic rock was still hot when the acid rock consolidated, veins or junctions of the latter with the former being coarse in grain. At the same time, the periods of consolidation of the two rocks are sufficiently close to account for apparently contradictory phenomena along their line of junction—veins of the acid rock in the basic might be converted into isolated inclusions by earth-movements, while local re-fusion might be caused by the heat resulting from mechanical movements.<sup>1</sup>

The micropegmatite forming, as described, an intricate system of veins running through the framework of previously-crystallized augite and plagioclase, represents what the older geologists understood by 'contemporaneous veins,' veins which, though formed after sufficient consolidation of the rock penetrated by them, are yet derived from the same magma, and form part of one geological unit.

The separation of anhydrous minerals during the early stages of consolidation would result in the exclusion of the water originally contained in the magma to the mother-liquor. This residual, and generally more acid, mother-liquor would thus be in a state of more perfect aquo-igneous fusion; and hence, although the temperature may be below that at which the first portions separated, when the proportion of water in the magma was lower, it may still be above that at which the more aqueous residue would consolidate, and as a result the 'contemporaneous veins' may be as coarse as, and often coarser than, the rocks which they penetrate.

<sup>1</sup> In comparing the intimate admixture of micropegmatite and augite-diorite on a microscopic scale with associations of the same rocks in large masses, it is interesting to observe that the changes suffered by the augite, where it abuts directly against the micropegmatite, are precisely similar to those noticed by Harker in the augite of the Carrook Fell gabbro (augite-diorite) at its junction with the granophyric rock, while Sollas has described similar changes in the diallage which occurs as xenocrysts in the Carlingford granite (granophyre, in the modified sense suggested by Rosenbusch).

## EXPLANATION OF PLATE XXIX.

- Fig. 1. Augite-diorite with micropegmatite. Large dyke crossing the gneiss. Seven Pagodas, Chingelput district.  $\times \frac{20}{2}$ . The augite and plagioclase make up the main mass of the minerals included within the field. Where the augite abuts directly against the water-clear micropegmatite, as in the centre and lower parts of the field, green hornblende, brown biotite, and opaque magnetite are formed, while the edges of the augite meeting the plagioclase are generally quite unaltered.
- Fig. 2. A finer-grained variety of the same rock occurring as a narrow dyke near Nemeli, South Arcot district. The micropegmatite, as well as the augite and plagioclase, is finer in grain and sometimes almost cryptographic. This rock shows the intergrowths of augite and plagioclase to indicate an average simultaneous crystallization of the two minerals.  $\times \frac{40}{2}$ .
- Fig. 3. Augite-andesite, the hemicrystalline selvage of an augite-diorite dyke near Perumbakam, South Arcot district. The glomero-porphyrific groups of augite and plagioclase show these two minerals crystallizing at about the same time, being intimately intergrown although they are in a free matrix. The presence of vitreous material in this matrix could not be demonstrated.  $\times \frac{20}{2}$ .
- Fig. 4. Augite-diorite with micropegmatite. A dyke in biotite-gneiss, Jaulikerai, Hosurtaluk, Salem district. The hydrous decomposition which has commenced in this rock has manifested itself most markedly in, and immediately around, the micropegmatite, the feldspars of which have been converted into an aggregation of minute chloritic flakes, while the plagioclase in the immediate neighbourhood has been kaolinized, and secondary quartz has been deposited in crystallographic continuity with that forming part of the micropegmatite. This rock is an example also of the types in which enstatite forms a considerable portion of the pyroxenic constituent, and which form a link with certain norites described in a paper in the Records of the Geological Survey of India (vol. xxx).  $\times \frac{20}{2}$ .
- Fig. 5. Portion of rock shown in fig. 4, seen in polarized light, so as to show the interstitial micropegmatite.  $\times \frac{80}{2}$ .
- Fig. 6. Portion of rock shown in fig. 1, seen in polarized light.  $\times \frac{80}{2}$ .

## DISCUSSION.

Gen. McMAHON said that he had listened to the paper with great interest, and looked forward to studying it in print. He thought that the micropegmatitic structure arose in different ways in different rocks, and that one explanation was not true for all cases. A difficulty in holding that the structure was formed during the primary consolidation of the rock arose from the fact mentioned by the Author that the micropegmatitic portion of his rock altered the pyroxenic minerals in contact with it. The Author spoke of heat being generated in igneous masses by mechanical motion. Might not this superinduced heat account for the formation of a micropegmatitic structure? His observations had led him to believe that the initial stage of remelting resulted, in some cases, in the separation of free silica from feldspars in the way seen in micropegmatite.

Prof. G. A. J. COLE observed that, while the dyke-like and sheet-like masses of Madras and the Whin Sill of England, taken alone, would certainly seem to support the view of differentiation of one original magma, yet the matter must be judged by comparison with areas which the Author has himself quoted. The speaker had recently returned from Slieve Gallion, in South-eastern Londonderry, where a granite, probably of Lower Old Red Sandstone age, has invaded a volcanic and plutonic basic series, probably of Arenig age. The phenomena of the junction-surfaces, and of the smaller veins, repeat those described by Sollas, Harker, and others; and the most extensive intermingling appears to have gone on. Even the ferromagnesian constituents of the Slieve Gallion granite may possibly result from the process of absorption. Hence the intimate intermixtures, so well represented by the Madras dykes, may arise from the joint intrusion of materials already well worked together and intermingled in the main mass lower down.

Mr. W. W. WATTS, after ascertaining that the previous speaker was inclined to regard the biotite and hornblende of the Slieve Gallion granite as having been derived from a basic rock, pointed out that in the rocks described by Harker from Skye the hornblende derived from the augite of gabbro was quite distinguishable from the indigenous hornblende of the granophyre. It was therefore certain that some of the ferromagnesian minerals in granitic rocks were original, and not derived at the expense of basic rocks.

Mr. RUTLEY agreed with a previous speaker in thinking that the Author was probably right in his conclusion that the micropegmatitic matter was not of secondary origin, but doubted whether 'augite-diorite' was a perfectly satisfactory name to apply to a rock such as that described. The diagram did not indicate a truly ophitic structure, although it showed an approximation to it.

Rev. J. F. BLAKE asked whether in this particular case the Author had definitely proved to his own satisfaction what were the actual mineral constituents of the 'micropegmatite.' If one of them was optically continuous with a plagioclase, and there were also orthoclase and quartz, this would make three minerals; but he had not been able to gather from the reading of the paper anything definite on the question. He also enquired why the optical continuity of part of the micropegmatite with the neighbouring plagioclase proved it to be of the same general age, when similar accretions were found round quartz-grains which meanwhile had been rolled on the sea-shore.

Mr. J. J. H. TEALL and Mr. P. N. DATTA also spoke.

Prof. JUDD stated that he had been in communication with Prof. Sollas, who unfortunately was not able to attend and take part in the discussion of this paper. Prof. Sollas, from the perusal of the abstract and an examination of a slide of the Madras rock forwarded to him, had been able to supply the following contribution to the discussion, which, by the permission of the President, was read:—

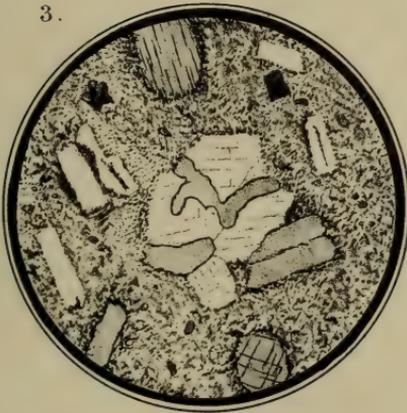
1.



2.



3.



4.



5.



6.



T.H.H. & M.P.P. del.  
M.P. Parker lith.

Mintern Bros. imp.

MICROPEGMATITIC AUGITE-DIORITES  
FROM SOUTHERN INDIA.



‘As regards the primary origin of micropegmatite in basic rocks, I would prefer to wait for further information before committing myself. As against it, I note the alteration in adjoining minerals which seems to be usually associated with the presence of micropegmatite. This alteration is very marked in the augite of the slide sent to me. The crystallographic continuity of the orthoclase with the plagioclase proves nothing, except that these two kinds of felspars are sufficiently isomorphous for the growth of the one to follow on the lines of the other: as well might one argue that the quartz enlargements of quartz-grains in a sandstone-rock were primary, because they are in crystallographic continuity.

‘The co-variation in coarseness of grain simply indicates to my mind that where druses exist there is room for the growth of large crystals, and that the size of the crystals will bear some proportion to the size of the druses. We see this in the druses of the Mourne Mountains granite, and I have frequently observed in basalts and dolerites structures in the immediate neighbourhood of cavities which are now filled with large zeolitic crystals. The interstitial character of the micropegmatite does not seem to me an argument of much force.

‘The strongest argument to my mind against the secondary origin of the micropegmatite is the existence of druses which it postulates; and it is this which leads me to a suspense of judgment.

‘As regards Barnavave, I take up a decided position, at least as regards the so-called contemporaneous veins. They are not only easy to trace into connexion with the great granitic masses of the district, but they include clastic fragments of the gabbro and of its constituent minerals. If a rock injected in a fluid state into another previously consolidated can be called contemporaneous with the rock it penetrates, the Author’s argument may possibly hold, but I maintain that to apply the word contemporaneous in this case is a misuse of terms.

‘As regards the Madras dykes, the absence of exposed acid rocks is negative evidence solely; there is probably acid rock in every igneous district; but it does not always come to the surface: I quite agree with the Author that his supposed case (*b*) will not hold.’

Prof. Judd added that he felt sure that the Author would be greatly gratified to find that his views had met with the support of Mr. Teall, Mr. Rutley, and other speakers that evening. In adopting a name for the rock, the Author stated in the paper that he followed Prof. Cole. It would be seen that from some of the admitted facts the Author of the paper and Prof. Sollas drew deductions of an exactly opposite character. With respect to the use of the term ‘contemporaneous veins,’ Mr. Holland maintained that the old geologists who first employed the term were justified in using it in cases where, though there must evidently have been a succession in time between the formation of two kinds of igneous rock, yet both were comprised within the same general period of eruption.

30. *The GRAVELS and ASSOCIATED DEPOSITS at NEWBURY.* By  
E. PERCY RICHARDS, Esq., F.G.S. (Read May 12th, 1897.)

## [PLATE XXX.]

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§ 1. INTRODUCTION AND REMARKS ON THE GENERAL GEOLOGY OF THE  
DISTRICT.<sup>1</sup>

THE observations recorded here were taken during the progress of the main-drainage works at Newbury in 1894. Pressure of work greatly curtailed my opportunities; nevertheless I trust that my notes, though not of so much value as I could wish, will be of use to geologists who are systematically studying our drifts and other gravel-deposits.

The strata which I have examined may be apportioned into four groups, as follows:—

- (1) Pre-Glacial Southern Drift.
- (2) Glacial (?) Drift.
- (3) A lower and an upper Palæolithic River-gravel.
- (4) Neolithic peat, loam, and shell-marl.

The Kennet Valley at Newbury is about 2 miles wide, broad and fertile, with flat water-meadows over the peat, stretches of cornland and firm pasture upon the river-gravel terraces, while woods clothe the low parallel hills which continuously enclose the valley.

River-gravels rest upon the Chalk-with-flints in the middle of the valley at Newbury; but a few miles down stream both the valley and the hills are formed in Eocene strata.<sup>2</sup>

§ 2. THE PRE-GLACIAL DRIFT.

The first-mentioned gravel in the above list occurs in wide regular layers over the Tertiary rocks in the district, and produces the heathy commons, on each side of the valley, occupying an average level of 440 feet above O.D. This gravel was said to be probably 'Southern Drift' by the late Sir Joseph Prestwich, in his

<sup>1</sup> See Note I. in Appendix I., p. 433.

<sup>2</sup> As well seen in some sections shown to me by Mr. Fidler, of Newbury, published, I think, in the 'Engineer,' in relation to a proposed water-supply of London by draining the Kennet Valley, and forming a lake from Aldermaston to Thatcham; wells and borings were recorded. See also Prestwich's Map of the Pre-Glacial Drift-beds of the Thames Basin, Quart. Journ. Geol. Soc. vol. xlv. (1890) pl. viii.

'Westleton' papers.<sup>1</sup> The following section, from a gravel-pit on Greenham Common, south of Newbury, at 401 feet above O.D., is typical of this gravel:—

	Feet.
Peaty soil; the surface of the gravel beneath is much bleached...	1
Flint gravel, with a brown clay-and-sand matrix (slightly stratified) .....	} 6 exposed.
70 % brown subangular flints, averaging 3 inches in diameter...	
22 % subangular flints, brown inside, white outside, and less rolled than the former.....	
8 % perfectly rounded, small flints, stained throughout red, purple, black, brown, and grey .....	

The well-rounded pebbles are all very small, and much decomposed externally; a few small subangular 'sarsens' of fine, cold-grey, compact sandstone or quartzite, as well as fragments of chert, were present; the surface of this gravel is much bleached. On Snelsmore Common, north-west of Newbury, the following section of a similar gravel was exposed, capping the Tertiaries at a level ranging from 429 to 483 feet above O.D.:—

	Feet.
Peaty soil .....	1
Flint-gravel in clay-and-sand matrix, with greyish intercalation of clay .....	} 6 exposed.
38 % pebbles; 62 % subangular = 100 .....	
50 % warm-brown flints .....	
45 % flints coloured black .....	
5 % small subangular sarsenstones } = 100 .....	
An entire absence apparently of white quartz-pebbles, of green-coated flints, gritstones, and Triassic pebbles.	

As the Greensand does not reach the surface between the pre-Glacial southern watershed and Snelsmore Common, we can understand the scarcity of Greensand débris, as previously pointed out, in reference to other sections, by the late Sir Joseph Prestwich.<sup>2</sup>

The most important points to be considered in determining the age of this gravel are the levels, the entire absence of quartz-pebbles, green-coated flints, and Triassic and quartzite-pebbles; also its extent and mode of occurrence. The consideration of these points, I think, fully warrants me in regarding it as 'pre-Glacial Southern Drift.'

No bones or fossils of any kind have ever been found in this gravel, to my knowledge. The exposed situation would facilitate their removal by the infiltration of rain, if they had not been previously destroyed by the strong water-action which arranged the heavy débris.

At the borders of the commons this drift sometimes appears to trail off into a reddish gravel, clearly shown as part of the Southern Drift, in section AB (Pl. XXX), below the 400-foot level, commencing at the Workhouse. This I have not closely examined; but it appears to have resulted from the slipping down of the truncated edge of the sheet of Southern Drift towards the valleys, and its subsequent commingling with rainwash, and possibly with other gravels of Glacial age.

<sup>1</sup> Quart. Journ. Geol. Soc. vol. xlv. (1890) p. 142.

<sup>2</sup> *Ibid.* p. 162.

## § 3. THE GLACIAL (?) OR DONNINGTON GRAVEL.

The next distinct gravel upon the south side of the valley at Newbury is the 'Terrace-gravel' (3); its upper surface is about 260 feet above O.D.

On the north side of the town, however, there is a deposit of loam and gravel, occupying in section AB almost the same level as the terrace-gravel does on the south side of AB, but rising considerably above the terrace-gravel at Donnington Square, and extending just over the 300-foot contour on the Bath Road, as against 260 feet in the terrace-gravel.

This gravel and my 'Lower River-gravel' have been marked on Mr. Bennett's section through Newbury (now in the Town Hall at Newbury) as 'Reading Beds.' But this I find to be incorrect; for in the section of a well in Greenham Park, 440 feet above O.D., the Chalk was reached at 217 feet above O.D., and the lowest layers of the Reading Beds consisted of hard, dark-green sands, with a few included layers of flints, succeeded by other green sands and dark clays. Following the long section AB, it will be seen that these are entirely wanting from the Great Western Railway to Donnington Square. A green sand forms the base of the terrace-gravel, skirted by the railway on the south side of the river, and this may belong to the Reading Beds; but north of this the river-gravels and the Donnington Glacial Drift rest immediately upon the Chalk-with-flints.

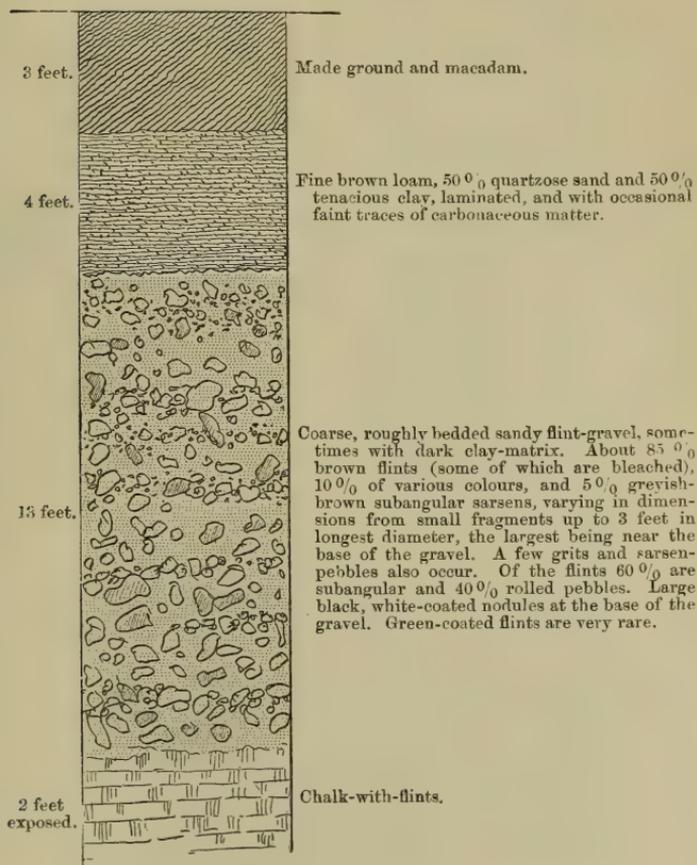
*Section of a Well in Greenham Park: 440 feet above O.D.*

ft.	in.		
12	0.	Gravel and loam (Southern Drift).	} Bagshot Beds.
2	0.	Brown loam.	
4	0.	Brown sand, with water.	
10	0.	Brown loam.	
7	0.	Blue clay.	
1	6.	Black pebbles.	
4	6.	Blue sand, little water.	
5	0.	Dead-blue sand.	
1	2.	Hard dark stone.	
5	0.	Dark-grey sand.	
2	10.	Blue sandy clay.	} Reading Beds.
36	0.	London Clay.	
	6.	Black pebbles.	
24	6.	Black sandy clay; water at base.	
4	0.	Coloured sand and clay.	
2	0.	Coloured sand.	
15	0.	Light, sharp, brown sand, with water.	
8	0.	Coloured clay and sand.	
15	0.	Mottled clay.	
13	0.	Green sand and water.	
4	0.	Black clay.	
8	0.	Hard dark-green sand.	
1	0.	Flints.	
27	0.	Hard dark-green sand and flints.	
		Chalk reached, 217 feet O.D.	

The presence of waterworn sarsens<sup>1</sup> in both the river-gravel and the Donnington gravel is another proof that these are not the Reading Beds.

Fig. 1 is a section through the Donnington gravels, near Donnington Square (road-surface 277 feet above O.D.), where the best exposure occurred.

Fig. 1.—Section in the Donnington Glacial (?) Drift, near Donnington Square. (No. 4 in the Map, Pl. XXX.)



[Vertical scale:  $\frac{1}{8}$  inch = 1 foot.]

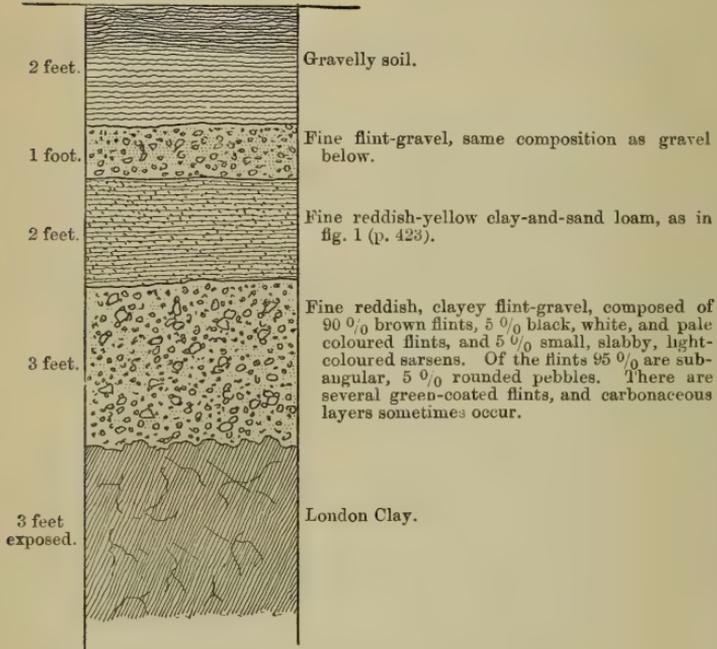
I obtained one fragment of bone in this gravel, which Mr. E. T. Newton, F.R.S., has referred to *Bison* or *Bos primigenius*.

A cutting on the Lambourne Railway, through the watershed separating the valleys of the Kennet and Lambourne, and at a little higher level than fig. 1, shows the same loam and gravel resting

<sup>1</sup> Note II. in Appendix I., p. 433.

upon an eroded surface of London Clay (fig. 2). During the railway-operations remains of *Elephas primigenius* were found very near this section, and they must presumably have occurred in this gravel.

Fig. 2.—Section in the Lambourne Railway-cutting.



[Vertical scale:  $\frac{1}{4}$  inch = 1 foot.]

At a gravel-pit on the Bath Road, near the 300-foot contour (No. 6 in the Map, Pl. XXX), I obtained another section:—

	Feet.
Gravelly soil .....	2
Red loam, siliceous grains, and fine reddish clay (laminated more or less) .....	2
Coarse flint-gravel, slightly bedded, with occasional thin lenticular inclusions of stiff, dark clay-with-flints .....	} 7 exposed.
70% large subangular brown-stained flints, with smaller ones intermingled; 20% large black flint-nodules coated white, slightly rolled; 5% well-rounded, stained flint-pebbles, always small.	
A few slightly rounded green-coated flints .....	

The colouring and appearance of the strata exactly coincide in the three sections last described.

The main points of difference between the Southern Drift and this Donnington gravel are:—(1) The great disparity in levels, amounting to a difference of about 120 feet. (2) The composition; the Glacial (Donnington) gravel containing numerous sarsenstones, also green-coated pebbles, gritstones, and large black flint-nodules, which are absent from the Snelsmore and Greenham Drift. (3) The presence of *Bison* or *Bos* and *Elephas* at Donnington,

peculiarly 'Glacial' species. (4) The non-occurrence of any fossils in the Southern Drift. The colour of the latter is grey, and the gravel is invariably bleached in the upper layers; whereas the Donnington gravel is always of a rich ferruginous brown. The matrix of both is a clayey quartzose sand; though clean patches, entirely free from clay, are often intercalated in both Drifts.

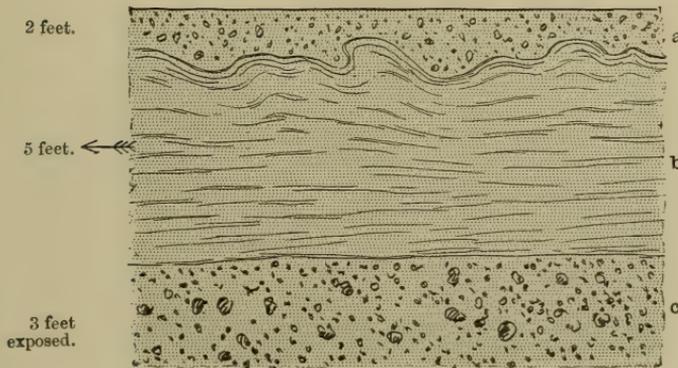
The Donnington gravel appears to thin out to the west, as the watershed region upon which it lies rises above the level of the gravel. Eastwards the carving out of the two valleys at their junction has of course removed it.

The northern boundary of this gravel is the Lambourne Valley; the southern is formed by the Kennet Valley, and the rising ground limits it westward.

#### § 4. THE UPPER RIVER-GRAVEL OR TERRACE-GRAVEL.

Below the level of the 'Glacial Drift,' at Newbury, there are fine broad terraces of 'River-gravel' on both sides of the valley. These terraces I have called 'Upper River-gravel' for the purposes of this paper. Where the base has been exposed, it is seen to rest upon firm green sands, which I conjecture are the lowest beds of the Reading Series, from the evidence given by the well at Greenham Park (p. 422). The Upper River-gravel is usually about 12 feet thick at the terrace-edges nearest the river. In Bull's Lane, on the south side of the valley, I obtained the following section:—

Fig. 3.—Section in the Upper River-gravel at Bull's Lane.  
(No. 7 in the Map, Pl. XXX.)



[Vertical scale:  $\frac{1}{6}$  inch = 1 foot.]

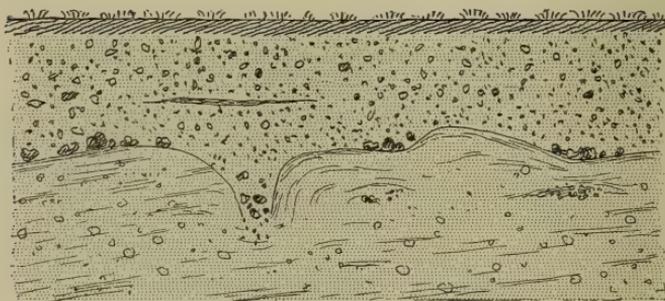
- a* = Flint-gravel of the same composition as *c*, but coarser. Surface unseen.  
*b* = Fine, soft, mealy quartzose sand with black, carbonaceous grains. Weathers to a ferruginous yellow. This bed thins out at 20 yards, in the direction of the arrow.  
*c* = Coarse flint-gravel, with large unstained, black, and white-coated flints, 1 green-coated flint, and a few red flints. No gritstone: a few rounded pebbles of quartzite and small flints. Composition as follows: 80% subangular brown flints, 19% rolled black flints, and 1% subangular sarsens, whose longest diameter is 12 inches. The matrix of the gravel is brown clay.

Here a lenticular mass of soft green sand is the lowest bed exposed, of very irregular thickness, and with an eroded surface, upon which the terrace-gravel rests. I consider this sand to have been derived higher up-stream from a former exposure of the hard green sand first mentioned. The surface-level is usually about 260 feet above O.D., but rises and falls with the general level of the river above and below Newbury, as is natural in a river-terrace gravel.

A very typical section, about 26 feet deep, is exposed in the Enborne Road gravel-pit, a little west of Newbury, and on the south side of the Kennet. It is very near the edge of the terrace.

At the base of the section (fig. 4) a thickness of 12 feet is

Fig. 4.—Section in gravel-pit on the Enborne Road, near Newbury. (No. 8 in the Map, Pl. XXX.)



[Vertical scale: 1 inch = 20 feet. Horizontal scale: 1 inch = 40 feet.]

occupied by hard, green, slightly bedded, ferruginous sand, to which the overlying mass of river-gravel is sometimes conformable and sometimes unconformable. Hard, much oxidized, ferruginous nodules, about 2 inches in diameter, are fairly numerous: they weather concentrically. The surface of this sand, upon which the river-gravel rests, is eroded: swallow-holes and inclusions of gravel being frequent in the upper portion. There are usually small sarsens<sup>1</sup> and large flint-nodules, the latter both stained and black, resting on the eroded surface, at intervals. This hard green sand may be the base of the Reading Series, judging from the evidence obtained in the Greenham Park boring (p. 422). The occasionally apparent conformity of the river-gravel, I was inclined to think (at the time of observation) due to concentric weathering of the sand from the eroded surface downward: the river-gravel being very permeable to water, and possibly to air. I may add that this was a freshly-exposed section.

The gravel shown in fig. 4 is coarser than at Bull's Lane, and a few carbonaceous layers occur; its composition is as follows:—

<sup>1</sup> About 12 inches in their longest diameter.

- 60 % subangular brown flints of all sizes.  
 20 % " " black " "  
 10 % well-rounded brown and black flints.  
 9 % subangular sarsens, up to 6 inches in longest diameter, coloured variously brown and grey. These sarsens are bigger where they rest on the sand.  
 1 % subangular green-coated flints.

The composition of this gravel does not tell us much, though a comparison with the other gravels shows it to have been derived from them both, with perhaps débris from the Reading Beds brought from higher reaches of the Kennet Valley; the larger percentage of rolled flints is noticeable. The level (260 feet above O.D.) of this gravel, and its exceptionally fine broad terraces, however, leave no doubt as to its order of formation. Geologists visiting Newbury can obtain a most comprehensive view of these Upper River-gravel terraces, from the Great Western Railway-bridge in Gashouse Road.

Worked flints of Palæolithic type may be picked up in the ploughed fields that cover the Upper River-gravel. They are usually rolled and stained like the flints. I have not been able to secure any from the gravel itself.

The animal remains were found in groups; and as the bones are quite unrolled and in fair preservation, we may consider the fauna to have inhabited the near vicinity. I obtained all the fossils in this Upper Gravel myself, with the exception of *Elephas primigenius*, which was found during excavations for the Great Western Railway some years ago.

Mr. E. T. Newton, F.R.S., to whom I am greatly indebted, kindly named these bones, in addition to other mammalian remains from Newbury. The list from the Upper River-gravel comprises *Ovis*, *Bos taurus*, *Sus scrofa*, *Equus caballus*, *Rangifer tarandus*, and *Bos primigenius*.<sup>1</sup>

The Upper River-gravel is not well shown on the north side of the Kennet (see Pl. XXX. section AB), owing to local disturbance through road-making, though  $\frac{1}{2}$  mile farther up-stream the terrace is clearly defined. A fault in the Chalk almost follows the northern terrace-edge at Newbury, and its probable position is shown in section AB. This fault was predicted by Prof. T. Rupert Jones, F.R.S., before our excavation confirmed it, his reason being the copious and steady supply of Chalk water obtained by sinking some 20 feet at the Newbury Waterworks in Northercroft, situated upon the line of fault which runs east and west with the valley.<sup>2</sup>

#### § 5. THE LOWER RIVER-GRAVEL.

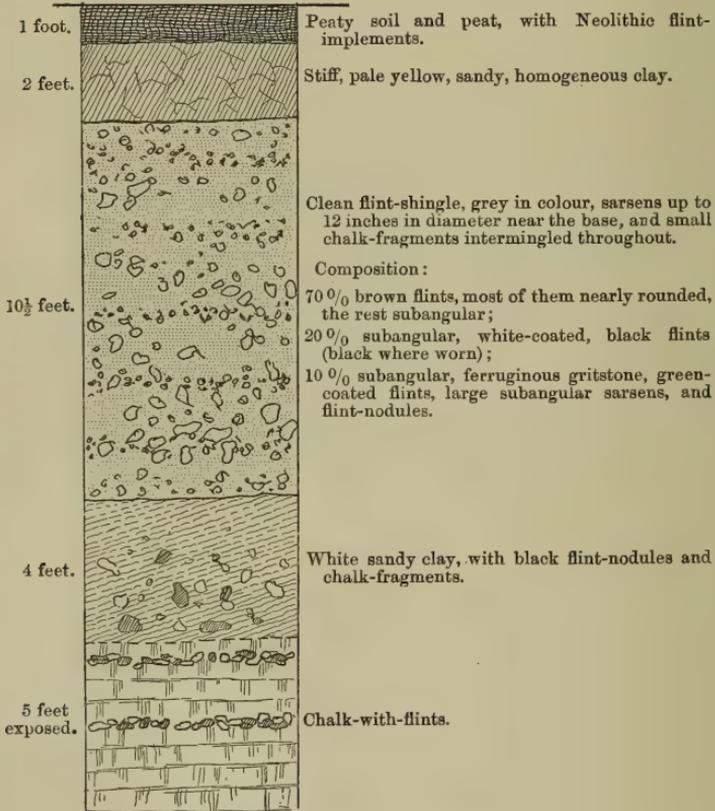
The Lower River-gravel, resting at Newbury upon the Chalk, chiefly occupies the centre of the valley; it forms the base upon which the Neolithic peat and shell-marl have been deposited, and

<sup>1</sup> [A large tusk of mammoth was found by the late Dr. Silas Palmer, of Newbury, in this gravel by the river-side at Northercroft Lane in that town, some years ago.—T. R. J.]

<sup>2</sup> Note III. in Appendix I., p. 433.

is the lowest gravel found at Newbury. It appears to be a gravel derived from all the other gravels mentioned, but with a larger percentage of flints direct from the Chalk. The finest section was exposed at the pumping-station of the drainage-works, in the flat water-meadows near the Kennet (on Cook's Farm), represented by fig. 5. The base of the gravel is about 240 feet above O.D. The white flinty clay underlying this was sticky, adhering tenaciously to the flint-nodules intermingled with it.

Fig. 5.—Section at the Pumping-station of the Drainage-works.



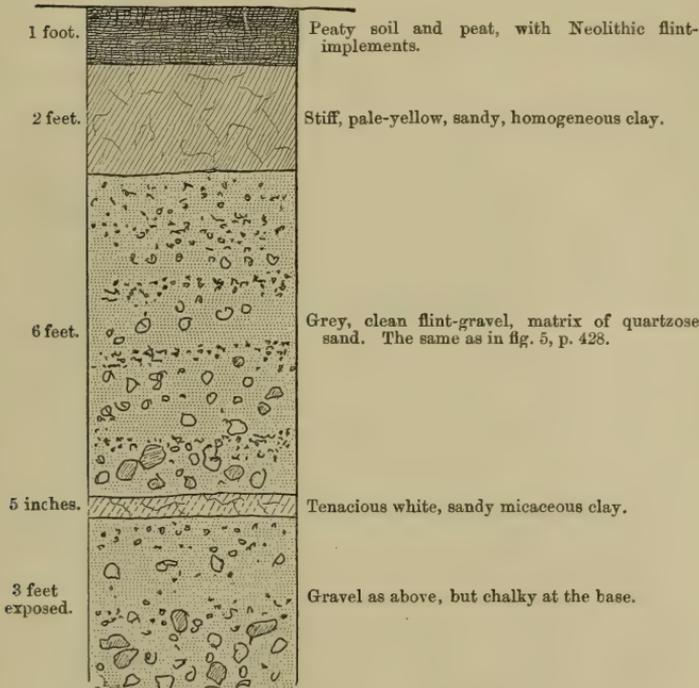
[Vertical scale:  $\frac{1}{8}$  inch = 1 foot.]

About 30 yards north of the pumping-station I obtained the section shown in fig. 6. This gravel usually has a grey appearance: the flints, unless rounded, being much battered and abraded. The matrix is frequently absent; when present, it is of the cleanest quartzose sand, and rarely the upper portion has a matrix of white shell-marl, loosely filling the interstices. The water percolated through this gravel into our sinkings at an extraordinary rate, necessitating the use of three steam-pumps at one time, to keep the water from rising in a shaft 19 feet square, when only sunk 15 feet

deep. The currents which had dealt with this lowest gravel appear to have been extremely violent, judging from the battered condition of the flints, and the absence of any matrix but the coarsest clean quartzose sand.

Wave-action and storm-beaches would be inferred if near the coast, as the gravel rises in curious ridges, which traverse the valley from side to side, more or less at right angles to the present course of the Kennet. These mounds show very little, or not at

Fig. 6.—Section 30 yards north of the preceding.  
(No. 10 in the Map, Pl. XXX.)



[Vertical scale:  $\frac{1}{4}$  inch = 1 foot.]

all, upon the surface; but the peat, clay, and marl thin out over these old lines of lake-barriers. This is what we expect, and have found, in valleys debouching upon the sea-coast; and at Newbury the lacustrine deposits certainly in several instances do repose behind successive barriers of this battered gravel.

No traces of shells or organic remains of any kind have, however, been forthcoming from this gravel, and we know of no submergence at the period whereof we treat which turned the Kennet Valley into an arm of the sea; the wave-action hypothesis is, therefore, untenable. Is it possible that ice-action, or heavy water-action following the close of the Ice Age, could have had anything to do with the origin of the barriers? Here fuller investigation is doubtless necessary.

## § 6. THE NEOLITHIC LAKE-SERIES AND RECENT DEPOSITS.

Section CD, in Pl. XXX, shows two of these ridges (see Map), which I have been able to trace more or less completely across the valley. Gaps appear in them near the present river-channel; and they appear to have been cut by ancient river-action, which gradually drained the lakes, leaving the peat and marl to ultimately clothe themselves with meadow and wood.

The typical strata in these Neolithic lake-basins are well illustrated in fig. 7, taken in Northbrook Street. The beds shown in this interesting section are fairly constant throughout the two lake-sites, with the exception of the green loam, which is frequently absent. The successive stages of formation, and the subsequent disappearance of the lakes, are well marked by the strata. First the clay, probably deposited over the lower gravel by the river when in flood; next the partial barrier, producing a peat-marsh and the peaty pools, in which the green loam was laid down; followed by a further raising of the barrier, sufficient to drown the peat and form a lake, the water teeming with the mollusca found in the white shell-marl; and lastly, the breached barrier draining the lake.

The peat and marl are very constant associates throughout; and, as a rule, where the peat is thick the marl is thin, and *vice versa*. This I account for by supposing the thin peat to indicate the deepest parts of the lake-bottoms, which would be the first portions converted into pools, stopping the growth of peat and giving a more prolonged period for the deposition of marl. The contrary of this would, of course, explain the thick marl and thin peat; the differences in level, however, are not sufficient to clearly show this.

Taking this little lake-series in order:—the base, which rests upon the 'Lower River-gravel,' is generally a bed of very stiff, dark-yellowish clay, probably resulting from the denudation of surrounding London Clay hills. Several roughly-worked black flints were found in this clay, and occasional pieces of rolled wood, but no bones.

The green loam lying above it consists of about equal parts of fine sand and dark-greenish clay. Freshwater shells and logs of birch and oak, with leaves, twigs, and nuts of the hazel, occur frequently, and are identical with those in the peat above. I obtained a pelvis of roe deer from the green loam near the pumping-station.

The peat next in the series is of great interest as being here the chief repository of human relics.<sup>1</sup> Among those found were flint-implements, one fragment of carved bone, pieces of sun-dried pottery, and bone-drills, all of Neolithic types. No bronze or iron weapons were found in the peat. I observed a kidney-shaped pebble of Bath Oolite in the peat, the presence of which I attributed to human agency.

As in the green loam underneath, logs of birch, oak, and fir (trunks and roots) were abundant. I also found large tree-fungi,

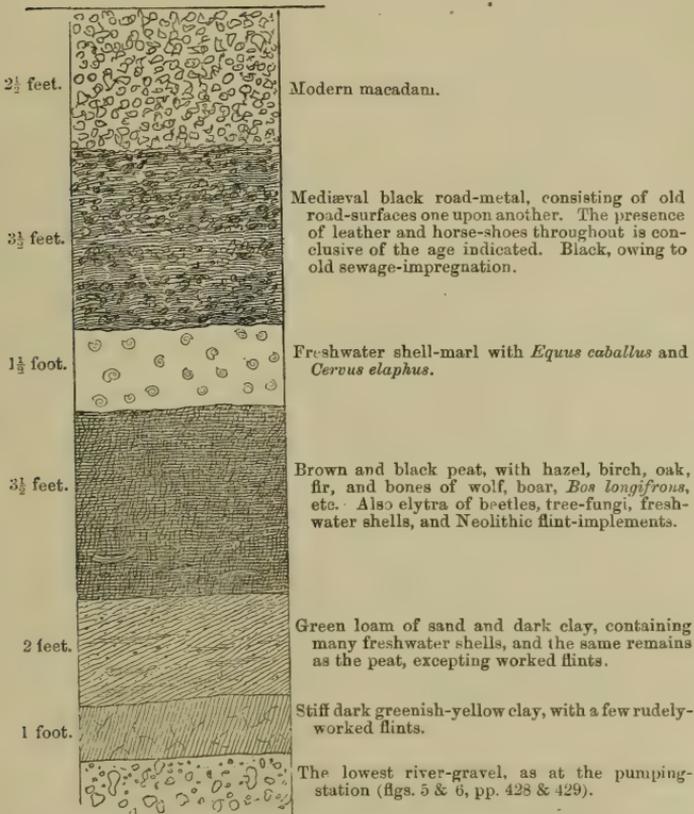
<sup>1</sup> Note IV. in Appendix I, p. 433.

elytra of beetles, sedges, bracken, and hazel-nuts. Bones and teeth of the following animals occurred:—

- |                                  |                              |
|----------------------------------|------------------------------|
| 1. <i>Bos longifrons</i> .       | 7. <i>Sus scrofa</i> .       |
| 2. <i>Rangifer tarandus</i> (?). | 8. <i>Ovis</i> .             |
| 3. <i>Cervus elaphus</i> .       | 9. <i>Canis familiaris</i> . |
| 4. <i>Capreolus caprea</i> .     | 10. <i>Canis lupus</i> .     |
| 5. <i>Equus caballus</i> .       | 11. <i>Mustela martes</i> .  |
| 6. <i>Capra hircus</i> .         |                              |

The reindeer was represented only by a drilled and ornamented piece of antler, and it is doubtful whether this animal was contem-

Fig. 7.—Section in Northbrook Street, Newbury.



[Vertical scale:  $\frac{1}{4}$  inch = 1 foot.]

porary with the peat. The other remains, both vegetable and animal, indicate a temperate clime, unsuited to the reindeer. This piece of antler, however, is interesting as being a slender bit of evidence for a migration of Man from the North. The marten, however, indicates a colder climate than that of modern Berkshire.

I found numerous flint-implements in the peat, including one axe-like instrument, many scrapers, knives, and needle-like flints, together with wasters in abundance. Traces of fire were frequent in calcined flints and quantities of charcoal-fragments. Nearly all the marrow-bones of the animals were split longitudinally. Many of the flints were quite unused, and their fine keen edges distinctly indicated that they had been made where found.

The freshwater marl, composed of land and freshwater shells, attains its greatest thickness, 8 feet, in Market Street. Here, as elsewhere, it is very loose and friable.<sup>1</sup> It is always white or greyish in colour.

A list of shells has been very kindly supplied by Mr. B. B. Woodward, F.G.S. (See Appendix II, p. 434.)

Mr. Woodward considers the series to indicate a climate similar to our own, adding, however,—‘A more extended list might, of course, furnish other data.’

I obtained also remains of the following animals:—*Equus caballus*, *Cervus elaphus*, and *Capreolus caprea*. These always occurred in groups, parts of single skeletons being dug out bone by bone, and always quite unrolled. In the peat the bones were scattered.

Before leaving this part of the subject it should be mentioned that we unearthed a pile-dwelling opposite, if not partly under, the ‘Coopers’ Arms’ in Bartholomew Street, a few hundred yards south of Newbury Bridge, about 6 or 7 feet under the roadway. It was constructed of fir-piles, about 6 inches in diameter, driven into the peat, and with numerous parallel timbers crossing the pile-tops; the surface of the platform was at the surface of the peat. We exposed only a very small portion of this structure, and I was unable to find the method of affixing the horizontal timbers to the piles. They must have been fixed, otherwise when the lake covered them they would have floated, for the marl covers the platform.

Just above the shell-marl and peat in Northbrook Street and elsewhere is a black abraded gravel (see fig. 7, p. 431), consisting of old layers of road-metal. The lowest are probably of Roman age; the upper portions are mediæval; the maximum thickness is about 7 feet. The whole has been blackened by ancient sewage. On the top of this is the modern ‘macadam’; 18 inches beneath the present road-surface cannon-balls and weapons of the 17th century were discovered.

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Prof. T. Rupert Jones, F.R.S., has very kindly given me his valuable advice and useful help in finding references and in making notes upon some important particulars. See Appendix I.

<sup>1</sup> [Hard, ovoidal, concretionary nodules of the marl have been noticed in this deposit at and near Newbury, and close to the Thames at Old Windsor, Berks.—T. R. J.]

## APPENDIX I.

1. (1) Dr. Buckland treated of some points in the geology of Newbury in his memoir 'On the Formation of the Valley of Kingsclere and other Valleys by the Elevation of Strata that enclose them; and on the Evidences of the Original Continuity of the Basins of London and Hampshire,' in *Trans. Geol. Soc. ser. 2, vol. ii.* (1826) pp. 119-130, illustrated with a geological map of 'The Valleys of Kingsclere and Ham in the Basin of Newbury' (pl. xvii).
  - (2) The geology of the Newbury district was described and illustrated in 'A Lecture on the Geological History of the Vicinity of Newbury, Berks,' by T. Rupert Jones (1854). See also the Rev. John Adams, 'Geological Sketch of the Kennet Valley,' *Wilts Archæol. & Nat. Hist. Soc. Mag.* vol. xi. (1869) pp. 274, etc.
  - (3) Prof. (afterwards Sir Joseph) Prestwich has alluded to several particulars in the geology of the neighbourhood of Newbury in *Quart. Journ. Geol. Soc.* vol. x. (1854) pp. 86, 87, & 129, & vol. xlvi. (1890) p. 162.
  - (4) Geological notes on this part of Berkshire have been given in *Mem. Geol. Surv. Expl. Sheet 13*, 1861; *Expl. Sheet 12*, 1862; and *Expl. Sheet 7*, 1864.
  - (5) Many facts and opinions as to the geological structure of the district are mentioned in the four volumes of the *Transactions of the Newbury District Field Club*, as follows:—vol. i. (1871) pp. 21-32, 104-109; vol. ii. (1878) pp. 2-6, 64, 246-250; vol. iii. p. 101; vol. iv. pp. 206-210.
- II. A full account of the characters, position, and origin of the sarsens or sarsenstones was given by Prof. T. Rupert Jones in *Wilts Archæol. & Nat. Hist. Soc. Mag.* vol. xxiii. (No. 68, December 1886) pp. 122-154; with a bibliographic list of references. In a note on p. 133 it is stated that 'sarsens are particularly abundant in the gravel of the Kennet Valley, near Newbury' (Enborne Road, for instance). These are small waterworn pieces of the original large blocks, such as are still abundant on some of the uplands traversed by the Kennet.
- III. See Mr. Grover's 'Report on the New Water-Supply at Newbury,' *Trans. Newbury District Field Club*, vol. ii. (1878) pp. 246-248.
- IV. A human skull from the peat was referred to by Dr. Buckland in *Trans. Geol. Soc. ser. 2, vol. ii.* (1826) p. 128. Dr. Rolleston described this skull and another in *Trans. Newbury District Field Club*, vol. ii. (1878) pp. 241-245. Remains of two other human skulls from the peat are mentioned by Dr. Palmer in his memoir 'On the Antiquities found in the Peat of Newbury,' *Trans. Newbury District Field Club*, vol. ii. (1878) pp. 123-134. The Appendix to that paper (pp. 135-147) contains interesting descriptions of the peat from older writers.

Flints exhibiting traces of human workmanship, from the peat-fields, have been noticed; and those found by the present Author in the peat and gravels of Newbury are enumerated at p. 208 (vol. iv.) of the same Transactions, in his notes contributed to Mr. Walter Money's memoir 'On the Prehistoric and Mediæval Antiquities found at Newbury during the Drainage Operations in 1894.' A general geological section through Newbury (pl. ii) was also contributed by Mr. Richards at the same time.

A list of mammalian remains from the peat and marl was published in T. Rupert Jones's 'Lecture Geol. Newbury,' 1854, p. 41. This was copied in Mem. Geol. Surv. Expl. Sheet 12, 1862, p. 48, with a mark of doubt to *Ursus spelæus* [?]. It may probably have been *U. arctos*.

In Dr. Palmer's memoir above referred to (pp. 131-133) the list of mammalian relics from the peat-beds includes—

Wolf.	Ass.
Badger.	Red Deer.
Otter.	Roe.
Bear.	Goat.
Beaver.	Gigantic fossil Ox, or Ure Ox.
Water-Vole.	Long-fronted or small fossil Ox.
Horse.	Wild Boar.

See also Owen's 'British Fossil Mammals and Birds,' 1846, pp. 193 etc.

Such as were found during the excavations for the drainage in 1894 are briefly mentioned in Trans. Newbury District Field Club, vol. iv. (1895) p. 209.

An antler of *Cervus megaceros* is said to have been dug out of the peat of the Kennet Valley a few miles below Newbury, Geol. Mag. 1891, pp. 95 & 480.

- V. Prof. T. Rupert Jones's list of the land and freshwater shells found in the peat and shell-marl was reproduced in Mem. Geol. Surv. Expl. Sheet 12, 1862, p. 48 (with the nomenclature after Sowerby's 'Illustrated Index,' etc., 1859, instead of Turton's 'Manual,' etc., 1840), and slightly shortened.

The seed-vessels of *Chara* were also noticed, and some Cyprididæ, which were described (Annals & Mag. Nat. Hist. ser. 2, vol. vi. 1850, pp. 25-27 & pl. iii. figs. 3, 7 & 8) as *Cyprid setigera*, *Candona reptans*, and *Candona lucens*.

## APPENDIX II.

### VI. NOTES on the MOLLUSCA from the KENNET VALLEY DEPOSITS. By A. S. KENNARD, Esq., and B. B. WOODWARD, Esq., F.L.S., F.G.S.

The first list of the mollusca from the Holocene deposits of the Kennet Valley at Newbury was given in 1854 by Prof. T. Rupert Jones ('Lecture on the Geological History of the Vicinity of Newbury,' pp. 41, 42), and contained fifty-one names. The collection on which this list was founded was made in 1842 by Prof. Rupert

Jones, and his friend Mr. J. Pickering furnished him with the list. Two years later Mr. S. V. Wood enumerated forty-five species, all of which are contained in the previous catalogue, the printer perhaps being responsible for the missing species ('Monogr. Crag Mollusca,' vol. ii. pp. 304-310). In 1883 one of us pointed out that the single example of *Helix aspersa* recorded as occurring in the Newbury marl was probably of quite recent date, since the numerous pits which from time to time have been dug in the peat quickly fill up ('Science Gossip,' 1883, pp. 115, 237). This will also account for the fact that Saxon remains have been found at a depth of 10 feet in the peat. All efforts to trace Mr. Pickering's collection have failed; but there is a series of shells from these and other Pleistocene deposits in the British Museum (Natural History), which series had been presented by him to the Geologists' Association,<sup>1</sup> and transferred by that body to the National Collection. This has been supplemented from a series in our own possession.

From these sources we have been enabled to compile a list of forty-two species, seven of which have not previously been recorded. Besides *Helix aspersa*, it has been considered advisable to reject five other records as being probable errors in identification, namely, *Limax carinatus* [= *Amalia Sowerbyi*, Fér.]; *Zonites* [= *Vitrea*] *alliaria*; *Helix hortensis*, an error for *H. nemoralis*; *Helix* [= *Helicella*] *virgata*, and *Vertigo alpestris*. Two of Mr. Pickering's species are now considered as only varieties of other forms.

The list thus shows now a total of fifty species:—

<i>Agriolimax agrestis</i> , Linn.	<i>Limnæa pereger</i> , Müll.
<i>Vitrea nitidula</i> , Drap.	— <i>palustris</i> , Müll.
— <i>radiatula</i> , Ald.	— <i>truncatula</i> , Müll.
<sup>2</sup> — <i>crystallina</i> , Müll.	<sup>2</sup> — <i>stagnalis</i> , Linn.
— <i>fulva</i> , Müll.	<i>Planorbis corneus</i> , Linn.
— <i>nitida</i> , Müll.	— <i>albus</i> , Linn.
<sup>3</sup> <i>Arion ater</i> , Linn.	<sup>3</sup> — <i>glaber</i> , Jeff.
<i>Pyramidula rotundata</i> , Müll.	— <i>nautilus</i> , Linn.
<i>Vallonia pulchella</i> , Müll.	— <i>marginatus</i> , Drap.
<i>Hygromia hispida</i> , Linn.	— <i>vortex</i> , Linn.
<sup>2</sup> — <i>granulata</i> , Ald.	— <i>spirorbis</i> , Linn.
<sup>2</sup> — <i>rufescens</i> , Penn.	— <i>contortus</i> , Linn.
<i>Helicigona arbustorum</i> , Linn.	— <i>fontanus</i> , Light.
<sup>3</sup> <i>Helicella ericetorum</i> , Müll.	<sup>2</sup> <i>Physa fontinalis</i> , Linn.
<i>Helix nemoralis</i> , Linn.	<sup>3</sup> — <i>hypnorum</i> , Linn.
<i>Cochlicopa lubrica</i> , Müll.	<i>Bythinia tentaculata</i> , Linn.
<i>Pupa muscorum</i> , Linn.	— <i>Leachii</i> , Shepp.
<sup>3</sup> <i>Vertigo antivertigo</i> , Drap.	<i>Valvata piscinalis</i> , Müll.
— <i>pygmæa</i> , Drap.	— <i>cristata</i> , Müll.
<i>Succinea putris</i> , Linn.	<sup>2</sup> <i>Neritina fluviatilis</i> , Linn.
— <i>elegans</i> , Riss.	<i>Sphærium corneum</i> , Linn.
<i>Carychium minimum</i> , Müll.	<i>Pisidium amnicum</i> , Müll.
<i>Ancylus fluviatilis</i> , Müll.	— <i>pusillum</i> , Gmel.
— <i>lacustris</i> , Linn.	— <i>fontinale</i> , Drap.
<sup>2</sup> <i>Limnæa auricularia</i> , Linn.	<sup>3</sup> — <i>milium</i> , Held.

One egg of a small *Helix* was also found.

<sup>1</sup> Proc. Geol. Assoc. vol. i. (1860) pp. 85-87.

<sup>2</sup> Included in the list on the authority of Mr. Pickering.

<sup>3</sup> Not recorded before from Newbury.

Of these the most noteworthy are *Arion ater*, *Planorbis glaber*, and *Pisidium milium*. The last-named form has hitherto been unrecorded in a fossil state in this country. At the present time it is a widely distributed, though local, species. *Planorbis glaber*, though extremely abundant in Pleistocene deposits, is equally rare in those of later date, and its area of distribution has certainly diminished. *Arion ater* has only once been recorded from any deposit in this country, and that is one of doubtful age near Maidstone; but it has probably been overlooked, since the internal calcareous granules are very small indeed, and these are the only portions which would be preserved in a deposit.

Our collection has been derived from three sources:—firstly, a series collected by one of us during an excursion of the Geologists' Association to Newbury<sup>1</sup>; secondly, some specimens sent by Mr. F. J. Bennett, F.G.S.; and, lastly, a large quantity of material forwarded by Mr. E. Percy Richards, F.G.S. It is noteworthy that from each a different series of forms has been obtained. Thus, in the first case, *Helix nemoralis*, *Bythinia tentaculata*, and *Helicella ericetorum* occurred, though unknown in the other two. Mr. Bennett's specimens included numerous examples of *Valvata piscinalis*, which are the only specimens that we have seen; while the material from the last source was certainly deposited in swampy ground and not in deep water, as evinced by the abundance of *Vertigo antivertigo*, *Carychium minimum*, *Arion ater*, *Agriolimax agrestis*, and *Limnæa truncatula*—forms which are characteristic of such localities.

#### PLATE XXX.

Map of Newbury and sections in the immediate neighbourhood of the town.

#### DISCUSSION.

Mr. E. T. NEWTON referred to the careful and detailed work contained in this paper, which he thought would prove a valuable addition to our knowledge of the beds immediately succeeding the Pleistocene gravels, and would help to a better understanding of the events which came between Palæolithic and Neolithic times; he also remarked on the vertebrate-remains which had been collected by the Author, not only from the undoubted Pleistocene gravels, but also from the Neolithic and more recent deposits.

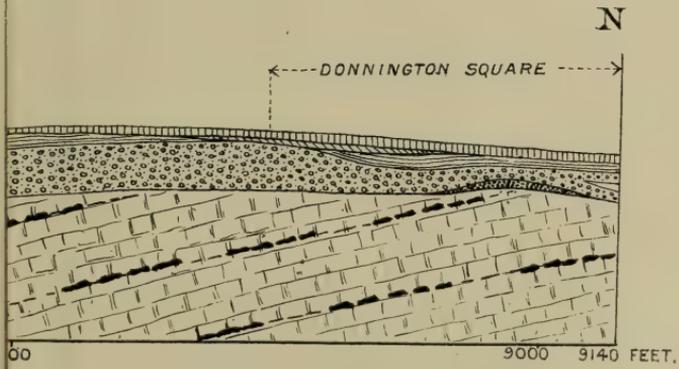
Mr. MONCKTON thought it a pity that the term 'Glacial Gravel' was used for the gravel near Donnington Square, as it did not appear from the account of its composition given in the paper that it belonged to the class of gravels included in the Glacial Drift by most modern authors (see remarks by Mr. Whitaker, 'Geol. of London,' vol. i. 1889, p. 299). The speaker had examined all the sections in gravel that he could find near Newbury, but had not seen anything which he should include in the Glacial Drift. Thus he had not found boulders or pebbles from the Triassic pebble-beds.

<sup>1</sup> Proc. Geol. Assoc. vol. vi. (1879) p. 185.

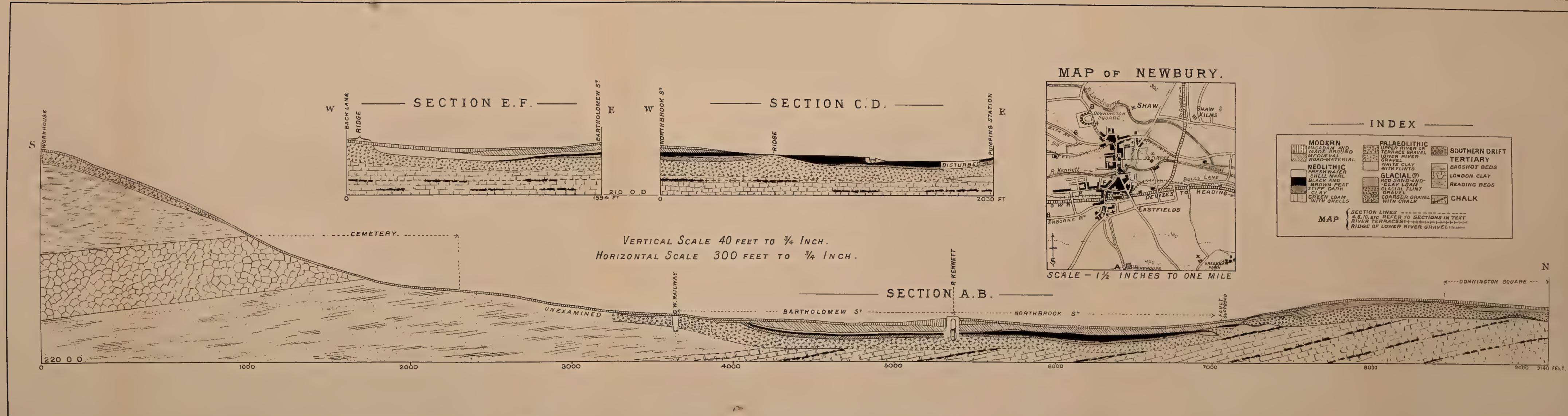
INDEX

	<b>PALAEOLITHIC</b> UPPER RIVER OR TERRACE GRAVEL		<b>SOUTHERN DRIFT</b>
	LOWER RIVER GRAVEL		<b>TERTIARY</b> BAGSHOT BEDS
	WHITE CLAY WITH FLINTS		LONDON CLAY
	<b>GLACIAL (?)</b> RED SAND-AND- CLAY LOAM		READING BEDS
	GLACIAL FLINT GRAVEL		<b>CHALK</b>
	COARSER GRAVEL WITH CHALK		

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 E OF LOWER RIVER GRAVEL |||||

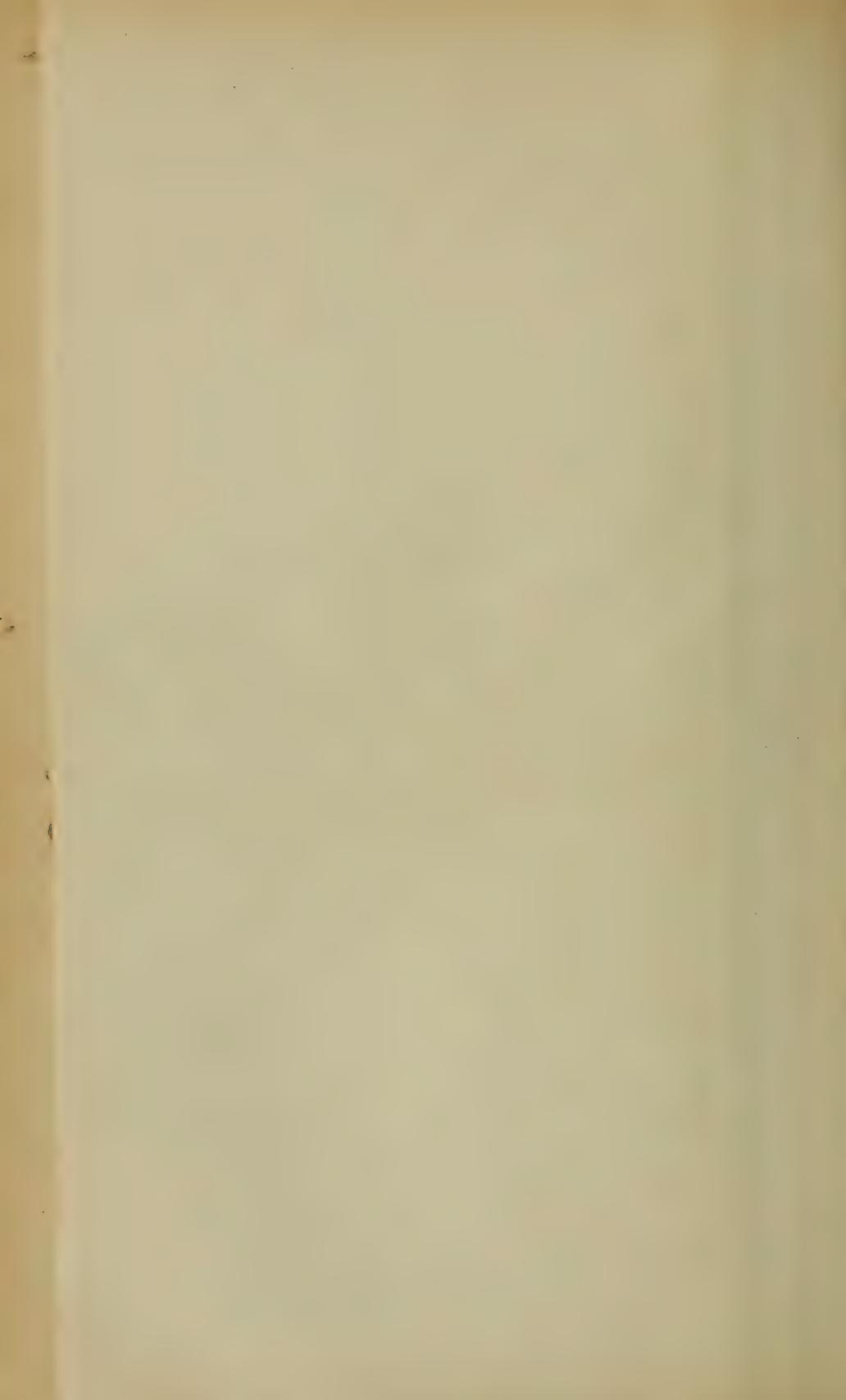






E.P. Richards del.

Minton Bros. lith.



or of igneous rock. Referring to the Southern Drift of Snelsmore Common, the speaker said that a few quartz-pebbles up to  $\frac{1}{4}$  oz. weight occur, but that he had failed to find fragments from the Lower Greensand.

Mr. H. B. WOODWARD remarked that he had seen, under the guidance of Mr. F. J. Bennett, some of the plateau-gravels near Newbury, and he asked whether they might be of Bagshot age. The only reason for grouping them as Drift seemed to be the fact that these gravels contained a few foreign stones; but now that Mr. Clement Reid had shown that the Bagshot Beds of Dorset contained many kinds of rock-fragments, it would be well to reconsider the age assigned to the high-level Newbury gravels.

Mr. A. E. SALTER was much interested in the descriptions of the various gravel-deposits, occurring as they do near the centre of the valley of a river—the Kennet—the water-parting of which on three sides was over 500 O.D. The composition of the gravels on Snelsmore and Greenham Commons was singularly like that at Upper Hale near Aldershot (615 to 475 feet above O.D.), where also large sarsens occur near the base. Deposits referable to the so-called 'Westleton Shingle' were apparently absent, and no mention had been made of the occurrence of Greensand chert. According to the list of constituents given as occurring in the Donnington and Bath Road gravels, they were not necessarily of Glacial origin. They do not appear to contain any transported material from the North, and as their situation is peculiar it would be interesting to know upon what grounds they are so designated by the Author.

Mr. R. S. HERRIES said, with regard to Mr. H. B. Woodward's suggestion, that he did not think the gravels on Snelsmore Common could be of Bagshot age, and referred to a paper by Mr. Monckton and himself in the Proceedings of the Geologists' Association for 1889, where his reasons would be found.

Mr. W. WHITAKER also spoke.

Prof. T. RUPERT JONES replied on behalf of the Author.

31. *On the MORTE SLATES, and ASSOCIATED BEDS, in NORTH DEVON and WEST SOMERSET.—PART II.*<sup>1</sup> By HENRY HICKS, M.D., F.R.S., P.G.S. With DESCRIPTIONS of the FOSSILS by the Rev. G. F. WHIDBORNE, M.A., F.G.S. (Read April 7th, 1897.)

## [PLATES XXXI-XXXV.]

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## I. INTRODUCTION.

SINCE the first part of this paper was published (May, 1896) I have had another opportunity of visiting North Devon and West Somerset, the former district as one of the Directors of the Excursion of the Geologists' Association in July 1896, and the latter district in company with the Rev. G. F. Whidborne, M.A., F.G.S., the Rev. H. H. Winwood, M.A., F.G.S., Mr. J. G. Hamling, F.G.S., Mr. R. S. Herries, M.A., F.G.S., and Mr. Upfield Green, F.G.S. The only addition to the fauna in North Devon was the discovery near Barricane, in Morte Bay, of a portion of an *Orthoceras* (by Dr. Barrois, F.M.G.S.); but in West Somerset some forms not previously known to occur in that area were obtained.

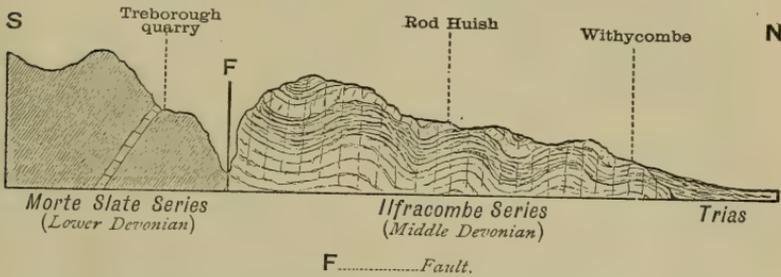
The faunas so far discovered in West Somerset differ very markedly from those found in the Morte Slates in North Devon, and belong to higher horizons in the succession; but it must be understood that there are still large areas which have been but imperfectly explored. In so great a thickness also, occupying an average width in West Somerset of from 5 to 6 miles, it is only natural to suppose that several other faunas must occur, especially as in the faunas already described there appear to be few, if any, fossils in common. As many parts of this district are very inaccessible, and the exposures comparatively few, much time will have to be spent before anything like a complete examination can be made. The evidence so far obtained, however, is so important in its bearing on the succession of the Devonian rocks in North Devon and West Somerset that I venture to submit it to the Society.

The first discovery of fossils in the so-called Morte Slates of West Somerset was made in the spring of the year 1895 by Mr. Whidborne, Mrs. Whidborne, and myself in the slate-quarry

<sup>1</sup> For Part I., see this Journal, vol. lii. (1896) pp. 254-272 figs. & pls. x-xi.

at Treborough. (See Map, Pl. XXXV, & section, fig. 1.) In July of the same year Mr. Hamling was good enough, at my request, to visit the Oakhampton slate-quarry near Wiveliscombe, and afterwards to send me some specimens. In the following August Mr. Hamling, Mr. Whidborne, and I collected other specimens from this quarry, and afterwards we also obtained some fossils from the Combe quarries near Whitfield, on the opposite side of the ravine

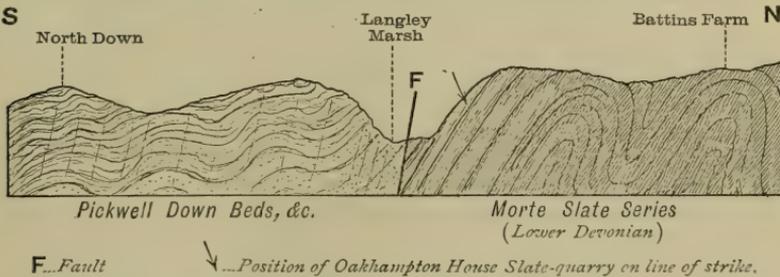
Fig. 1.—Section from Treborough to Withycombe.



[Horizontal scale = about 1 inch to the mile.]

(fig. 2). Both the Oakhampton and the Treborough quarries have been since visited by us on many occasions, and numerous fossils have been collected from each. We have also made several traverses across the district intervening between Treborough and Oakhampton, and have explored the rocks to the north and south, and collected largely from those beds.

Fig. 2.—Section from North Down to Battin's Farm.



[Horizontal scale = about 1 inch to the mile.]

The so-called Morte Slates vary considerably in character in different areas, and probably include beds of very different age. Some of these may be faulted patches thrust in among the older rocks; but as there is no palæontological evidence to guide us as to their age, they cannot, at present, be properly classified. Faults are of frequent occurrence, and the beds in places are much crushed, though not so much as in North Devon. The boundary-lines between the

so-called Morte Slates and the Ilfracombe Beds on the north, and between the former and the Pickwell Down Beds on the south, are probably throughout faulted junctions. Many areas beyond the limits of the accompanying map have been examined, but the only new evidence of importance from those areas has been the discovery of plant- and fish-remains in the Pickwell Down Sandstones, which are in contact with the Morte Slates near Barlinch Abbey in the Exe Valley, and of plant-remains in the Hangman Grits at Timberscombe. I must not omit to express my great indebtedness, for much valuable information and guidance to localities, to the valuable papers on these areas by Mr. R. Etheridge, F.R.S., and by Mr. Ussher, F.G.S., of the Geological Survey, and the late Mr. Champenowne, F.G.S.

## II. THE TREBOROUGH DISTRICT.

The line of junction between the so-called Morte Slates and the Ilfracombe Beds in this area has been hitherto but imperfectly defined, mainly owing to the fact that there is at Treborough a fairly thick band of limestone in association with the slates; for, as is well known, it has been generally assumed that the Morte Slates in North Devon are entirely devoid of limestone-deposits.<sup>1</sup> In his map (*Quart. Journ. Geol. Soc.* vol. xxiii. 1867, p. 580) Mr. Etheridge gives the line of division as north of Exton, passing by Treborough to Monksilver, and at p. 602 he says:—‘It may be assumed with but little hesitation that a line drawn from Lee Bay to Challacombe (north of Bratton Down), Eyeson Hill, and Treborough would nearly indicate the marked division that takes place between the lower group of slates, with its associated limestones and well-marked Middle Devonian fauna, and the higher, pale-grey, glossy, unfossiliferous series, accompanied by the quartz-veins that form so conspicuous a feature at Lee Bay, Bull Point, Rockham Bay, and Morteheoe,<sup>2</sup> and which unmistakably strike from the sea on the west to Wiveliscombe on the east, passing north of Bittadon, Arlington, Withypool, Winsford, the Exe Valley, and Exton Hill,’ a distance in length of over 40 miles. Mr. Ussher, in his map in the *Proceedings of the Somersetshire Archæological & Natural History Society for 1889* (vol. xxxv) has not attempted to separate the Morte Slates from the Ilfracombe Beds, merely dividing them as Upper (Morte) and Lower (Ilfracombe) Beds in the Middle Devonian, and at p. 20 he says:—‘These slates occupy an area of about 90 square miles in Sheet 20. There is even less distinction between the upper and lower portions than in the typical districts from which their names are derived. The upper part is less evenly fissile than in North Devon, and does not maintain so uniformly its pale green-grey tint.

<sup>1</sup> It is a mistake to say that there are no limestone-bands in the Morte Slates of North Devon, for I have found several, usually in a decomposed state on the surface, in Morte Bay, Lee Valley, and elsewhere.

<sup>2</sup> In the first part of the paper I stated that the quartz-veins so frequently seen in the Morte Slates in North Devon occur in fault-lines, and where the folds have been much crushed.

The lower beds are distinguished, as a whole, by the presence of grits and masses of limestone, and by greater variety of colour and texture.'

As the Treborough Slates are unlike any slates which occur in the typical Ilfracombe Beds, and are essentially like the slates which crop up in the adjoining areas to the south, marked by all as 'Morte Slates,' it is quite clear that they should be classed with the latter, and not with the Ilfracombe Beds. Moreover, the Ilfracombe Beds, as may be seen in the section (fig. 1, p. 439), are separated from the Treborough Slates by a well-marked fault. The palæontological evidence also shows that these slates belong to much lower horizons in the succession than the Ilfracombe Beds. The stratigraphical evidence further seems to point to a physical change of some importance as having affected the area after the deposition of the Treborough and Oakhampton Slates, and before the Ilfracombe Beds had been laid down. The lowest Ilfracombe Beds, immediately beyond the fault, are massive sandstones, sometimes conglomeratic, dipping away to the north-east at a low angle (about 20°). The Treborough Slates south of the fault, on the other hand, dip at a high angle (60° to 80°) almost due south. No fossils had been recorded from the Treborough slate-quarries until we discovered them in 1895, though numerous forms characteristic of Middle Devonian rocks in other areas have been mentioned by Mr. Etheridge, Mr. Spencer Percival, and others, from the limestone-bands in the Ilfracombe Beds to the north, namely, at Goldsoneot, Rod Huish, and Withycombe.<sup>1</sup> These beds, as shown in the section, are repeated in gentle folds with a general inclination to the north-east, hence away from the Treborough Slates. In the Treborough quarries the fossils described by Mr. Whidborne occur in beds below the limestone-bands, and the latter at present have yielded only fragments of encrinurites and some imperfect corals. These limestone-bands are much cleaved, and differ greatly in appearance from any of the limestones in the Ilfracombe Beds to the north. They also contain much more argillaceous material than the latter. The slates in the quarry are hard and well cleaved, and, as the cleavage runs nearly in the line of the bedding, the fossils on the whole are not much distorted. The most characteristic fossil seems to be the large *Strophomena* (originally *Leptaena explanata*, and mentioned by Sowerby as occurring in the then so-called Silurian rocks of the Rhenish provinces), of which a great number of specimens have been collected. Up to the present the following is the list, as made out by Mr. Whidborne:—*Dalmanites* sp., *Homalonotus* sp., *Gossetia*? *Kayseri*, Frech, sp.?, *Cypricardinia*? sp., *Grammysia*? sp., *Spirifera* sp., *Strophomena* (*Stropheodonta*) *explanata* (Sowerby), *Streptorhynchus*? *persarmentosus* (M'Coy), *Chonetes plebeia*, Schnur, *Ch. sarcinulata*, Schlotheim, *Petraia* sp., *Eridophyllum* sp., *Cladichonus* sp., crinoid-segments, and sponge-spicules.

<sup>1</sup> At Rod Huish we collected numerous corals and other fossils in a fine state of preservation, which Mr. Whidborne at once recognized as the same species as those found in the Middle Devonian Limestone of Torquay.

## III. THE BRENDON HILLS.

In following the section southward from Treborough Quarry, there appears to be very little change in the character of the deposits until we reach Treborough Common, and the dip is everywhere at a high angle. Here, however, the beds are more sandy and flag-like in character, but often much crushed. The change is so marked that I have classed them under the name of Brendon Hill Series. At some points they could easily, from their mineral character, be classed with some of the Hangman or Pickwell Down Beds; and beds of like appearance farther west have been coloured by Mr. Ussher on his map as Pickwell Down Beds, thrust in by faults among, or reposing upon, the Morte Slates. They occupy an area of more than a mile in width, and the Brendon Hill mines of iron-ore occur in them. The evidence would lead one to suspect that some at least of these beds are much newer than the Treborough or Oakhampton Slates, and that they occur here as the result of faults, in a crushed and broken condition, among the older rocks. They extend evidently for a considerable distance in an east-and-west direction, and form the highest ground in the area. South of the Brendon Hills slates are again found on the surface, the beds dip at a high angle, and are repeated in numerous folds until we reach the neighbourhood of the Oakhampton and Combe slate-quarries.

## IV. THE WIVELISCOMBE DISTRICT.

The slates of the Oakhampton and Combe quarries north of Wiveliscombe have been universally classed with the Morte Slates of North Devon, and Mr. Etheridge refers to them in the following words (*Quart. Journ. Geol. Soc.* vol. xxiii. 1867, p. 592):—‘From Hawkham through the Oakhampton House Quarries, Whitfield, etc., we are unmistakably in the grey fissile slates of Morte-hoe and Morte Bay, which here dip south from  $65^{\circ}$  to  $70^{\circ}$ , with cleavage coincident, but in some places nearly vertical; the same system of quartz-veins that occurs at Lee, Morte-hoe, and Woolacombe occurs here—a circumstance, connected with other features, tending to clearly identify their position below the range of the Upper Old Red Sandstone before mentioned.’ Mr. Etheridge makes the slates pass conformably under the Pickwell Down Sandstones of Maundown; but Sir H. De la Beche and Prof. Jukes inserted a fault between the two series, and indicated it as passing in an east-and-west direction through Langley Marsh. It seems to me that there is undoubtedly a well-marked fault here, and the beds are much crushed in the valley which intervenes between the sandstones on the south and the slates on the north side. Prof. Jukes, however, instead of placing the slates on a lower horizon than the sandstones, supposed that the latter, which he called Old Red Sandstones, passed under the slates, which he classed as Carboniferous Slates. In this he was entirely mistaken, as the slates are now known to contain Lower Devonian fossils. No fossils had been found in the

slates of Oakhampton and Combe until we searched them in the summer of 1895, but in that year and afterwards we discovered several important fossils in the slates, and these have now enabled us to fix the horizon of the beds with tolerable accuracy. One of the most important fossils discovered is *Cryphæus laciniatus*, a characteristic Lower Devonian fossil both in Europe and America. The fossils defined by Mr. Whidborne are:—*Cryphæus laciniatus*, F. Römer, *Limoptera semiradiata*, Frech?, *Aviculopecten mundus*, sp. nov., *Spirifera* sp., *Rhynchonella hercynica*, Kayser?, *Rh. nympha*, Barrande?, *Stropheodonta tæniolata*, Sandberg., sp., and crinoid remains.

In the section (fig. 2, p. 439) it will be seen that the beds at Whitfield, near the Combe quarries, are at a very high angle, and dip to the south. A like dip can be traced in the ravine which separates these quarries from the Oakhampton quarries for  $1\frac{1}{2}$  mile to the north; but there are indications of several folds in the beds. Between that point and the Brendon Hill Beds the exposures are less clear, though there is no marked change in the character of the sediments. The few fossils obtained from the Combe quarries agree with those found at Oakhampton Quarry, and up to the present no other well-marked zone of fossils has been found in this area. The beds in places certainly resemble some of the Morte Slates of North Devon, but they are, on the whole, of a darker colour and less hard. They are also much less crushed, and the cleavage is nearly in the line of the bedding. Slaty beds can be traced continuously in a westerly direction from here to near Dulverton in the Exe Valley, but up to the present they have not yielded any fossils in that area. The evidence seems to point to an extension of the fault from Langley Marsh to the Exe Valley, marking the boundary between the Pickwell Down Beds and the so-called Morte Slates. The Pickwell Down Beds, however, frequently dip at a low angle, and are repeated in several folds to the south. Resting upon them are beds resembling in a marked manner the Sloly Beds near Barnstaple, and upon the latter occur Pilton Beds full of the usually characteristic fossils. The Pilton Beds also are repeated in several folds, and they can be examined in various quarries in the Tone Valley west of Wiveliscombe. These beds have been well described in the paper by Messrs. Champernowne & Ussher in this Journal, vol. xxxv. (1879) p. 542. Farther south the Pilton Beds are succeeded by the Culm Measures, with chert-bands, as in North Devon.

## V. GENERAL CONCLUSIONS.

It has now been shown that the so-called Morte Slates of North Devon and West Somerset, which, up to the time when we commenced our researches among them, were always considered to be barren of organic remains, contain several zones of fossils, and that beds of very different horizons have been included under that term. In North Devon evidence has been brought forward to show that some of the beds are of Silurian age, as the fossils are unlike any

known to occur in the Devonian, but agree well with fossils which occur in the Silurian rocks in other areas, especially in Pembrokeshire, on the opposite side of the Bristol Channel. Up to the present, four well-marked zones have been made out, two in North Devon and two in West Somerset. Few fossils appear to range from one zone to the other, and none between the zones in North Devon and those in West Somerset, which latter appear to be on higher horizons than any as yet discovered in North Devon. In so great a thickness of beds, however, there is a possibility that other zones may yet be found, as the nature of the sediments would lead one to suppose that there is a gradual passage from the lower (Silurian) to the higher (Lower Devonian) slates, and that if there is a physical break in the succession it must be above these slates. The presence of typical Lower Devonian fossils in the slates of West Somerset is a fact of great importance, for it shows that there, as in North Devon, the oldest beds occur in the centre of the area, and that there cannot be a regular upward succession, as has been supposed, from north to south. Indeed, there are numerous exposures which indicate that the beds are thrown off to the north and to the south from this central axis. The questions relating to the comparative age of the beds north of this axis and that of those on the south have not, at present, been completely worked out; but that they are in each case newer than the typical beds of the central axis is abundantly clear. In the Ilfracombe Beds on the north and the Pilton Beds on the south there appear to be several fossils in common, but none between either of these and those of the so-called Morte Slates which form the axis. So important a difference in the faunas could not have occurred unless the beds were on markedly different horizons. The beds, therefore, classed as Morte Slates in North Devon and in West Somerset cannot, in future, be placed as passage-beds between Middle and Upper Devonian, but must be looked upon as older than, and in each area as underlying, the Middle Devonian Beds.

If the fossils found at Treborough and at Oakhampton be compared with those found in the well-known Lower Devonian in the Rhenish area, we find that the Treborough fossils (*Chonetes sarcinulata*, *Ch. plebeia*, etc.) occur there in the lowest beds; and that *Cryphæus laciniatus*, which is a characteristic Oakhampton Quarry fossil, occurs in the Rhenish area in higher beds of the Lower Devonian.<sup>1</sup>

<sup>1</sup> Since the reading of this paper our attention has been directed to the following passage in M. D. P. Ehlert's paper on the 'Devonian Fossils of Santa Lucia' (Bull. Soc. géol. France, ser. 3, vol. xxiv. 1896, p. 841):—

'If we consider the vertical and horizontal distribution of the genus *Cryphæus*, we are at first sight struck by the fact that it is more especially localized in the Coblentian and the Eifelian. In fact, it is characteristic of the strata of that age in the Rhenish area, and is also found in the deposits with Hercynian facies of the Harz. On the other hand, it has not been recorded in Bohemia in the beds above stage E. In the Ardenne *Cryphæus* is unknown, and in England this group is represented by only one species, quoted and figured by Salter, which moreover appears to be a rarity. In the West of

## VI. DESCRIPTION OF THE FOSSILS.

By the Rev. G. F. WHIDBORNE, M.A., F.G.S.

DALMANITES (*CRYPHÆUS*) LACINIATUS, F. Römer, ? var. OCCIDENTALIS. (Pl. XXXIII. figs. 9-13.)*Locality.* Oakhampton Quarry. Four heads, 5 tails.*Size.* Head about 15 mm. long, 32 mm. wide. Tail about 15 mm. long, 17 mm. wide. Tail-spines nearly 10 mm. long.*Description.* Head wide, semi-oval, slightly lobate in front. Glabella large, subconical, with large, tuberculate, overhanging anterior lobe, and with three lateral lobes, of which the two upper are rather large and subtriangular, and the lower is small and narrow; furrows strong, nearly reaching to the centre. Eyes about  $\frac{1}{2}$  the length of the head, prominent, composed of more than 170 lenses in about 28 vertical rows of 9 or fewer lenses each. Cheek-spines long, narrow, curved, tapering. Neck-lobe prominent.<sup>1</sup>

Pygidium elongate, rather narrow, subtriangular, with a rather narrow tapering axis of probably about 12 segments; lateral lobes with 5 strongly marked widening ribs, indistinctly bordered, and bearing 5 very long, narrow, distant, thorn-like, nearly straight lateral spines, and a (seemingly) rather shorter and broader terminal spine.

*Remarks.* Salter<sup>1</sup> refers to *C. punctatus*, Steininger,<sup>2</sup> three specimens from Liskeard, which chiefly differ from ours in having smaller eyes, longer and stouter cheek-spines, and a broader tail. Kayser,<sup>3</sup> however, tabulates the species of *Cryphæus* in two divisions, based on the presence or absence of a clear terminal spine. Such a spine, according to him and other authors, is wanting in *C. punctatus*; but our specimens always have clear indications of

France, however, so soon as we come to the horizon of the *Orthis Monnieri*-sandstone, *Cryphæus* is abundant, as also in the *O. undata*-beds, while it becomes scarcer in the *Sp. Decheni*-beds (= Erbray Limestone), and in the *Phacops Potieri*-zone (= Grauwacké of Hierges). Again, in the Devonian of Spain and in that of the Bosphorus, the genus *Cryphæus* is found to occur.

<sup>1</sup> In America, the genus *Dalmanites* passes up, with but little modification, from the Silurian into the Devonian; but, so soon as we reach the base of the Coblentian (Oriskany), types appear in conjunction with it which are referred to it under the heading of subgenera, and are evidently derived from it. Among these, *Cryphæus* is the latest comer, and is the one which persists the longest (up to the top of the Coblentian). It attains its greatest development in the Hamilton Group, especially at the horizon of the Hamilton Shales, where the other subgenera of *Dalmanites* cease to appear, and where this genus itself is merely represented by a single species. Finally, a last survivor of the group recurs in the Tully Limestone, that is, at the horizon of the Givetian.

<sup>2</sup> From the foregoing facts we conclude that *Cryphæus* is more especially localized in the Coblentian beds of the Rhine and the Harz, and also in those of the West of France, Spain, and the Bosphorus (the last three are very similar from many points of view), while in America it made its appearance later and did not so soon become extinct.—May 15th, 1897.]

<sup>1</sup> 1864. Salter, 'Mon. Brit. Trilob.', p. 59, & pl. i. figs. 17-19.<sup>2</sup> 1834. Steininger, Mém. Soc. géol. Fr. vol. i. pt. ii. p. 356, & pl. xxi. figs. 7-7b.<sup>3</sup> 1878. Kayser, Abh. geol. Specialk. Preuss. vol. ii. pt. iv. p. 33.

one, and therefore they cannot (on this basis) be identical with *C. punctatus*.

On the other hand, in *C. laciniatus*, F. Römer<sup>1</sup> (as also in *C. rotundifrons*, Emmerich,<sup>2</sup> *C. acutifrons*, Schlüter,<sup>3</sup> and *C. Grotii*, F. A. Römer,<sup>4</sup> which Kayser identifies with it), and still more so in *C. Lethææ*, Kayser,<sup>5</sup> the spines seem usually much shorter, closer, and stouter than in our specimens, the terminal spine particularly so. In *C. limbatus*, Schlüter,<sup>6</sup> they are said to be shaped like those of *C. laciniatus*, but separated by equally wide intervals. In *C. Calliteles*, Green, as figured by Hall,<sup>7</sup> they vary much, being sometimes as stout and short as in *C. laciniatus*, and sometimes more like ours; but its pygidium is much broader, and its cheek-spines much stouter. If Hall, indeed, were right in referring all his specimens to one species (a reference which Kayser questions), the development of the terminal spine would have little specific weight. *C. laciniatus*, Barrois,<sup>8</sup> seems, as suggested by himself, to agree with some forms of *C. Calliteles*. *Cryphæus* sp., Kayser<sup>9</sup> (identified by him with the *Phacops stellifer*, Burmeister, of F. A. Römer<sup>10</sup>), is imperfect, but, so far as can be seen, is very like our pygidia, except that it is broader. In *Ph. stellifer*, Burmeister,<sup>11</sup> itself the tail seems broader, the terminal spine longer, and the glabella-lobes differently arranged. *C. Pleione*, Hall,<sup>12</sup> appears to be known only by a single imperfect pygidium, which looks as though it possibly might agree with ours; Kayser has doubtfully quoted it from Daun (Lower Devonian).

It may be noted that, while in most of our pygidia the spines seem very acute and narrow, in one specimen they are broader and more blade-like. Possibly this may be due to a difference in sex.

From the above comparisons it does not seem that we can identify our fossil very certainly with any known species; but on the other hand the distinctions observable are not, in the state of our present material, sufficiently pronounced to justify us in treating it at present as a distinct species. I therefore place it provisionally as a variety of *C. laciniatus*, only observing that I expect that, when better specimens are found, it will prove to be quite as distinct from it as are several of the various forms that are quoted above.

<sup>1</sup> 1844. F. Römer, 'Rheinisch. Uebergangsgeb.' p. 82 & pl. ii. fig. 8.

<sup>2</sup> 1839. Emmerich, 'Dissert. Trilob.' p. 23, fig. 1, and 1846, Burmeister, 'Organ. Trilob.' p. 92 & pl. iv. fig. 2.

<sup>3</sup> 1881. Schlüter, Verhandl. n. Vereins Rheinl. vol. xxxviii. p. 144.

<sup>4</sup> 1843. F. A. Römer, 'Verst. Harzgeb.' p. 39 & pl. xi. fig. 11.

<sup>5</sup> 1889. Kayser, Abh. k. Preuss. geol. Landesanst., n. s., pt. i. pp. 81, 86, & pl. xi. figs. 3, 5, 6, & pl. xxiii. figs. 7-9.

<sup>6</sup> 1881. Schlüter, Verhandl. n. Vereins Preuss. ser. 4, year 8, p. 77.

<sup>7</sup> 1888. Hall, 'Pal. N.Y.' vol. vii. p. 45, pl. xvi. figs. 5-22 & pl. xvi a.

<sup>8</sup> 1889. Barrois, Mém. Soc. Géol. Nord, vol. iii. p. 267 & pl. xvii. fig. 11.

<sup>9</sup> 1889. Kayser, Abh. k. Preuss. geol. Landesanst., n. s., pt. i. p. 82 & pl. xi. fig. 4.

<sup>10</sup> 1850. F. A. Römer, 'Beitr. z. geolog. Kenntn. d. nordwestl. Oberharz,' pt. i. p. 62 & pl. ix. fig. 28.

<sup>11</sup> 1846. Burmeister, 'Organ. Trilob.' p. 97 & pl. iv. fig. 8.

<sup>12</sup> 1888. Hall, 'Pal. N.Y.' vol. vii. p. 41 & pl. xvi a. fig. 2.

**DALMANITES** sp. (Pl. XXXI. figs. 1-3.)

*Locality.* Treborough. Two heads, 1 thorax, 1 tail.

*Size.* A distorted head is about 15 mm. long, and 21 mm. wide.

*Description.* Head probably rather elongate, semi-oval. Glabella large; anterior lobe tuberculate, subcircular, occupying the whole front of the head; lateral furrows short and indistinct; genal angles apparently produced into spines of unknown but probably considerable length. Eyes extremely large, prominent, with more than 100 lenses in 18 vertical rows. Neck-lobe rather narrow and straight.

Thorax with narrow, raised axis. Pleuræ about half as wide again as the axis, curved gently backward, and then slightly recurved at the fulcrum, divided by a strong furrow.

Tail with a very narrow, tapering axis, reaching to the border, but apparently not produced beyond it, having probably 10 or 12 ribs, each bearing a lateral tubercle. Lateral lobes with 5 or 6 furrowed ribs. Border narrow.

*Remarks.* The evidence given by these somewhat imperfect specimens is rather unsatisfactory. Though much like *Phacops Stokesii* (from the Silurian) or *Ph. Mushenii* in general look, the shape of the base of the head and the apparent existence of a cheek-spine seem to show that they really belong to *Dalmanites*. I do not know any German or American species of that genus that appear to be identical with them. Some Bohemian species approach them in the size of the eye.

**HOMALONOTUS** sp. (Pl. XXXI. fig. 4.)

*Locality.* Treborough.

Two fragmental specimens, insufficient for specific comparison, appear to belong to this genus. Of these one is part of the side of a thorax, showing 8 ribs, which seem deeply and obliquely grooved near their margins, which are straight and perpendicular, and have signs of a tubercle near them. The other is still more indistinct, and can only be said to have a strong likeness to an oblique view of the side of such an animal without showing details; in it a smooth triangular surface may represent the cheek, and there seem to be 11 long ribs, with no defined axis, and also indications of a distorted tail.

**CYPRICARDINIA** ? sp. (Pl. XXXI. fig. 5.)

*Locality.* Treborough. One specimen.

*Size.* 7 mm. high, 14 mm. long.

*Description.* Transverse, suboblong. Upper margin very long, nearly straight, punctated (apparently by the ends of the ribs). Posterior margin straight, slightly oblique. Postero-inferior corner nearly subangular. Inferior margin slightly convex, curving rapidly in front. Anterior side only about  $\frac{3}{4}$  the height of the posterior side. Contour of back flattish generally, but definitely convex below. Surface marked by 20 linear ridges, which are parallel to the rear

margin, and turning suddenly near the inferior margin become subparallel to it; the line through the angles thus produced forms a concave curve from the posterior-inferior corner to the limbs. Umbo apparently inconspicuous, situate nearly at the antero-superior corner.

*Remarks.* It seems to me by no means certain that this fossil is a lamellibranch. It is somewhat like *Leaia Leidyi*, Rupert Jones, in shape, but has no radiating ridge. The species of *Estheria* described by Rupert Jones are all more oval, and show no sudden bend in the striation. On the other hand, while it has a general resemblance to *Cypricardinia*, the posterior slope (occupying  $\frac{2}{3}$  of the shell) would be unusually large for that genus, and there are no signs of its usual median constriction. The size of the slope may, however, have been exaggerated by its compression.

It is a longer and more oblong shell than *C. scalaris*, Phillips, sp.

GOSSELETIA ? KAYSERI, Frech ? (Pl. XXXI. figs. 6 & 6 a.)

*Locality.* Treborough. One specimen.

*Size.* About 25 mm. long.

*Remarks.* This is a very indistinct and enigmatical fossil. It consists of a low, convex, transversely ovoid central cast, having some grooves at the upper corner of the broad end, and terminated by an abrupt deflexion at the narrow end. It is bounded above by a sharp impressed straight line, beyond which is a narrow border, bearing numerous obliquely horizontal striæ, which vanish toward the broad end of the fossil.

Its nature is very doubtful; but a comparison of *Gosseletia devonica*,<sup>1</sup> Barrois, and *Myalina lodanensis*, Frech,<sup>2</sup> suggests a relationship, while Frech's<sup>3</sup> and especially Kayser's<sup>4</sup> figures of the Lower Devonian *G. Kayseri* render it not impossible that it may be a small specimen of that species.

GRAMMYSIA ? sp. (Pl. XXXI. figs. 7-9.)

*Locality.* Treborough. Two specimens.

*Size.* A crushed and imperfect specimen is 14 mm. high by 32 long.

*Remarks.* Of these fossils it can only be said that they seem transversely oval, very oblique bivalves, apparently with small umbones and strongly curved lateral margins, and covered with about 12 rather irregular growth-lines, which seem to vanish on the posterior slope. They may possibly belong to *Grammysia*, but there is nothing to prove that they do so, and it must be distinctly understood that they are at present only doubtfully and provisionally placed under this heading for convenience.

<sup>1</sup> 1882. Barrois, Mém. Soc. Géol. Nord, vol. ii. p. 274, pl. xii. figs. 1-1 g.

<sup>2</sup> 1891. Frech, Abh. geol. Specialk. Preuss. vol. ix. pt. iii. p. 158 & pl. xv. figs. 1-2 a.

<sup>3</sup> *Ibid.* p. 126 & pl. xiii. figs. 1-3.

<sup>4</sup> 1889. Kayser, Abh. k. Preuss. geol. Landesanst., n. s., pt. i. p. 18 & pl. viii. fig. 6.

*AVICULOPECTEN MUNDUS*, sp. nov. (Pl. XXXIII. figs. 14, 14 a, 15 & 15 a.)

*Locality.* Oakhampton Quarry. Two good, and some imperfect, specimens.

*Size.* Height 25 mm., length 32 mm.

*Description.* Left valve moderate in size, slightly transverse, obliquely oval. Umbo situate at or about the anterior third of the length, acute, slightly surpassing the hinge-line and tending slightly forward. Anterior wing long, narrow, triangular, acutely pointed, and extending beyond the front of the body. Posterior wing (very indistinctly seen) apparently nearly similar in shape, but rather larger. Margins arching in a continuous curve, which is deepest rearward. Surface with 40 or 50 narrow subacute ribs, sometimes alternating, separated by rather wider concave furrows; the whole crossed by extremely regular, close, sharp, minute threads, which seem to undulate so as to be slightly convex to the beak on the ribs, and concave on the furrows.

*Remarks.* This species is very similar to *A. gracilis*, Beushausen,<sup>1</sup> but that species is more oblique, its hind wing is shorter and of a different shape, and the transverse marks are described as irregular. *A. perovalis*, Beushausen,<sup>2</sup> is less oblique, and has a much shorter hinge-line. *A. Wulfi*, Frech,<sup>3</sup> is very similar in shape and ornament, except that its umbo seems blunter and more central, its anterior notch shallower, its front wing broader, and its hind wing apparently much larger, bringing it within the section *Pterinopecten*; both in Frech's figures and our specimens, however, the hind wings are badly preserved. It seems to me that our shell cannot be identified with either of these three Lower Devonian species, though standing midway between the first and the last.

*Avicula Neptuni*, Goldfuss,<sup>4</sup> is also similar, but has less acute ears, coarser transverse striæ, and apparently a longer hinge-line.

*LIMOPTERA SEMIRADIATA*, Frech. (Pl. XXXIV. figs. 1, 1 a, 2 & 2 a.)

1889. *Pterinea* aff. *lineata*, Kayser, Abh. k. Preuss. geol. Landesanst., n. s., pt. i. p. 21 & pl. viii. fig. 2.

1891. *Limoptera semiradiata*, Frech, Abh. geol. Specialk. Preuss. vol. ix. pt. iii. p. 65 & pl. v. figs. 1-3, 5-8.

*Locality.* Oakhampton. Two specimens.

*Size.* Length and height, about 40 mm.

These obscure specimens, one of which is much crushed and the

<sup>1</sup> 1884. Beushausen, Abh. geol. Specialk. Preuss. vol. vi. pt. i. p. 54 & pl. ii. fig. 5.

<sup>2</sup> *Ibid.* p. 53 & pl. ii. fig. 6.

<sup>3</sup> 1891. Frech, Abh. geol. Specialk. Preuss. vol. ix. pt. iii. p. 25 & pl. ii. fig. 7.

<sup>4</sup> 1834-40. Goldfuss, 'Petref. Germ.' vol. ii. p. 125 & pl. cxvi. fig. 4.

other much blurred, appear to agree with figures of a right (?) and left valve of Frech's species. The wings look smaller, but are probably very defective. The surface of one specimen seems covered with very numerous minute flexuous and irregular rays (*cf.* Frech, fig. 2); in the other the ribs are fewer and stronger, and the transverse lines scalloped (*cf.* Frech, fig. 6). In both I think I can detect, though very doubtfully, the peculiar characteristic shape of *Limoptera*. The ornament of the first of the two specimens is very like that of a Daleiden specimen of the left valve of *Pt. lineata*<sup>1</sup> lent me by Mr. Upfield Green. In that species, however, the right valve is said to be smaller. *L. semiradiata* is said to be frequent in the Lower Coblentzian of St. Johann (Eifel).

SPIRIFERA sp. (Pl. XXXI. fig. 10.)

*Locality.* Treborough.

*Size.* 17 mm. wide. Area about 5 mm. wide.

A single fossil shows a wide, slightly concave area, with a triangular fissure, bounded apparently by strong dental plates. Its valves are almost destroyed by compression, but they evidently had strong ribs, of which there are indications of at least 3 or 4 on each wing and possibly of 3 or 4 on the fold.

From the appearance of its area it might very possibly be a specimen of *Sp. subcuspidata*, Schnur,<sup>2</sup> but it is far too poor to be identified.

SPIRIFERA sp. (Pl. XXXIV. fig. 3.)

*Locality.* Oakhampton Quarry.

The ventral valve of a spirifer occurs lying on an elongate decayed organism, which is either the continuation of its hinge-line or more probably one of the enigmatical aciculate bodies that are so common at Treborough. Its umbo is low and incurved; its shape transverse, subfusiform, and probably acutely alate; its sinus rather broad, with an indication of a minute median rib. On each side are about 6 strong, sharpish, distant ribs, which seem separated by broad concave furrows. The surface seems crossed by very distant, regular, transverse lines. Thus it is not unlike *Spiriferina cristata*, var. *octoplicata*, Sowerby, but the specimen is much too indistinct and obscured by clothing matrix to be identified. As it lies, it presents a striking likeness to a figure by Kayser<sup>3</sup> of a broken specimen of *Spirifera Hercyniæ*, Giebel.<sup>4</sup>

<sup>1</sup> 1834-40. Goldfuss, 'Petref. Germ.' vol. ii. p. 135 & pl. cxix. fig. 6.

<sup>2</sup> 1852. Schnur, Palæontographica, vol. iii. p. 202, pl. xxxiii. fig. 3 a-f & pl. xxxiv. fig. 1 a-g.

<sup>3</sup> 1878. Kayser, Abh. geol. Specialk. Preuss. vol. ii. pt. iv. p. 168 & pl. xxxiii. fig. 11.

<sup>4</sup> 1858. Giebel, 'Sil. Faun. Unterharz,' p. 30 & pl. iv. fig. 14.

RHYNCHONELLA HERCYNICA, Kayser? (Pl. XXXIV. figs. 4, 4a, 4b & 5.)

*Locality.* Oakhampton. Four specimens.

*Size.* Probably about 14 mm. in width and length, and 7 mm. in depth.

*Description.* Shell suborbicular, rather flattened. Umbo rather elevated, incurved. Area large, slightly concave, with defined edges. Dental lamellæ strong. Fold and sinus low, wide, probably arching. Ribs strong, numerous, reaching to the umbo, transversely plaited, numbering about 7 on the fold, 6 on the sinus, and 8 or 9 on each side.

This seems to belong to the group of *Rh. pleurodon*, but differs from the Upper Devonian members of that group in the much greater number of ribs on its fold. In that respect it approaches *Rh. Uandoveriana*, Davidson,<sup>1</sup> but its dental lamellæ are placed much nearer together, and it does not seem to have the serrations, described by Davidson, on that shell. None of Schnur's species approach it.

In its crushed condition the shape of its fold is obscured, but if, as seems possible, it was gently arched, it might be referred to the Lower Devonian *Rh. hercynica*, Kayser,<sup>2</sup> which, in the number of ribs and other characters, it seems to approach.

RHYNCHONELLA NYMPHA, Barrande? (Pl. XXXIV. figs. 6 & 7.)

*Locality.* Oakhampton Quarry. Three specimens.

*Size.* Apparently something like 25 mm. wide by 20 mm. high.

This form seems distinguished from the preceding by its larger size, by its fewer and stronger ribs, and by its more extended sinus bearing fewer ribs. It appears to be common, but in Dr. Hicks's collection is represented only by very fragmental specimens.

Its fold appears to have been somewhat elevated, flattened, and considerably extended in front, and to have borne either 5 or 6 strong ribs, while there were probably about 7 smaller ribs on each side. The ribs are very acute and elevated, extend quite over the umbo, and sharply interlock at the margins.

So far as can be seen in their defective state, our specimens accurately agree with the figures of *Rh. nympa*, Barrande,<sup>3</sup> given by Kayser [from Lower Devonian shells].<sup>4</sup> While from their evidence it cannot be said to be identical, so far as that evidence goes it is indistinguishable from them.

<sup>1</sup> 1869. Davidson, 'Brit. Foss. Brach.' vol. iii. p. 184 & pl. xxiv. figs. 8-13.

<sup>2</sup> 1878. Kayser, Abh. geol. Specialk. Preuss. vol. ii. pt. iv. p. 153 & pl. xxv. figs. 9-11.

<sup>3</sup> 1847. Barrande, 'Naturw. Abhandl.' vol. i. p. 422 & pl. xx. figs. 6-8; and 1879. Barrande, 'Syst. Sil. Bohême,' vol. v. pl. xxix. figs. 10-18, etc., Étage F.

<sup>4</sup> 1878. Kayser, Abh. geol. Specialk. Preuss. vol. ii. pt. iv. p. 142 & pls. xxv. figs. 1, 2, 6-11, xxvi. figs. 15-18.

From *Rh. daleidensis*, F. Römer,<sup>1</sup> or *Rh. livonica*, von Buch,<sup>2</sup> sp., it seems to differ by the greater number of ribs on its fold.

STROPHEODONTA TÆNIOLATA (Sandberger). (Pl. XXXIV. figs. 8 & 9.)

*Locality.* Oakhampton Quarry. Three specimens.

*Size.* About 20 mm. long by 22 wide.

*Description.* Semi-oval, flattish; width nearly if not quite equal to length; apparently geniculate near the margins. Hinge-line equal to greatest length, straight, bearing on the margin a series of serrations fitting into those of the opposite valve. Muscular impressions rather small, cordate, radially striated (?), bounded by raised margins and divided by a median ridge. Pallial region strongly papillose within. Surface covered with very numerous fine rays, between each of which there appear to have been possibly several still finer.

*Remarks.* With its serrated hinge and probably double system of striae this shell seems akin to *Stropheodonta (Leptæna) interstitialis*, Phillips, sp.,<sup>3</sup> but may, I think, be distinguished by its greater size, less transverseness, etc. Where so few characters are seen it is difficult to point out distinctions, but the general impression which it conveys seems different from that of Lummaton examples of Phillips's shell. From the Lower Devonian (Daleiden) fossils, however, figured by Schnur<sup>4</sup> under the same name, it does not seem separable. *Strophomena tæniolata*, Sandberger,<sup>5</sup> from the Spiriferensandstein of Daleiden, etc., seems also almost exactly alike, his figures differing only in being slightly longer and in having rather large muscle-scars. With this shell Sandberger unites *St. Phillipsii*, Barrande<sup>6</sup> (which Barrande compares with *St. interstitialis*), but in it the serrations on the hinge are much finer and the shape more spherical. *St. imbrex*, Pander,<sup>7</sup> differs internally, while *St. euglypha*, Sowerby,<sup>8</sup> has the ventral valve concave instead of convex.

STROPHOMENA (STROPHEODONTA ?) EXPLANATA (Sowerby)? (Pl. XXXI. figs. 11-13, & Pl. XXXII. figs. 1-3.)

*Locality.* Treborough. Numerous specimens.

*Size.* One specimen (elongated) is 80 mm. long by 60 mm. wide; another (widened) is 50 mm. long by 100 mm. wide.

*Description.* Very large, apparently nearly flat, perhaps rather longer than wide. Umbo slightly produced. Hinge-line as long

<sup>1</sup> 1844. F. Römer, 'Rhein. Uebergangsgeb.' p. 65 & pl. i. fig. 7.

<sup>2</sup> 1834. Von Buch, 'Ueber Terebrat.' p. 37 & pl. ii. fig. 30 a-c.

<sup>3</sup> 1841. Phillips, 'Pal. Foss.' p. 61 & pl. xxv. fig. 103.

<sup>4</sup> 1853. Schnur, 'Eifel Brach.' p. 222 & pl. xli. figs. 2 a-f.

<sup>5</sup> 1856. Sandberger, 'Verst. Rhein. Nassau,' p. 360 & pl. xxxiv. figs. 11-11 c, Étage F.

<sup>6</sup> 1847. Barrande, 'Naturw. Abhandl.' vol. ii. p. 226, pl. xxi. figs. 10-11.

<sup>7</sup> 1871. Davidson, 'Brit. Foss. Brach.' vol. iii. p. 286 & pl. xli. figs. 1-6.

<sup>8</sup> 1871. *Ibid.* p. 288 & pl. xl. figs. 1-5.

as the width of the shell. Hinge-area narrow, slightly triangular, with fine crenulations on the proximal margin. Margins curving slightly on the sides and more rapidly in front. Surface covered with between 150 and 200 fine straight elevated striæ, divaricating at rather regular intervals, separated by somewhat wider furrows, and crossed by a few strong growth-lines, and by very numerous fine threads, which on portions of the specimens give rise to minute radially-arranged slits (possibly due to these threads becoming foliaceous on the striæ).

*Remarks.* Some of the specimens are magnificent, but unfortunately their critical characters are much obscured. It may be noted (1) that in one or two specimens there seems the appearance of a slight median fold, which, however, is probably due only to accidental causes; (2) that the ribs are extremely regular, though occasionally a stronger one occurs, and there are no signs of a minor intermediate series; (3) that on the wings where longitudinal strain has occurred the transverse marks are represented by radiating scalariform rows of exceedingly regular slits, abruptly ended; (4) that while in all the specimens the hinge is very defective, one seems to have crenulations which indicate that it is a *Stropheodonta*, and another shows a definitely triangular though very narrow area, while one or two others show short umbonal grooves on crural ridges set at right angles to each other, and extremely indistinct signs of a rather large muscular area; and (5) that while nearly every specimen has lost its true shape, a small one, which seems to have retained it, is nearly square.

Several equally gigantic forms occur in the Lower Devonian of other localities. *St. gigas* (M'Coy),<sup>1</sup> from Looe, is at once distinguished by its numerous minute minor ribs between the major series. M'Coy describes the ribs of that species as separated by punctured lines, while Davidson mentions that in *Streptorhynchus umbraculum* (which is similarly distinguished by its minor ribs) 'the ribs are crossed by scale-like striæ, while the interspaces are crossed by finer and more numerous lines of growth.'

*Strophomena Steini*, Kayser,<sup>2</sup> equals ours in size and apparently in shape, but its ribs seem fewer, wider apart, and more arching laterally (the latter character being apparently regarded by Kayser as of specific value).

On the other hand, I find nothing to separate our shells from *St. explanata* (Sowerby),<sup>3</sup> which is also figured by Kayser<sup>4</sup> from

<sup>1</sup> 1852. M'Coy, 'Brit. Pal. Foss.' p. 386 & pl. ii A. fig. 7.

<sup>2</sup> 1889. Kayser, Abh. k. Preuss. geol. Landesanst., n. s., pt. i. p. 103 & pl. xii. fig. 1.

<sup>3</sup> 1842. Sowerby, Trans. Geol. Soc., ser. 2, vol. vi. pt. ii. p. 409 & pl. xxxviii. fig. 15.

<sup>4</sup> 1889. Kayser, Abh. k. Preuss. geol. Landesanst., n. s., pt. i. p. 102 & pls. xxi. figs. 1-3, xxii. fig. 1. He says: '*St. explanata* is known to me from all the beds of the Rhenish Lower Devonian. . . . and is nowhere particularly rare.'

the Lower Devonian. It agrees in size and ribbing, and, so far as can be seen, in internal arrangement. Again, *St. subarachnoidea* (de Vern.),<sup>1</sup> is very similar and may be identical, but is much smaller and appears to be a more recurved shell. Kayser distinguishes *St. explanata* from it only by its greater size, flatness, and width.

*Orthis spathulata*, F. A. Römer,<sup>2</sup> is described as having broad ribs and narrow furrows, but *Orthis* aff. *spathulata*, Quenstedt,<sup>3</sup> which is identified by Kayser<sup>4</sup> with *St. gigas* (M'Coy), more nearly approaches the present form.

‘STREPTORHYNCHUS ? PERSARMENTOSUS (M'Coy).’ (Pl. XXXII. figs. 4 & 5.)

*Locality.* Treborough. Two specimens.

*Size.* About 10 mm. long by 25 mm. wide.

Two very imperfect specimens accurately agree with M'Coy's figure,<sup>5</sup> except that they are rather smaller and not quite so wide. They show the same coarse, ramose, median and fine, straight, lateral ribs. M'Coy describes this shell as common in the Lower Devonian of Fowey, Looe, etc., and he gives a very similar species, *Orthis sarmentosa*,<sup>6</sup> from the Bala Beds.

Davidson, however, is evidently disinclined to regard these as a true species; and our examples almost certainly seem to owe their peculiar character chiefly to distortion. In recording it, therefore, I do not suggest that *St. ? persarmentosus* is a true species, but simply that our shells are identical with M'Coy's and must stand or fall with it. It may be noted that one of our examples of *Stropheodonta explanata* shows the same peculiarities in an incipient degree.

CHONETES PLEBEIA, Schnur. (Pl. XXXIII. figs. 1 & 2.)

[Of this species Œhlert says (Bull. Soc. géol. France, ser. 3, vol. xi. p. 519: ‘The vertical range of *Ch. sarcinulata* is much greater than that of *Ch. plebeia*, which is observable particularly in the inferior beds of the Devonian Limestone, where sometimes this species occurs almost exclusively.’]

*Locality.* Treborough. Common.

*Size.* About 5 mm. long by 8 mm. wide.

*Description.* Shell very small, slightly transverse, semi-oval.

<sup>1</sup> 1842. D'Archiac & de Verneuil, Trans. Geol. Soc., ser. 2, vol. vi. pt. ii. p. 372 & pl. xxxvi. fig. 3; and 1889. Kayser, Abh. k. Preuss. geol. Landesanst., n. s., pt. i. p. 101 & pl. xix. figs. 1-2 a.

<sup>2</sup> 1852. F. A. Römer, ‘Beitr. Harzgeb.’ pt. ii. p. 98 & pl. xv. fig. 2.

<sup>3</sup> 1871. Quenstedt, ‘Petref. Deutschl. (Brachiop.)’ p. 583 & pl. lvi. figs. 53, 54.

<sup>4</sup> 1890. Kayser, Jahrb. k. Preuss. geol. Landesanst. p. 101 & pl. xiii. figs. 1, 2.

<sup>5</sup> 1852. M'Coy, ‘Brit. Pal. Foss.’ p. 385 & pl. ii A. fig. 9; and 1865. Davidson, ‘Brit. Foss. Brach.’ vol. iii. p. 84 & pl. xvi. fig. 5.

<sup>6</sup> 1871. Davidson, ‘Brit. Foss. Brach.’ vol. iii. p. 262 & pl. xxxvi. figs. 35-38.

Hinge-line as long as the width, bearing a few large, obliquely-set, arching spines. Surface with 40 or 50 coarse, rounded, close rays, which have increased by intercalation at various distances from the umbo. Interior of ventral valve with two strong grooves, reaching more than halfway forward, and with several coarse punctations. Lateral margins slightly alate where they join the hinge-line.

*Remarks.* The ribs are coarsely granulate as seen on the inside of the dorsal valve, and are crossed by fine regular concentric threads. Our shells appear to agree accurately with *Ch. plebeia* as described by Schnur<sup>1</sup> and Ehlert<sup>2</sup> as well as by Kayser,<sup>3</sup> who first united it to *Ch. sarcinulata*, Schloth., but afterwards,<sup>4</sup> following Ehlert, again separated it.

At Treborough it seems to have been gregarious, occurring abundantly in a different part of the quarry from that which has yielded *Ch. sarcinulata* and most of the other fossils.

CHONETES SARCIKULATA, Schlotheim, sp.? (Pl. XXXIII. figs. 3-5.)

[Ehlert, Bull. Soc. géol. France, ser. 3, vol. xi. p. 520, remarks: 'This species, whose geographical extension is very great, is characteristic of the Lower Devonian.']

*Locality.* Treborough. Eight specimens.

*Size.* Length 11 mm., width 16 mm.

*Description.* Shell small, transverse, semi-oval. Hinge-line showing a double area and a triangular fissure, and bearing a few rather large, obliquely-set, arching spines. Muscular area large, heart-shaped, with a median sinus. Surface covered with very numerous minute radiations.

*Remarks.* These specimens appear to agree with the various figures of *Ch. sarcinulata*,<sup>5</sup> except that they seem less oblong and perhaps not quite so transverse, and that the front margin is more curved than usually appears in that species. It is, however, quite possible that the latter difference may be simply due to crushing and flattening. The size of the ribs seems to vary considerably, two of the specimens having much coarser ribs and thus approaching *Ch. plebeia*. On the other hand, our typical specimens are quite different from the much smaller shells from this quarry above referred to *Ch. plebeia*, and it is possible that these two aberrant specimens, which are very indistinct, may belong to neither species or not even to the genus *Chonetes* at all.

<sup>1</sup> 1854. Schnur, Palæontographica, vol. iii. p. 226 & pl. xlii. fig. 6.

<sup>2</sup> 1883. Ehlert, Bull. Soc. géol. France, ser. 3, vol. xi. p. 517 & pl. xiv. fig. 3.

<sup>3</sup> 1878. Kayser, Abh. geol. Specialk. Preuss. vol. ii. pt. iv. p. 200 & pls. xxx. figs. 13, 14?, xxxiv. fig. 9.

<sup>4</sup> 1889. Kayser, Abh. k. Preuss. geol. Landesanst., n. s., pt. i. p. 63 & pls. vii. figs. 2-5, x. fig. 7.

<sup>5</sup> 1820. Schlotheim, 'Petrefact.' p. 256 & pl. xxix. fig. 3.

*Ch. sordida* (Sowerby)<sup>1</sup> will, I expect, probably prove to be a synonym of *Ch. sarcinulata*.

*Ch. tenuicostata*, (Ehlert,<sup>2</sup> seems distinguished by its much more erect spines.

#### Crinoid-remains.

*Locality.* Oakhampton.

Fragmentary grouped stems occasionally occur. In one specimen are seen several minute rootlets of five or six joints grouped round these stems, but they are too vague to give definite character.

#### Crinoid-segment.

*Locality.* Treborough. Limestone above the slate-quarry.

A single segment is in a good state of preservation. It is circular, rather short, with a periphery formed by the revolution of a vertical semicircle. The articulating surface is concave, bounded by an impressed circular line, within which are 33 impressed radii about the central channel, which appears to be in the form of a four-pointed star.

#### Sponge-spicule.

*Locality.* Treborough. Limestone.

*Size.* Fragment, 2 cm.

A minute fossil, apparently a spicule, is on the same slab as the above-named crinoid-segment. It consists of six rods in one plane, meeting in a focus from which a seventh rod rises perpendicularly.

#### CLADOCHONUS? (Pl. XXXIII. fig. 8.)

*Locality.* Treborough.

*Size.* 30 or 40 mm.

Two specimens of free-branching organisms of small size appear to me to belong to this genus, but, being in their state of preservation, little more than elongated cylinders or cones, which seem at intervals to thicken and divaricate into two or more branches the length of which cannot be traced, it is impossible to decide their nature. They seem less regular than most species of *Cladochonus*, but they may be compared with *C. Schlüteri*, Holzapfel,<sup>3</sup> which appears to present a similar irregularity.

#### PETRAIA sp. (Pl. XXXIII. figs. 6, 6a & 7.)

*Locality.* Treborough. Four specimens.

*Size.* About 20 mm. high, 15 mm. wide.

*Description.* Cup irregularly conical, small, rather elongate. Septa 19 or 20, thin, smooth. No tabulæ or developments. One

<sup>1</sup> 1840. Sowerby, Trans. Geol. Soc., ser. 2, vol. v. pt. iii. pl. liii. fig. 5.

<sup>2</sup> 1883. Ehlert, Bull. Soc. géol. France, ser. 3, vol. xi. p. 515 & pl. xiv. fig. 2.

<sup>3</sup> 1895. Holzapfel, Abh. k. Preuss. geol. Landesanst., n. s., pt. xvi. p. 305 & pl. xvi. figs. 1, 2, 4, 5, 7.

(or perhaps more) septal fossulæ. Secondary septa rudimentary, hardly indenting the interseptal spaces in the cast. Reproduction from the outside margin of the cup. Base dilate.

*Remarks.* This species is represented by casts and natural sections. I do not think that it is identical with either of the forms described by Phillips.

#### ERIDOPHYLLUM sp.

*Locality.* Treborough.

*Size.* About 80 mm. long.

*Description.* Coral composite, free, growing from a single original in a series of calicularily-produced cups, which swell out into nodes at rapid intervals. Epitheca apparently thick. Septa few, strong, and apparently short, only reaching part way to the centre. Dissepiments few and coarse.

This fossil, which was found by Mr. R. S. Herries, Sec.G.S., has perplexed me much, as its details of structure are only partially exposed in the only specimen. It appears to me that in all probability it belongs to the Devonian (America) and Silurian (Gothland) genus *Eridophyllum* of Milne-Edwards and Haime, though whether its swellings possess the root-like character of those of that genus is not yet clear.

### EXPLANATION OF PLATES XXXI.-XXXV.

#### PLATE XXXI.

Treborough Slate-quarry.

- Figs. 1-3. *Dalmanites* sp. 1. Head, nat. size. 2. Cast of the reverse of 2 a. 3. Pygidium, nat. size.  
 Fig. 4. *Homalonotus* sp.  
 5. *Cypricardinia*? sp.  $\times 2$ .  
 6. *Gosseletia*? *Kayseri*, Frech? 6 a. Portion  $\times 3$  showing the oblique lineation.  
 Figs. 7-9. *Grammysia*? sp.  
 Fig. 10. *Spirifera* sp. A compressed specimen showing a wide area.  
 Figs. 11-13. *Strophomena* (*Stropheodonta*?) *explanata* (Sowerby)? 12. A small specimen which has apparently escaped distortion.

#### PLATE XXXII.

Treborough Slate-quarry.

- Figs. 1-3. *Strophomena* (*Stropheodonta*?) *explanata* (Sowerby)? Various distorted.  
 4 & 5. *Streptorhynchus persarmentosus* (M'Coy),  $\times 2$ . 4. From Mr. Upfield Green's Collection.

#### PLATE XXXIII.

Treborough Slate-quarry.

- Figs. 1 & 2. *Chonetes plebeia*, Schnur,  $\times 2$ . 1. Showing hinge-spines.  
 3-5. *Chonetes sarcinulata*, Schlotheim,  $\times 2$ . 4 & 5. Showing hinge-spines.  
 5. With coarser ribs than usual.  
 6, 6 a, 7. *Petraia* sp. 6, 6 a. Opposite views of a flattened cast. 7. Cast seen from below; from Mr. Herries's Collection.  
 Fig. 8. *Cladochonus* sp.

PLATE XXXIII. (*continued*).

## Oakhampton House Quarry.

- Figs. 9-13. *Dalmanites (Cryphæus) laciniatus*, F. Römer?, var. *occidentalis*.  
 11, 12. Pygidia showing the terminal spine and the long thorn-like lateral spines separated by wide intervals. 13. Rather more than half the margin of a pygidium with rather broad and closer (but still not contiguous) spines. The lowest spine but one is probably the terminal spine.  
 14 & 15. *Aviculopecten mundus*, sp. nov. 14 a & 15 a. Portions of surface enlarged, showing the transverse ornament.

## PLATE XXXIV.

## Oakhampton House Quarry.

- Figs. 1 & 2. *Limoptera semiradiata*, Frech? 1 a, 2 a. Portions  $\times 3$  to show the ornament of the opposite valves.  
 Fig. 3. *Spirifera* sp., showing the umbonal portion of the ribs adjacent to an elongate body of doubtful character.  
 Figs. 4 & 5. *Rhynchonella hercynica*, Kayser? 4 is twice nat. size.  
 6 & 7. *Rhynchonella nympha*, Barrande? (The best fragments of this shell are too imperfect to convey any idea of it in a drawing.)  
 8 & 9. *Stropheodonta taniolata* (Sandberger).  $\times 2$ .

## PLATE XXXV.

Geological Map of a portion of West Somerset, on the scale of  
 2 miles to the inch.

## DISCUSSION.

Mr. ETHERIDGE could not agree with the Author of the paper upon the important question at issue, either as to the stratigraphical or palæontological evidence afforded by the Morte Slates justifying the assertion that they are 'the oldest rocks in North Devon'; and he differed entirely from the Author in the conclusions drawn, as based upon this assertion. No proof has been shown for the attempted change in the stratigraphical position of the Morte Slates either in North Devon or West Somerset, the eastern (or West Somerset) extension of the North Devon Morte Beds being only a continuity of the same set of glossy or slaty beds from Morte-hoe to the quarries at Oakhampton, and its apparently rich Devonian fauna, 40 miles distant. The few fossils obtained by the Author from the western part of the Morte Series were said to be Silurian, but close examination shows them to have been wrongly identified. This somewhat hasty determination gave rise to the view that the Morte Beds must or should be assigned to the Wenlock Group of the Upper Silurian, and that as a consequence of their stratigraphical position they should be regarded as the oldest rocks in North Devon, interstratified in the Middle Devonian Series. No attempt has now been made by the Author to establish, or even suggest, how or whence this 40 miles of faulted area, between the Ilfracombe and

Pickwell Down Series, was derived, it being sufficient to announce it on the assumption of doubtful fossil evidence. If these Morte Slates are the oldest rocks in North Devon, it is incumbent upon those who assert the fact to show clearly by good evidence that such interpolation took place, and whence and how derived; but no evidence exists of the asserted thrust-faults over this part or in any of the northern or eastern rocks or areas of North Devon. The great red sandstone series and limestone-beds of Ilfracombe, ranging from Morte-hoe to Hangman Point, show no evidence of thrust-faults, however great their foldings. There is as yet no proof in the Morte Group of passage-beds between Silurian and Lower Devonian, either on the dip or strike. Sedimentation along this strike of the Morte Beds of North Devon and West Somerset for 40 miles may readily be misunderstood, and very difficult to determine; numerous enough have been the traverses across the so-called thrust-fault on the north side of the Morte line of fault, and also the less faulted beds upon the South or Pickwell Down side. These traverses have not yet shown any affiliation of Silurian species with those in the Morte Series. The assertion, therefore, that 'the position now given to the Morte beds removes one of the greatest difficulties experienced by previous writers in their attempts to correlate the strata in North Devon' has yet to be proved. Again, the assertion that 'the diversity of fossils in the Morte Slates belonging to several horizons as low as the base of the Upper Silurian, added to the stratigraphical evidence, enables us to speak with confidence as to their place in the North Devon succession,' has yet to be determined.

Prof. HUGHES thought that the point which the Author wished to emphasize was that there was in the area described an anticlinal carrying newer beds belonging to the Devonian Series over an axis of rocks belonging to an older part of the same series; this structure confirming the view previously advanced by the Author, that there was a fold of Devonian rocks stretched unconformably over a ridge of Silurian farther west at Morte-hoe. These two sections showing a different sequence could certainly be reconciled on the hypothesis that along the belt of country indicated by the area referred on the older maps to the Morte Slates there was an anticlinal, the axis of which sloped to the east, thus bringing on the newer beds in that direction in a succession of half-spoon shaped folds. And he was willing to build this golden bridge for his friend Dr. Hicks.

The evidence for the Silurian upfold he had already criticized, and he would only add that all his subsequent examination of specimens had confirmed the views which he then expressed. The particular traverse now exhibited by the Author in support of his contention showed a fault at either end, at the junction of the up-thrust part of the Series with the supposed overfolded newer beds. He did not think there was reason for believing that the throw in

the two bounding faults was great, but that it was rather one of those very common cases in which a displacement was observed along the junction when two rocks of different compressibility and ductility were contorted together. Hence the theory almost involved the idea that the beds on the north usually referred to the Ilfracombe and Hangman stages must be the same as those on the south which were in the old nomenclature spoken of as the Pickwell Down and Baggy Beds. He considered, therefore, that although the lithological characters might enable us to discriminate between the various subdivisions in the field, the real question before them, namely, the relative age of the beds in the medial belt and the beds on either side of it, was chiefly palæontological, and he thought that, taking into account the difference of sediment and other circumstances which tend to modify the distribution of life, no sufficient evidence had yet been offered to establish the Author's principal contention.

Mr. MARR remarked that the Devonian system had been founded on stratigraphical grounds by Sedgwick and Murchison, on palæontological grounds by Lonsdale and Etheridge. Dr. Hicks had re-opened the question, and as the speaker had doubted the convincing nature of the proofs brought forward by the Author in favour of the Silurian age of some of the Morte Slates, he felt it only due to him to state that he thought the fauna exhibited was a Lower Devonian one, and therefore that the Author had established one of his main contentions, namely, that the apparent succession in North Devon was not the true one.

The Rev. H. H. WINWOOD remarked that whatever difference may exist in the two views as to the stratigraphy of the North Devon beds, yet one fact was indisputable, that the Author had found fossils in the Morte Slates which previous observers had failed to do. Whether the fauna proved to be Silurian or Lower Devonian, the evidence so far showed that these slates could not be an upward succession of the Middle Devonian or Ilfracombe Beds. During his last visit to this district in company with the Author he was much impressed with the enormous folding and disturbance which those rocks had undergone, thereby very much reducing their estimated thickness, as the late Prof. Jukes had stated.

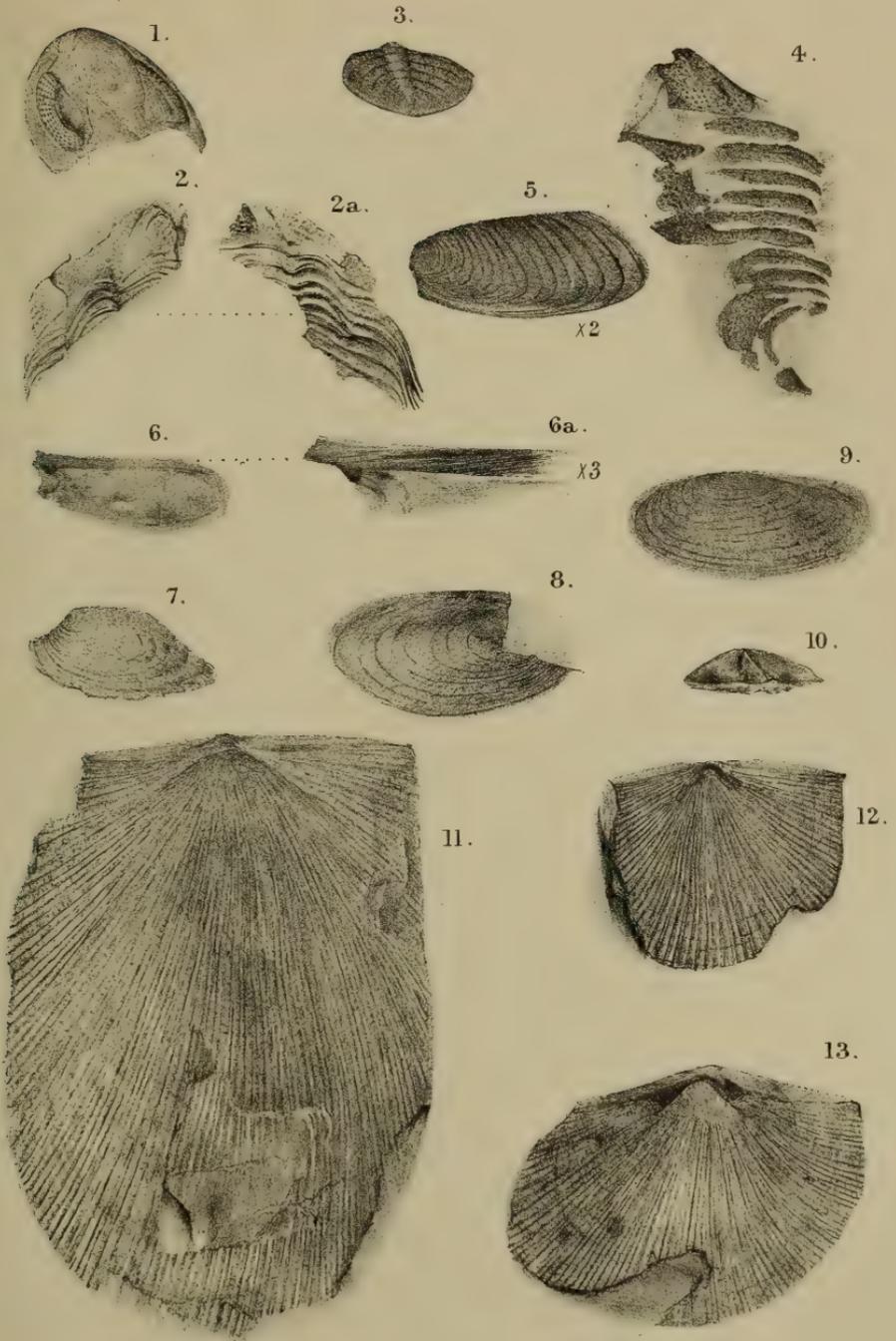
Mr. R. S. HERRIES said that he had been over part of the area with the Author. He had not examined the south side, but he thought that on the north there could be no doubt that on stratigraphical grounds the Treborough Slates belonged to a series entirely distinct from the beds immediately north of them. The exact age of these slates was of minor importance. The real point was whether they were older or younger than the beds to the north. If the palæontological evidence showed that they were older, as the Author contended, then the inference was a very strong one that the Morte Beds of North Devon, where the fossil evidence was not nearly so convincing, were also older than the Ilfracombe Beds to the north

of them. From the fact that so many fossils had been obtained at Treborough in a comparatively short time, the speaker thought that the fauna might be largely extended by anyone who had time to work the quarries systematically.

Dr. J. W. GREGORY said that he would refer only to the palæontological questions, and not to the stratigraphical difficulties. The case for the Lower Devonian age of the fauna appeared, from the evidence quoted by the Author, to rest on the *Cryphæus* (as the Author preferred to call it) *laciniatus*. Dr. Hicks described this species as characteristically Lower Devonian; but it is commonest at the extreme top of the Lower Devonian, as in the Vichtian Beds, where it is associated with Middle Devonian forms. Gosselet quotes it from the Eifelian (Middle Devonian), and asserts its occurrence in the Upper Devonian. Hence the speaker doubted whether it proved much. He asked in what sense the Author used the names *Dalmanites* and *Cryphæus*, as they were regarded, at least by some American authors, as synonymous—*Cryphæus*, the name given by Green in 1837, having been abandoned owing to its prior use for a genus of beetles. He doubted whether the absence from Oakhampton and Treborough of species found in the beds to the north and south was of the value that the Author assigned to it. The great difficulty in Devonian correlation always had been the appearance of groups of species most characteristic of one horizon at a considerably lower level. For example, the Brilon Ironstone has been shown by Kayser to belong to the Middle Devonian with an Upper Devonian colony. Hence the speaker doubted whether a list of genera such as the Author had read was sufficient to prove whether the Oakhampton beds were Lower or Middle Devonian. He was surprised to hear the species *punctatus* spoken of as only a variety of '*Cryphæus laciniatus*'. He was also surprised to hear the name *Petraia* introduced into serious work: *Petraia* was a palæontological dustbin, into which indeterminate casts of all sorts of simple Palæozoic corals were thrown.

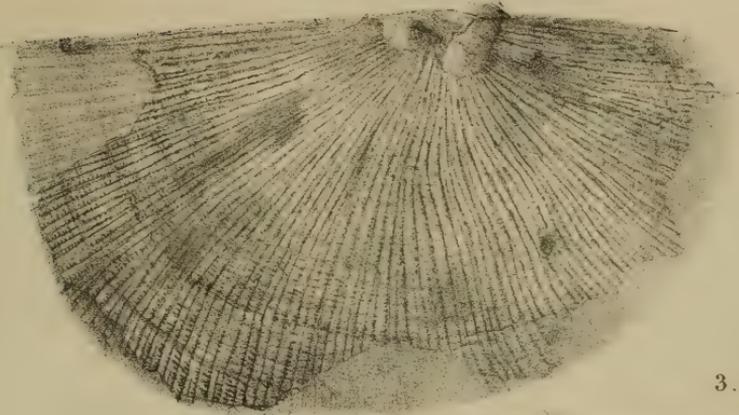
The AUTHOR said that as no facts had been given in the discussion which could in any way affect his conclusions, a reply was hardly necessary. He would, however, state that it seemed to him strange that those who were opposed to his amended reading of the succession in North Devon and West Somerset had not visited those areas in the interval which had taken place between the reading of the two parts of his paper. They had been made aware of the fact that the Morte Slates, previously considered unfossiliferous, contained several faunas; and if they believed that faunas were of any value in defining the age of the beds, they ought to have produced palæontological evidence to refute his arguments. It was entirely erroneous to state that any evidence had been given which tended in the least degree to minimize his statements in regard to the Silurian facies of the North Devon fossils or of the individual fossils which he had described. It was quite useless here, as in

other areas, to cling to the belief that previous observers could not have made a mistake: it was enough to say that they, at least, had not the advantage of seeing the new evidence which he and his friends who were working with him had obtained. He did not read in detail the descriptions of the species, as he thought that it would be sufficient to mention some of the most characteristic forms which elsewhere are supposed to mark fairly distinct zones. There was, in his opinion, a gradual passage from the Silurian rocks of North Devon to the Lower Devonian Beds of West Somerset, and it was interesting to find *Dalmanites* and *Homalonotus* (characteristic Silurian genera) in the latter, in association with well-known Lower Devonian fossils. The beds on the north side, previously supposed to be older than these, are separated from them by faults and contain typical Middle Devonian fossils.

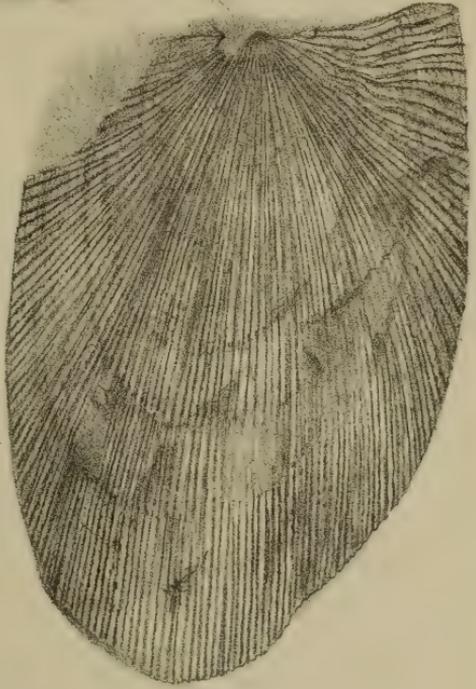




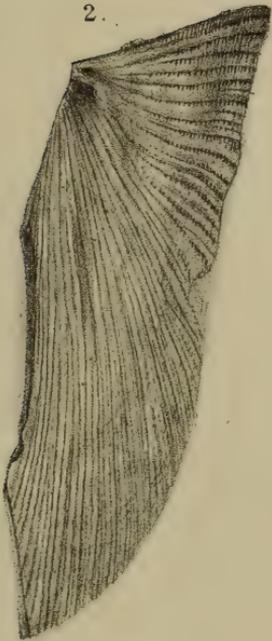
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3.



2.



4.



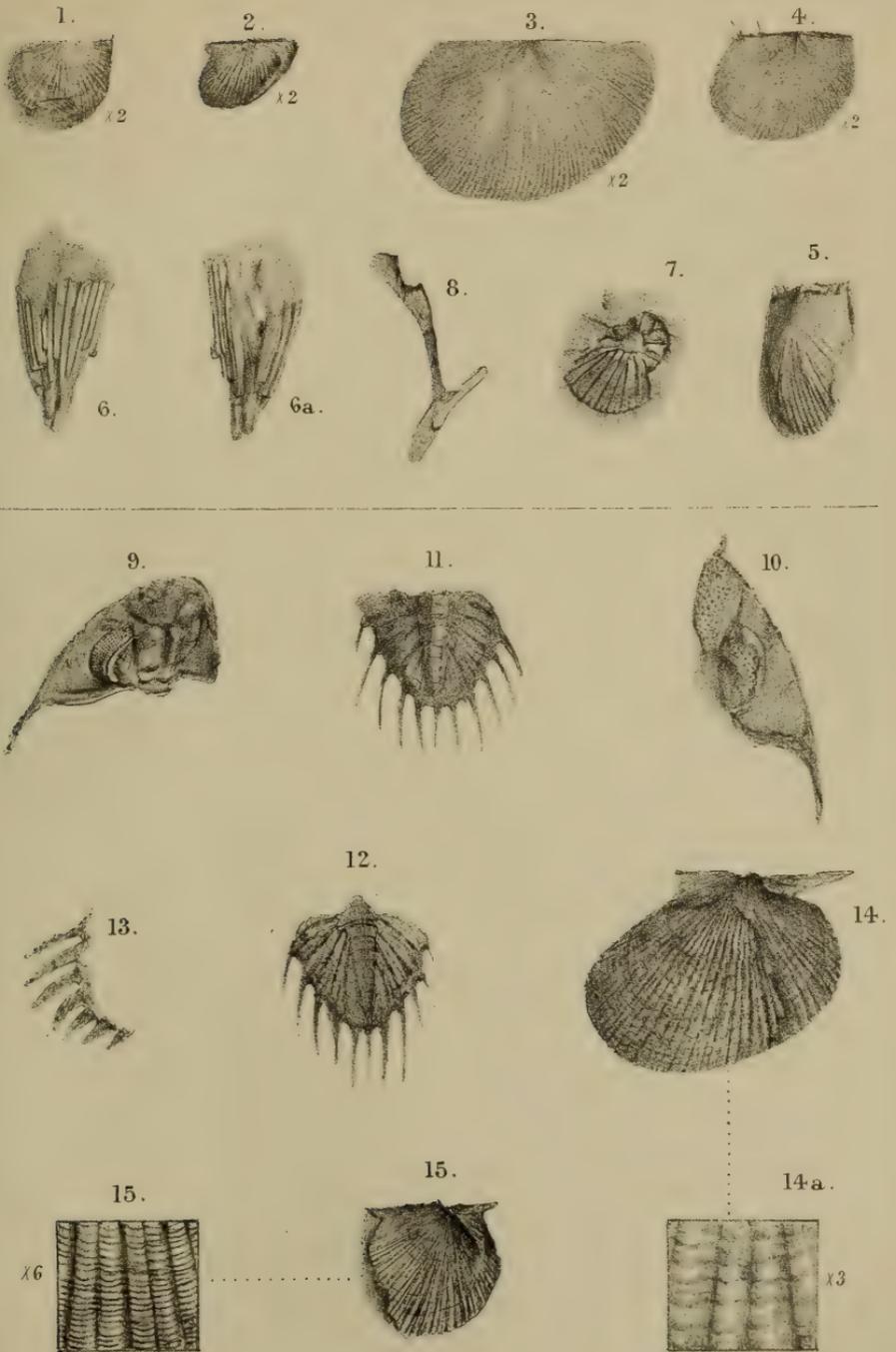
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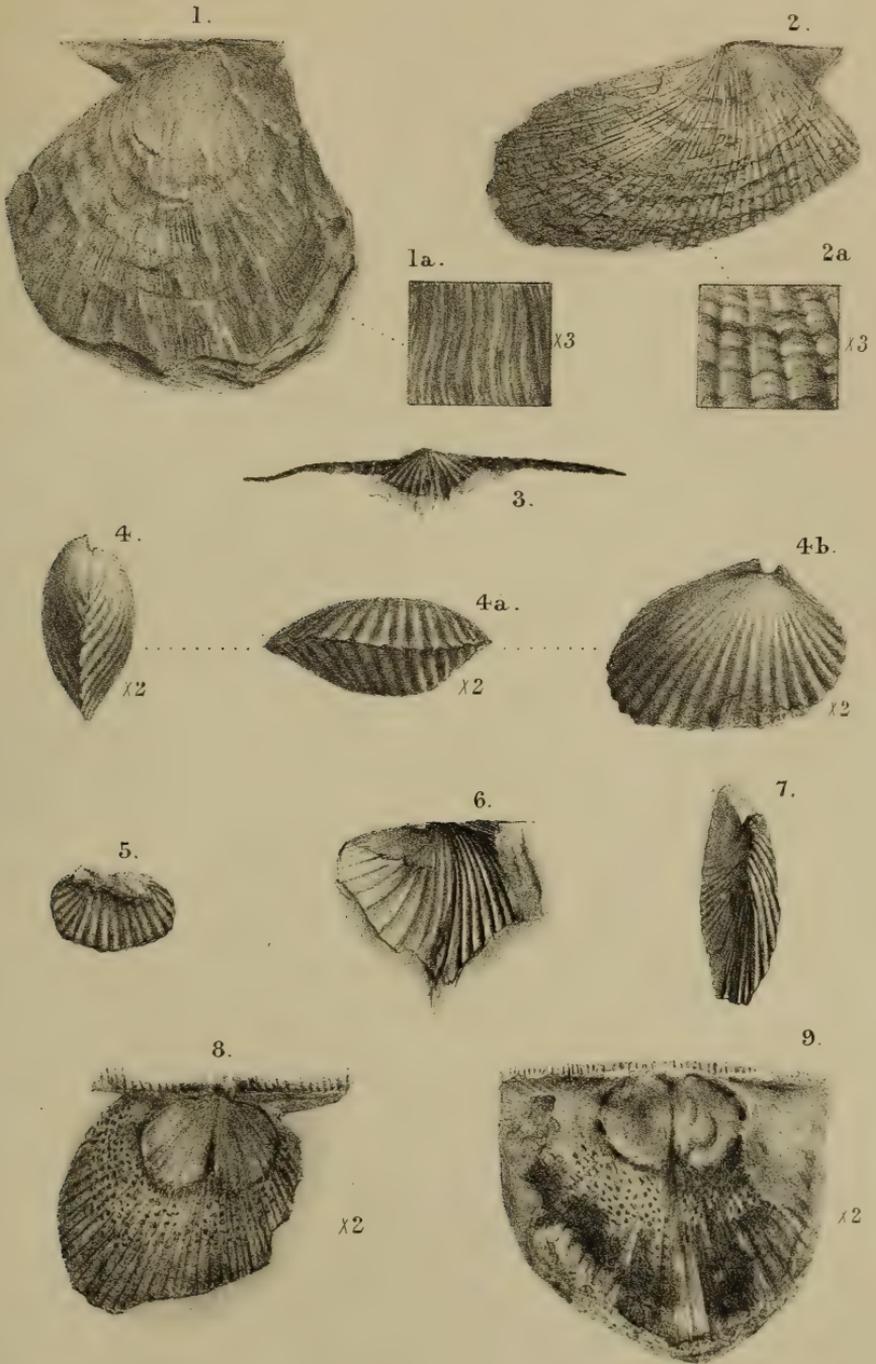


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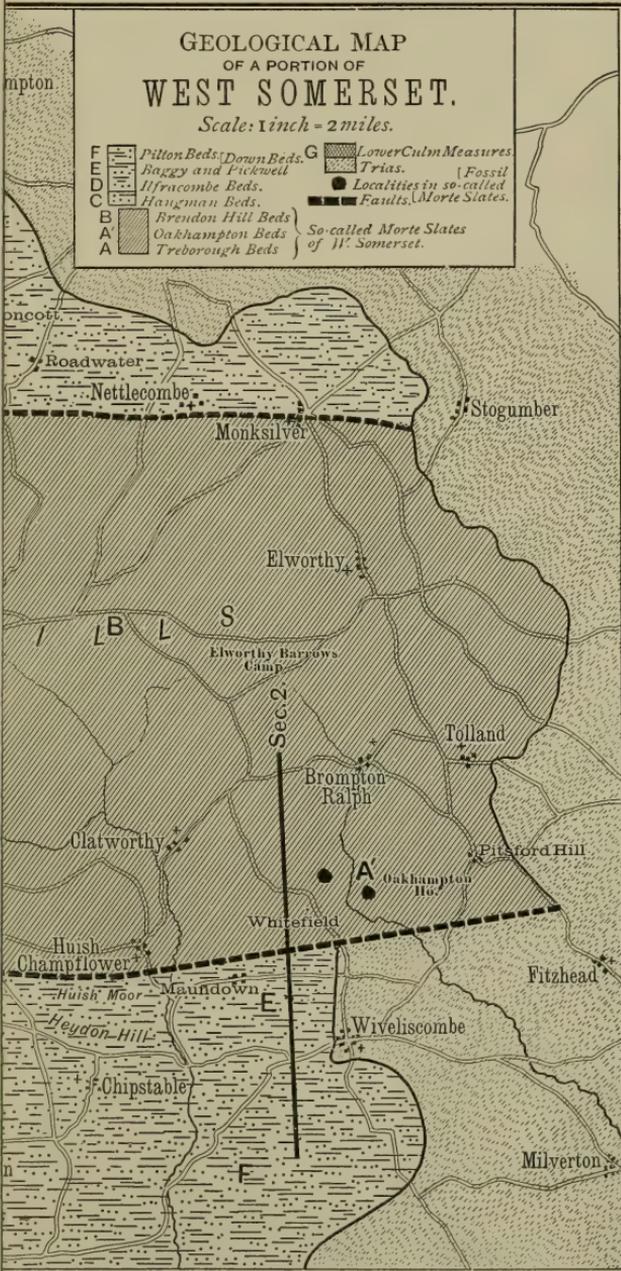




F.H. Michael del. et lith.

Mintern Bros. imp.











32. PLEISTOCENE PLANTS *from* CASEWICK, SHACKLEWELL, *and* GRAYS.<sup>1</sup>  
By CLEMENT REID, Esq., F.L.S., F.G.S. (Read June 23rd,  
1897.)

IN the year 1888, during a visit to Sir J. Prestwich, I had the opportunity of examining his Pleistocene collection. I saw among the specimens two lumps of clay which had been collected at Casewick and at Shacklewell, to illustrate papers by Morris and by himself. These he kindly permitted me to take away and examine, and out of them I obtained the plants mentioned below. In Prestwich's collection I observed also a number of plant-remains from Grays, which had been partially determined in 1861 by Gaudin and Heer. These, however, I was unable at the time to study, for Prestwich informed me that he was then engaged on a paper in which the deposits at Grays would be described. He died without completing the work, and his collection was given to the Natural History Museum, Lady Prestwich informing Dr. Woodward and myself that it was Sir Joseph's request that I should complete the examination of his Pleistocene plants. In this manner it happens that I am now writing a botanical supplement to papers which were read before the Society at such distant dates as 1853, 1855, and 1869.

#### Casewick (Lincolnshire.)

The alluvial deposit at this locality was described by the late Prof. John Morris, who gave to Prestwich the lump of clay from which I obtained the plants. There is nothing in the list to throw any light on the age of the deposit, and so far as the flora shows it may be of extremely recent date:—

*Nuphar luteum*, L.  
*Galium Aparine*, L.  
*Atriplex patula*, L.  
*Rumex crispus*, L.  
*Ceratophyllum demersum*, L.  
*Scirpus lacustris*, L.

#### Shacklewell (Middlesex).

The peaty clay was obtained by Prestwich from beneath 8 or 10 feet of gravel; but neither the mollusca nor the plants point to

<sup>1</sup> Forming a botanical supplement to three papers which have appeared in this Journal, namely:—Morris, 'On some Sections in the Oolitic District of Lincolnshire,' *Quart. Journ. Geol. Soc.* vol. ix. (1853) p. 317 [Casewick]; Prestwich, 'On a Fossiliferous Deposit in the Gravel at West Hackney,' *ibid.* vol. xi. (1855) p. 107 [Shacklewell]; Tylor, 'On Quaternary Gravels,' *ibid.* vol. xxv. (1869) p. 83 [Grays].

any great antiquity of the deposit, characteristic Pleistocene forms being absent:—

*Ranunculus repens*, L.  
*Rubus Idaeus*, L.  
*Rosa canina*, L.  
*Eupatorium cannabinum*, L.  
*Lycopus europæus*, L.  
*Alnus glutinosa*, L.  
*Quercus Robur*, L.

#### Grays (Essex).

The plants from Grays consist of a number of leaves, already examined by Gaudin and Heer, and some seeds which I have been able to wash out of the lumps of clay. The leaves, from long keeping, have suffered somewhat, and perhaps to this cause is due the absence of certain species noted in a MS. list by Heer. The missing plants are *Pteris aquilina*?, *Vaccinium myrtillus*??, and *Fagus*??, but it is noticeable that Heer records all three with doubt.

*Ranunculus repens*, L. (seed).  
*Rubus fruticosus*, L. (seeds).  
*Rosa canina*, L. (prickle).  
*Hedera Helix*, L. (leaves).  
*Ulmus*? (badly-preserved leaves).  
*Alnus glutinosa*, Gärtn. (leaves and cone).  
*Quercus Robur*, L., var. *sessiliflora* (leaves).  
*Corylus Avellana*?, L.  
*Populus*, cf. *canescens* (leaves).  
*Salix* sp. (leaf).  
*Potamogeton* (seed).  
*Cyperus*?  
*Phragmites*?  
 Grass nodes.  
*Equisetum*.

The plants occur associated with, or below the remains of, mammoth and *Corbicula fluminalis*. They point distinctly to a temperate climate and mild winters, for the ivy is extremely sensitive to winter cold. Both the character of the flora and the position of the deposit suggest correlation with the temperate plant-beds of Hoxne, which lie between the Boulder Clay and the deposit with Arctic species. The ivy and the poplar have not previously been recorded as British fossils.

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**No. 212.**

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[Business will commence at Eight o'Clock precisely each Evening.]

33. *Some IGNEOUS ROCKS in NORTH PEMBROKESHIRE.*

By JOHN PARKINSON, Esq., F.G.S. (Read June 9th, 1897.)

[PLATE XXXVI.]

THE acid rocks which form the subject of the bulk of the following notes are situated at the eastern end of the Prescelly Hills in North Pembrokeshire. Although igneous rocks differing from these do occur to a large extent, their petrological interest is not great, and the mention made of them will be brief. The Prescelly range has a general trend in an easterly and westerly direction, and may be considered as extending roughly from near the village of Rosebush—noteworthy for its slate-quarries—to the village of Crymmych, some 7 miles to the west. The slates of the country are coloured on the Geological Survey maps as Llandeilo; and it is unfortunate that the difficulty of finding fossils prevents much further and more definite information being added.

Although apparently organisms are sometimes found in the Rosebush slate-quarries, neither my endeavours nor those of the men employed in the place were successful during my visit. About  $\frac{1}{2}$  mile west of Crymmych, however, a few fragmentary fossils were obtained.

One species of graptolite was found, which has been kindly identified by Miss E. M. R. Wood as *Didymograptus* comp. *indentus*, var. *nanus*, Lapw., and some fragments of at least one species of *Trinucléus*, which Dr. Woodward has kindly allowed me to submit to him, but which were unfortunately not sufficiently well preserved for a specific identification. Miss Wood is inclined to think that the rocks are of Lower Llandeilo age, though there is a possibility that they may be Lower Arenig.

This conclusion is interesting, since the masses of acid rock which occur at the places marked Foel Trigarn and Carn Alw show all the characteristics of a true lava-flow. Those two localities are about  $1\frac{1}{4}$  mile apart, and although the development of the rock at either is but small, yet there are a few points which may be of interest.

As regards the general characteristics of the rocks, slides cut from two specimens obtained at Foel Trigarn may be taken as examples.

The first of these, which is quarried for road-metal on the northern side of the hill, is a compact, somewhat light blue-grey rock, often conspicuously banded, and weathering to a deep brown. In thin section it is seen to be cryptocrystalline, with occasional larger grains of irregular shape and brighter polarization-tints. The slide contains pyrite in some abundance, with a little hæmatite and also flakes of opacite arranged in a manner suggestive of flow.

A variety of this rock from the southern side of the hill is porphyritic, of a uniform slate-grey colour, weathers in a very slaggy

manner, and flies under the hammer. In thin section it is microcrystalline, with some quantity of microfelsitic matter, and shows an approach to a banded structure. Clearer secondary feldspar is formed in some instances, filling cracks in and forming a zone—always very narrow—round the porphyritic crystals.

As an instance of essentially similar rocks from Carn Alw a specimen may be taken of a medium tint of blue-grey, with irregular flecks and streaks of a darker colour which, on the broad surface of the specimen, are seen to have a certain parallelism. A rock of this character is typical of much from this locality, and may be briefly described as being of a compact nature, rather dark in colour, breaking with a subconchoidal fracture, not conspicuously porphyritic, and weathering white, or occasionally to a pinkish tinge. The quartz-crystals are corroded, and contain portions of the 'matrix,' while the feldspars have undergone considerable alteration.

In some cases there is a microcrystalline, in others a confused crystallization, which shows large irregular, though often fairly definite, patches as the stage is rotated between the two nicols, and with coarser areas and veins, having a tendency also in places to a radial structure.

In many of these rocks—notably from Carn Alw—flow-structure is beautifully developed (Pl. XXXVI, fig. 1). In a typical specimen the bands are very regular, about  $\cdot 1$  inch across on an average, but commonly exist as mere lines, the darker containing a green chloritic mineral. In many cases this may be seen to have spread, or to be in process of spreading, over the major part of the band, leaving often irregular but well-defined patches, having a roughly radial crystallization. There are, however, bands much thinner than the above, possessing a crystallization normal to their length; along the middle, and, finally, all over which the green mineral has spread. The slide contains porphyritic feldspars—monoclinic—and occasionally a small quartz-crystal. The constituent particles of the crypto-crystalline groundmass are generally rather elongated. Macroscopically there is a considerable resemblance between this rock and those from Penrhyn, near Fishguard, recently described by Mr. Cowper Reed.<sup>1</sup> The latter have a crystallization rather more definite and at the same time finer, but the Carn Alw rock is more finely fluidal. The principal difference exists in the presence of feldspar-microlites and in the absence of the green chloritic substance from the Penrhyn rock, both facts indicating, of course, a diversity in composition; but the general likeness is very great.

Possessing close affinities to the above is a light blue-grey rock, weathering white, and traversed with some regularity by innumerable lighter bands and lines, which vary from about  $\cdot 005$  to nearly  $\cdot 1$  inch in breadth. It contains porphyritic crystals of both quartz and feldspar, and in thin section the bands are found to consist of greenish microlites and of granular ill-defined matter, apparently essentially similar to the microfelsitic substance scattered more sparsely through the whole of the slide. Between the bands are

<sup>1</sup> Quart. Journ. Geol. Soc. vol. li. (1895) p 160.

irregular spherulitic growths, the matrix in which they are set containing an inert green 'chlorite' in some quantity. The arrangement of this 'chlorite' in places strongly recalls the perlitic patch figured by Mr. Rutley in a spherulitic rock from Beddgelert and an epidositic felsite from the Herefordshire Beacon,<sup>1</sup> and there can be little doubt that much of the present structure is due to the causes which he describes in those instances. The spherulites as a rule are rather confusedly crystalline, and show but little approach to a radial structure; their outlines are usually elliptical rather than circular, and they are free from the secondary chloritic mineral. It is perhaps worth mentioning that the microlites forming a large part of the bands which characterize the rock macroscopically lie in a direction not parallel to, but at an angle with, the length of the band, indicating—as Prof. Bonney has suggested to me—a slight movement of the rock in a new direction, immediately prior to consolidation, but which has not been sufficient to disturb the parallel regularity of the bands themselves.

Consideration of this not very markedly spherulitic rock leads to those in which the spherulites are conspicuous. In a slide from one of these a band about  $\frac{1}{2}$  inch across, with spherulites  $\frac{1}{10}$  inch in diameter, is cut.

The larger of these spherulites occur either singly or grouped in twos and threes, in the latter case arranged often in a linear manner and shading off into axiolites. They show concentric lines of growth, with generally a narrow outer border of clear matter in contrast to the darker and finely fibrous nature of the internal portion.

Interstitally, between the above, are closely-packed clear spherulites, showing commonly concentric lines of growth rather markedly. In the majority of cases these, like their larger representatives, have a clear but broader edge, which is distinctly separated from the less translucent central portion. The sharpness of the definition between the zones suggests occasional concentric fracture and infiltration. These smaller spherulites are in some instances grouped linearly, giving a scalloped appearance, on each side of a line of granular and less definite crystallization, of some width in proportion to the size of the spherulites, and which may extend for nearly the entire breadth of the slide. As Prof. Bonney has pointed out,<sup>2</sup> this kind of arrangement may be simulated in sheets of glass fused by fire, a surface of discontinuity being formed between two layers. In this case it would appear as if a crack had formed the necessary starting-point.

A variety of this rock, showing minor differences in the spherulites, but considerable differences in the character of the matrix in which they are embedded, presents a few points which may be of interest.

<sup>1</sup> Quart. Journ. Geol. Soc. vol. xlv. (1888) p. 740 & pl. xvii.

<sup>2</sup> Pres. Addr., Quart. Journ. Geol. Soc. vol. xli. (1885) *Proc.* p. 91.

The spherulites, or rather axiolites, for they are often twice as long as broad, show marked stages of growth even macroscopically; indeed, differences of texture, accentuated by an appearance of discontinuity between the inner and more peripheral parts, suggest an interval during their development when growth ceased (Pl. XXXVI, fig. 2). The outer border is frequently clear, in contrast to the darker, almost flocculent appearance of the centre; and the exterior is a surface of easy parting, since fracture of the specimen often leaves the knob-like surfaces of the axiolites standing out.

The matrix contains a few porphyritic crystals of both quartz and monoclinic felspar, and a second, less numerous generation of smaller spherulites. In thin section it is pale green in colour, slightly dichroic, very feebly anisotropic, and easily marked with a knife. The smaller spherulites to which I have just referred contain centrally a greenish substance, no doubt an inclusion of the matrix in which they lie. In places there is a slightly radial or tufted habit which recalls chlorite, but the chemical difficulties<sup>1</sup> in supposing the whole of the matrix to be converted into such a mineral are considerable, and I am indebted to Prof. Bonney for the suggestion that this somewhat structureless substance is probably of the nature of a glassy residuum, in which the iron silicates have been hydrated, and which would answer to the palagonite of the more basic rocks.

In some instances, this hydrated glass is reduced almost to a minimum (Pl. XXXVI, fig. 3), and the grouping of some of the axiolites, which are similar to those just described, recalls a figure of Zirkel's of a specimen from Nevada.<sup>2</sup> In the present as in the other case, the elongated, often sinuous, appearance of the axiolites suggests that flow-movement was indirectly concerned in their development, but the dark, granular, fluidal lines of the American rock, forming the meshes in which the axiolitic growths took place, are not present here. It seems, therefore, that the curving and at the same time complete structure is best explained by concluding that after their formation, but while they were still in a plastic state, a slight movement in the unsolidified magma occurred, forcing together and bending the axiolites, producing effects analogous to the contortion so often seen in a flow-band, and allowing little tongues of glass to penetrate the axiolites where such an entrance could be effected.

It is interesting to notice that in one or two cases a fluxional movement, which affected the particles prior to the beginning of spherulitic growth, has left a permanent impress. This is seen in the attempted formation of a spherulite round a porphyritic felspar; the bending of the flow-lines round the crystal is still distinctly seen, while a little distance away the radial growth and zoned structure of the spherulite are more conspicuous.

<sup>1</sup> 'Chemical difficulties': these consist in the large percentage of silica and the small percentage of magnesia which rocks of this kind contain. Assuming such a matrix to be changed in any great degree into chlorite, it is not easy to see what is to become of the excess of the former, or how the deficiency in the latter constituent is to be made up.

<sup>2</sup> 'Micro. Petr.' p. 171, pl. vi. fig. 2.

In some cases the spherulites are not so clearly defined as those just mentioned; they are finely cryptocrystalline, the periphery is less regular, and the radial growth not so marked.

The separation from the magma, or from the original glass, now represented by the inert green substance previously mentioned, has been accompanied by the formation of lines and bands, white in the hand-specimen, in contrast to the blue-grey colour of the rest of the rock, and weathering out as white ridges. There is no doubt that these are due to fluxional action, as is shown by their parallel habit, and the manner in which they bend round porphyritic crystals; also in the field the rock passes in a short distance into the ordinary banded type. The bands are now cryptocrystalline, but an attempt at a radial growth is shown by the elongation of the particles normally to the boundary of the band, meeting in a median line of discontinuity which is often rather marked between crossed nicols. Accordingly these may be regarded as an elongated variety of axiolite. They are closely related to other bands—in fact no hard-and-fast line can be drawn between them—which are outlined by markedly scalloped boundaries, and apparently formed by the linear arrangement and mutual interference of individual spherulites.

It follows then that stages can be traced from the isolated spherulite—outlined by the green inert substance representing the residual hydrated glass—through stages where two or three of these are arranged linearly, then losing the boundaries of the two sides, passing thus into an axiolite, or into a flow-band in which the crystallization is normal to the sides defining it in greater or lesser degree. These structures recall the 'granular axiolites' mentioned by Zirkel,<sup>1</sup> which in section show two series of roughly wedge-shaped grains with a distinct suture running between them. He remarks that these are closely related to the fibrous axiolites. The suture or median line of discontinuity referred to is often due to the dovetailing of opposed particles, but in some cases its straightness and definiteness suggest a crack.

Passing from those rocks which show normal and complete, to those which show incomplete spherulites, one finds, of course, the common type in which growth has taken place from several centres close together, so that mutual interference has prevented the perfect form from being produced. There is, however, another and less common variety which is characterized by the simultaneous action of fluxional and spherulitic forces, the former having modified the complete form which should have been produced by the latter.

As an example, a slide is selected from the same locality. The spherulites are arranged in bands, interrupted and of irregular thickness, parallel one to another, and much more opaque than the rock in which they lie; but the edges of the band on either side have been, as it were, abruptly truncated, leaving, however, a boundary which is by no means a straight line, owing to the

<sup>1</sup> 'Micro. Petr.' p. 174, pl. vii. fig. 1. Compare also Rutley, 'Felsitic Lavas of England & Wales,' Mem. Geol. Surv. 1885, p. 5, pl. i. figs. 11 & 12.

incomplete nature of the fibrous growths which form the band itself (Pl. XXXVI, fig. 4).

These spherulites occur frequently in fragments and segments, which are often placed in such a position that they form part of an unit whole, the missing parts being represented by confusedly crystalline matter, and rendering the idea of an originally complete, subsequently dispersed and broken spherulite, improbable. It is also to be noted that, if spherulitic growth had been set up after the final cessation of fluxion in the rock, we should have expected that a complete, and not a partially complete, spherulite would have formed. Suppose, for instance, that some part of a magma which had become in a greater or lesser degree separated from its surroundings be placed in conditions suitable for the formation of a spherulite; then, fluxion being inoperative, the resulting form would be a sphere, no matter what the shape of the differentiated area might be, since the residual peripheral parts would not participate in the radial growth.

This, however, as already stated, is not the case here. In other instances the spherulites most commonly consist of fragments of ellipses, and the banded structure characterizing the previous rock is absent (Pl. XXXVI, fig. 5). In the less strikingly spherulitic parts of the slide there is decided evidence of flow-movement, into which the radially-arranged outer zones of the spherulites pass gradually, so that they have no definite boundary such as would have been expected if their growth had been undisturbed.

When closely packed, these spherulites have a tendency to mutually interfere so as to produce hexagonal bounding lines, the interior well defined from the outer parts; in others, adjacent members may have a common and incomplete exterior, and there are occasional cases where axiolic fragments are grouped together in a manner which suggests that a curving line of flow has been a factor in determining their present position. There are also instances of adjacent spherulites the outer parts of which, though fairly well formed, are connected by lines undoubtedly due to flow, while, in others, part of a spherulite or of a group of spherulites may be formed of matter which has an appearance strongly suggesting movement. If this had preceded spherulitic growth and then stopped, there would seem to be no reason why these malformations should exist; and it seems, moreover, that any late renewal of movement which could thus modify the symmetry would have distorted the remainder to a greater extent than the slides exhibit. Spherulitic tufts may be seen in places wedged in between a spherulite with which they are more or less in continuity, and an external part which shows flow-lines and into which they grade. Thus they appear to represent material which was displaced outwards by fluxional movement.

MM. Fouqué & Lévy<sup>1</sup> have figured from Gratadis spherulites disturbed by flow-movements which show some resemblance to

<sup>1</sup> Mém. Carte géol. France, 'Minéral. Microgr.' 1879, pl. xv. fig. 1.

those just described. The evidences of flow seem rather stronger on the whole, and apparently the disturbance has taken place entirely after the formation of the spherulites. In the case of the Prescelly rock the structure of the slides indicates that movement has accompanied spherulitic growth, although in places here and there one or the other may appear to have been the stronger.

A second division of incomplete spherulites includes those in which flow-brecciation, accompanied by but very feeble radial growth, has resulted in the formation of globular bodies sometimes nearly  $\frac{1}{2}$  inch in diameter; possessing a complete discontinuity from, and showing a striking contrast to, the matrix in which they lie. As is common in the neighbouring rock, the specimen is marked by lighter bands, the appearance of which is identical with that of the nodules (if the term be allowed), so that it scarcely needs a microscopic examination to see that the causes which have produced the former must have been nearly concerned in the formation of the latter also.

In hand-specimens the nodules much resemble true spherulites, standing out prominently on a fractured surface, and leaving an oval cavity on removal. In thin section (Pl. XXXVI, fig. 6) they are distinguished from the matrix by their browner colour and consequent greater opacity, while under crossed nicols they show irregular patches of light with indefinite wavy clouds of shadow as the stage is rotated, again in contrast to the body of the rock, which is micro- and crypto-crystalline (often quite coarse), and which contains a green chloritic mineral in some quantity. The 'nodules' are often elongated, and are connected one to another in the manner which is usual in those portions of a rock which have become differentiated from their surroundings and influenced by flow-movements, since occasionally circular, but more frequently elliptical or irregularly oval, outlines are found, which often taper to a point.

There is in places a somewhat indefinite suggestion of radial growth, which in a few cases becomes more pronounced. Rather more often there is a tendency towards a concentric banding at the edge of the patch, giving the idea that after it had assumed its present shape segregation was again operative. In the interior of these 'nodules' there are irregular but more or less central quartzose areas, roughly concentric with the periphery. As regards the origin of these masses there can be no doubt—they are evidently one of the results of flow-brecciation, as indeed has been suggested in connexion with some of the Boulay Bay pyromerides.<sup>1</sup>

It seems, therefore, that a mixing of two materials, or the differentiation of one, has occurred, resulting after brecciation in the formation of clots which have been drawn out by the action of their more liquid surroundings, as just described, subsequently often losing their connexion with the original mass. The quartzose areas are sharply defined, and roughly follow, as above mentioned, the outline of the nodule, with occasional irregularities in various

<sup>1</sup> Miss C. A. Raisin, 'Nodular Felsites of the Lleyn,' *Quart. Journ. Geol. Soc.* vol. xlv. (1889) pp. 264, 265.

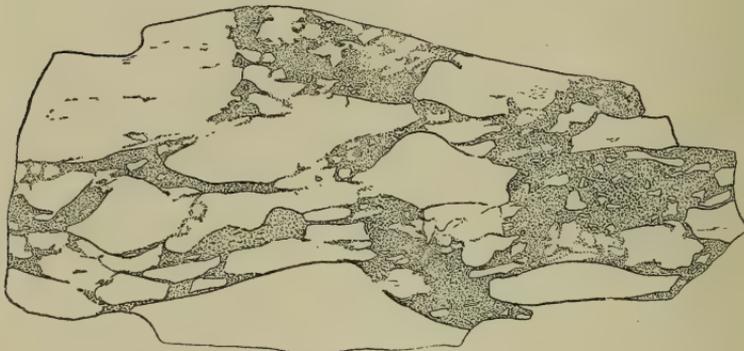
directions. There are also fine quartz-veins, which have probably formed the means of supply to what can be scarcely other than a vesicle.

It must be understood that this nodular structure, if indeed it may be called such, occurs only in one or two specimens, and it is merely the suspicion that other and better known cases are due to the same causes that has led me to record it here.

Before passing on to consider the true fragmental rocks, some notice must be taken of a variety having an appearance in the field strongly suggestive of a felstone-agglomerate.

In it white angular or subangular fragments, with a tendency to roughly resemble an almond in shape, of an average length of  $\frac{1}{2}$  inch, but which vary considerably, are embedded in a softish black or green-black matrix, which in places contains foreign-looking fragments, the whole presenting a well-marked type of some constancy.

*Rock with white fragments due to flow-brecciation.*



[The dotted portions represent the soft black matrix.]

In places the pieces of felstone are separated by a space considerable in proportion to their bulk; in others they are close together, and the appearance is then suggestive of a slight cracking, followed by a forcing apart by a second material.

It is evident that such an appearance as this might be produced by a brecciating force after the consolidation of the rock, subsequent infiltration giving rise to the black matrix in which the fragments are set. But it is also clear that, if such be the right interpretation, the magnitude of the force capable of moving neighbouring pieces of rock apart, and often of leaving fragments of different structure in close proximity, would have been sufficient to leave a clear impress, at all events microscopically. Of this, however, there is no indication, except in one instance of a brecciated felspar; if other cases had been present they would no doubt have been visible; on the contrary the evidence points sometimes the other way, as in

the case of a fragment of a spherulite embedded in the matrix and having an appearance by no means suggestive of crush.

It seems then that brecciation *in situ* will scarcely account for the facts, and one is obliged to believe that this is either a case of a true agglomerate or a rather exceptional one of flow-brecciation. The appearance in thin section presents some difficulties in the way of accepting the former view, for although in some instances the edge of the felstone-fragments is well defined, more often the boundary is almost impossible to determine between crossed nicols. The matrix, if such it may be called, is pale green with ordinary light, having low polarization-tints and crowded with minute clear spaces occupied by grains of quartz or felspar; it also contains patches free from these grains and a lighter green in colour, as if some differentiation had gone on in it, but the outlines are not well defined, and the clotting appearance which it suggests is not specially marked.

In one case there is a long porphyritic felspar which has been bent and cracked, without displacement of the parts, in a manner suggestive of softening and heat.

These facts, together with the absence of scoria, seem scarcely to favour the idea of an agglomerate, while the agency of flow-brecciation, by which a second onflow of lava has broken up and separated a mass probably still in a plastic state, seems to account for the observed facts. Under these circumstances one would certainly have expected to find more evidence of flow-movement; but if, as seems likely, this 'matrix' represent in some measure a hydrated glass, the changes which this would have undergone since its solidification may have masked any traces of original fluxion.

Specimens of brecciated felstone from Pen-y-chain, for an examination of which I am indebted to Miss Raisin, show macroscopically considerable resemblances to this Pembrokeshire rock both in the characters of 'matrix' and fragments. A thin section, however, shows that the structure is not due to fluxional action.

### The Fragmental Rocks

associated with those which have been just described are not sufficiently remarkable to demand anything but a brief notice. One of the common varieties consists of a felstone-agglomerate, the chips having an average length of 0.3 inch and a breadth equal to about half their length. There are also occasional fragments of more basic rock, often in well-rounded pebbles, and identical with those which have in places been caught up by the lavas themselves. They are never of large size.

Scattered through the matrix are detached feldspars and quartz-fragments, with a great quantity of a greenish-grey, filmy, secondary product, together with which occur patches of a green, dichroic, and probably chloritic mineral, showing yellow and violet polarization-tints, and which seems minutely fibrous or filmy. It is soft, and can be easily grooved with a knife. In places there seems to have

been less of the finer dust and débris, and the rock is then of a lighter colour.

Fine ashes are also found in the neighbourhood of Foel Trigarn. These in thin sections are seen to be finely granular or crystalline.

In some cases the true fragmental nature of the rock is not easy to make out, more especially as in places it has been considerably crushed.

The occurrence of these pyroclastic rocks, together with the petrographical evidence, leaves no doubt that the rocks which have been described constitute part of a true lava-flow.

Associated principally with the southern slopes of the hills are a series of rather more basic rocks, of somewhat uniform and monotonous appearance, which will be briefly noticed here. They occur intermittently over the entire length of the ground under notice, but seldom attain to any great thickness. The best exposure is found to the right of the path leading from Rosebush village to the disused slate-quarry at Craig-y-cwm. Here they form a rather conspicuous cliff.

The common type is greenish grey in colour, breaking with an uneven or subconchoidal fracture, and in general of a homogeneous appearance, except for the presence—occasionally in some quantity—of chloritic or quartzose amygdaloids. This even appearance may, however, be somewhat detracted from by dark patches resulting from flow-brecciation. These are occasionally present in quantity, and, in addition, in those cases where a crush has taken place the rocks are difficult to distinguish in the field from true ashes.

In thin sections the rocks are seen to contain a large number of microporphyrific feldspars, both monoclinic and triclinic. The base in which these are set contains much microfelsitic matter, with but little evidence of fluxional movement in those cases in which flow-brecciation is absent. Opacite is often abundantly present, and somewhat frequently the structure is obscured by secondary products.

West of Rosebush a slightly different type is found. It is often bluer in colour than the rocks just noticed, and contains porphyritic feldspars about  $\cdot 05$  inch in length which are referable to orthoclase. The cryptocrystalline base contains large quantities of oligoclase-microlites. The arrangement of these, together with the manner of formation of a considerable quantity of green, filmy, chloritic matter, affords evidence of flow-movement.

East of Rosebush an agglomerate occurs, consisting both of these rocks and of pieces of slate.

This fact, taken in conjunction with the general parallelism of the outcrop of these rocks to the strike of the slates, and added to such microscopical evidence as is afforded by their fine texture and amygdaloidal habit, with occasional evidences of flow, leads to the conclusion that they constitute a lava-flow antecedent to, and slightly more basic than, that which occurs at the north-eastern extremity of the range.

In conclusion, a few words must be said concerning the diabases or dolerites, which are by far the most conspicuous igneous rock of the district.

They are found throughout the greater part of the length of the hills, from Rosebush to near Crymmych. On some of the southern slopes of the hills near the former village the outcrops of diabase may be seen to make a high angle with the prevalent strike of the slates, while farther north and east diabase is found both above and below the acid lava-flow with its associated fragmental rocks. Hence the diabase must be considered as intrusive and the youngest igneous rock of the district. There is also a general linear tendency in the outcrops which suggests that part of the intrusion at all events was of the nature of a laccolite.

As a typical example a specimen may be taken from Foel Ervr, at the western end of the range. It is of a medium grain, of a general greenish tinge, and shows distinct black augite-plates. In thin section the predominating mineral is seen to be feldspar, in crystals generally long in proportion to their breadth and often somewhat decomposed. These feldspars are embedded in the plates of pale-brown augite. The more fine-grained varieties—for example, that from Carn Ddu-fach—resemble the above in the relations of their augites and feldspars; the latter are largely converted into grey saussuritic products.

The coarser varieties are also essentially similar. The augites are rather dark brown in colour, and much secondary replacement has gone on in the feldspars. There is, however, a considerable quantity of leucoxene (ilmenite), and the augites, though fairly well preserved as a rule, show local alteration, either into a brown hornblende giving place to a green actinolitic mineral, which itself becomes of a lighter tint; or into a chlorite—apparently the latter may represent a further stage of the former change. As in the other cases, the feldspars are considerably altered.

In places, as, for example, at Carn Gyffwy, the macroscopic appearance of the rock varies greatly in a small compass, being either comparatively light in colour when much feldspar is present, or almost black when the predominating mineral is augite. The development of large, irregular, white or pink feldspars with no definite crystalline shape, showing on a weathered surface simply as white circular lumps, gives rise to a rather handsome variety. This is found principally at Carn Meini. As in former cases, the feldspars are replaced by saussuritic products, rendering them in places almost opaque.

In concluding these notes I wish to express my indebtedness to Prof. Bonney for advice and invaluable help throughout; to Miss Raisin for the loan of slides; and to Miss E. M. R. Wood and Dr. Woodward for their kindness in examining the fossils.

#### POSTSCRIPTUM.

[After the meeting Dr. Gregory suggested to me, as a possible explanation of the incomplete spherulites of Pl. XXXVI, fig. 4,

that resorption might have produced the effects described. That the spherulites were altered in their present position rather than during motion after their first formation is, I think, clear from their form and mutual arrangement. The truncated edges of the bands do not suggest resorption, and the presence of a flow-line between two closely adjacent spherulitic bands, and passing a space over which resorption must have acted, necessitates after that process, when the spherulites would appear as they do now, an amount of movement for supposing which, as I have said, there is no warrant.—July 1st, 1897.]

#### EXPLANATION OF PLATE XXXVI.

- Fig. 1. Example of the finely fluidal rock from Carn Alw.
- Fig. 2. Axiolitic rock from Carn Alw. The axiolites are set in a somewhat structureless substance representing a glassy residuum. The fine wavy lines in the groundmass are due to the effects of pressure.
- Fig. 3. Another example of the axiolitic rock from the same locality.
- Fig. 4. An example of incomplete spherulites from Carn Alw. The imperfect form which they present is attributed to flow-movement during formation. They contain occasional minute clear spherulites giving a fairly definite cross between the two nicols.
- Fig. 5. Incomplete spherulites from the same locality, but of a different type. For these the same explanation is put forward. The absence of a definite boundary is seen, so that the outermost part of the spherulite grades into the flow-lines; in the centre of the figure it is seen that two spherulites in contact have half their outermost zone formed, the rest being occupied by flow-lines, while between crossed nicols traces of spherulitic structure are almost entirely lost and replaced by indications of flow.
- Fig. 6. One of the more perfectly rounded spheroids resulting from flow-brecciation, indications of which are still seen in part of its edge. Locality as for preceding figures.

#### DISCUSSION.

The PRESIDENT and Prof. BONNEY spoke, and the AUTHOR replied.

1.



4.



2.



5.



3.



6.





34. NOTES on a COLLECTION of ROCKS and FOSSILS from FRANZ JOSEF LAND, made by the JACKSON-HARMSWORTH EXPEDITION during 1894-1896. By E. T. NEWTON, Esq., F.R.S., F.G.S., and J. J. H. TEALL, Esq., M.A., F.R.S., V.P.G.S. (Read June 23rd, 1897.)

## [PLATES XXXVII-XLI.]

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## I. INTRODUCTION.

THE steamship *Windward*, which has now paid two visits to Franz Josef Land, brought back last year (1896) a series of rocks and fossils, collected by the Jackson-Harmsworth Expedition. This collection, by far the most important which has reached this country from Franz Josef Land, was forwarded to the Geological Survey, and at the request of the Director-General, Sir Archibald Geikie, we have undertaken its examination. Although the full results of the geological observations recorded by Dr. Kœttlitz cannot be made known until the return of the expedition, it has been thought desirable that a preliminary account of the district, based on the specimens already received, should be published.

## II. PREVIOUS WORK ON THE GEOLOGY OF FRANZ JOSEF LAND.

The geological literature relating to Franz Josef Land, though small in amount, is sufficient to prove that those portions of the district which have as yet been visited possess a comparatively simple geological structure. Scattered observations have now been made over more than two degrees of latitude by Payer, Leigh Smith, Jackson, and Nansen, and everywhere the features observed appear to be essentially of the same character. It is a region of plateau-basalts comparable, not only in its main features, but also in many of its minor details, to portions of the western coast of Scotland. Vast flows of basaltic lava, associated in all probability with intrusive sills of the same type of rock, form the greater portion of the district. Sometimes the basalt descends to the level of the sea, and sometimes, as at Cape Flora, rests on some 600 feet of nearly horizontal strata of Jurassic age. It may be safely predicted that if the capping of snow and ice which conceals so large a portion of the district were cleared away, the geological aspect and physical features of Northbrook Island would be very similar



to the northern part of the Isle of Skye, where basaltic lavas and intrusive sills are associated with nearly horizontal strata of Jurassic age.<sup>1</sup>

The geological observations made by the members of the Austro-Hungarian Polar Expedition under the command of Lieuts. Payer and Weyprecht were necessarily of a limited character. Payer calls attention to the plateau-like aspect of the land in the neighbourhood of Cape Tegethoff, the southern promontory of Hall Island, and to the fact that the plateau terminates with steep precipitous rocks.<sup>2</sup> He refers also to the occurrence of dolerite (the general term applied to the rocks by Prof. Tschermak) on Koldewey and Schönau Islands, that of the latter being remarkable for its beautiful columnar structure. He states generally that dolerite is the prevailing rock, but refers also to the occurrence of sandstones and of a shale containing white mica and plant-remains. There is no means of correlating the latter rocks with the beds discovered by Dr. Kœttlitz, of the Jackson-Harmsworth Expedition. The common occurrence of silicified wood is also noticed by Payer, and wood of this character is abundant in the present collection. The ship *Tegethoff* was abandoned, and only a few specimens appear to have been brought back. In his general remarks on the geology of Franz Josef Land, Payer clearly recognizes that it forms a part of an extensive volcanic province, stretching westward through Spitsbergen, Jan Mayen, and Iceland to Greenland.

The voyages of Mr. Leigh Smith in the *Eira* furnish additional information of importance as to the geology of Franz Josef Land. From the account of the first voyage in 1880 given by Mr. (now Sir) Clements R. Markham<sup>3</sup> we learn that May Island, the first land reached, is 200 feet in height, and formed of basalt. Cape Barents, the south-eastern promontory of Northbrook Island, is formed of 'columnar basalt like the Giants' Causeway.' It is stated that while the ship was in Eira Harbour Mr. Grant walked along the shore to the eastward, presumably on Mabel Island, and afterwards ascended with a party to the summit of the hill overhanging the harbour (Bell Island?), which proved to be 1040 feet above the sea. 'On the slope of this hill a good deal of petrified wood was collected, and some other fossils.' It is further stated that 'the lowest rocks belong to the Oxford Clay, and are represented in the collection brought home in the *Eira* by two belemnites. Above the Oxford Clay the rock is of the Cretaceous period to which the fossiliferous wood belongs, including one very perfect cone. There are also slabs with impressions of plants. Over all these has been an overflow of basalt and lava, forming a cap, as on the island of Disco.' In the discussion which followed

<sup>1</sup> See 'The Tertiary Basalt-plateaux of North-western Europe,' by Sir A. Geikie, Quart. Journ. Geol. Soc. vol. lii. (1896) p. 331.

<sup>2</sup> 'New Lands within the Arctic Circle.' See also Proc. Roy. Geogr. Soc. vol. xix. (1874) p. 17.

<sup>3</sup> Proc. Roy. Geogr. Soc. n. s. vol. iii. (1881) p. 129.

the reading of the paper, Mr. Etheridge referred to the widespread distribution of the basalts, which he regarded as being probably of the same age as those of the Giants' Causeway.

During the second voyage of the *Eira* in 1881, which unfortunately terminated in the loss of the ship, a raised beach, 90 feet above sea-level, was found in Gray Bay, and cliffs of columnar basalt, 800 feet in height, were observed at the same locality.<sup>1</sup> Fossil wood was found on David Island.

Dr. Nansen's book, 'Farthest North,' contains many references to the geology of the parts of Franz Josef Land visited by him. The first rock touched in his memorable journey towards the south is described as a coarse-grained basalt,<sup>2</sup> and he refers to the occurrence of basalt on the western coasts of Karl Alexander Land and Frederick Jackson Island; also at Capes McClintock, Fisher, and Richthofen. In justice to Mr. Jackson it should be remembered that he had visited most of these localities in 1895, and had observed the occurrence of basalt.

In many places the rock exhibited the characteristic columnar structure in the most perfect manner. While staying with Jackson at Cape Flora, Dr. Nansen examined the geological structure of the neighbourhood of that cape, the points of interest being shown to him by Dr. Kœttlitz, the doctor and geologist of the English expedition. The basalt appears at a height of 500 or 600 feet, and below this is a soft clay containing lumps of an argillaceous sandstone, in which fossils occur. At first Dr. Nansen held the view that the stratified deposits belonged to a late beach-formation, but Dr. Kœttlitz showed him that these deposits actually passed underneath the basalt. Dr. Nansen also observed thin strata of basalt in the clay, below the main mass. The fossils were mainly ammonites and belemnites, and these convinced him that they belonged to the Jurassic period. The main mass of basalt was coarser in grain than ordinary basalt, and resembled the so-called 'diabases' of Spitsbergen.

Dr. Nansen points out that the situation of the basalt on Northbrook Island is different from that which had been observed farther north. Here it was found at a height of 500 or 600 feet, whereas north of lat. 81°, at Capes Fisher, McClintock, Clements Markham, and many other localities, it descended to the sea-level. He regards the basalt as in great part of Jurassic age.

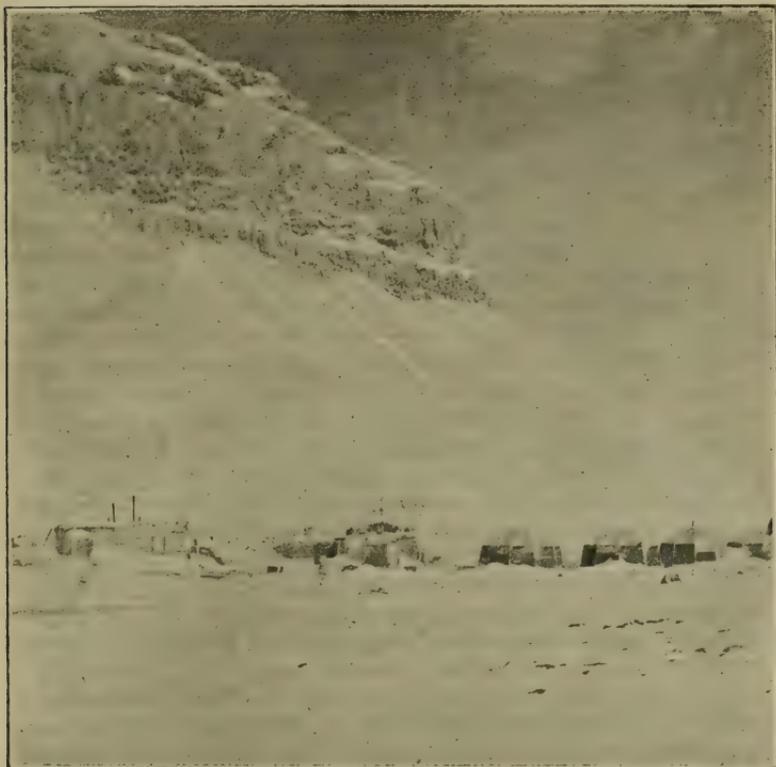
Mr. Jackson and Dr. Kœttlitz discovered innumerable fragments of rock, containing plant-remains, resting on a mass of basalt which, at a height of more than 700 feet above the sea, projected through the glacier on the north of Cape Flora. Dr. Nansen was taken to this spot by Dr. Kœttlitz, and they brought away a number of specimens, some of which were submitted to Dr. Nathorst, and

<sup>1</sup> See the account of the voyage by C. R. Markham, Proc. Roy. Geogr. Soc. n. s. vol. v. (1883) p. 204.

<sup>2</sup> Vol. ii. p. 306. In his diary the rock is called a granite, but in a footnote he adds that it was a coarse-grained basalt.

determined by him to be of Upper Jurassic age. The fact of these fossils having been found on the basalt also influenced Dr. Nansen in referring this rock, in part at least, to the Jurassic period. Evidences of recent changes in the relative level of land and sea are referred to in Dr. Nansen's book. Thus, Mr. Jackson's hut is

Fig. 2.—*Elmwood, Cape Flora.*



[From a photograph.—This view shows the exposure of basalts above, and the huts of the Expedition below the talus-heaps, which are here covered by snow.]

built on an old beach 40 to 50 feet above sea-level, and other beaches were found at still greater elevations. Raised beaches were also observed farther north, in the neighbourhood of the hut in which Dr. Nansen wintered.

A number of geological specimens were sent home by Mr. Jackson and his party when the *Windward* returned in 1895, and a short note on some of these was appended by our colleague, Mr. G. Sharman, and one of us to Mr. Montefiore Brice's report of the expedition.<sup>1</sup> The much larger series of specimens, of both rocks and

<sup>1</sup> Geogr. Journ. vol. vi. (1895) p. 518.

fossils, which has now been received, throws additional light on the geological structure of the Franz Josef Land archipelago. Although the cliffs are so largely hidden by talus-heaps and snow, that exposures of rock are few and far between, yet the specimens now collected by Mr. Jackson's party have all been so carefully labelled and localized that it has been possible to piece them together, so as to present what we believe to be a correct idea of the geology of some of the southern parts of Franz Josef Land. We have received much help from Mr. H. Fisher, the botanist of the expedition, who is now in England: his admirable coloured sketches and verbal descriptions doing much to aid us in realizing the actual conditions under which the specimens were found. Moreover, Mr. Fisher's patience in answering our innumerable and perplexing queries has helped us out of many difficulties, and we take this opportunity of tendering him our warmest thanks. We are also under obligation to Dr. G. J. Hinde for many hints, but especially for his Note on the radiolarian chert from the iceberg. We have moreover received help and many kind suggestions from our colleagues, Mr. Clement Reid, Mr. G. Shorman, and Mr. W. W. Watts, and we desire to thank all these friends, and to acknowledge our indebtedness to them.

### III. THE BASALTS OF FRANZ JOSEF LAND.

The basaltic rocks which form so important a feature in the geology of Franz Josef Land are well represented in the Jackson-Harmsworth collection by specimens from Cape Flora and Hooker Island. All these belong to one type, although the specimens may be massive, vesicular, or amygdaloidal; but another and a distinct type is represented by one or two specimens obtained from the under-surface of an iceberg found, tilted up, in De Bruyne Sound, between Northbrook and Hooker Islands.

The common type will first be described. It is represented by specimens collected *in situ*, and from the talus which so commonly conceals the lower portions of the cliffs. As there is no essential difference between the specimens collected under these different conditions, they will be grouped together for purposes of description. In the fresh condition the rocks are very dark, almost black, and of medium grain. They weather in the manner characteristic of basaltic rocks, and sometimes break up into spheroids. Examined with a lens, the feldspars are often seen to be of a yellowish colour, and the appearance of the rock under these circumstances is such as to suggest at first sight that olivine is an important constituent. This, however, is not the case; olivine does occur occasionally, but never in sufficient quantity to affect the macroscopic character of the rock.

A special feature of almost all the rocks of the common type is the tendency of some of the feldspars to be somewhat larger than the others, and to occur in groups, thus producing a kind of glomero-porphyrific structure. A few specimens may be fairly

termed 'porphyritic basalts,' but the porphyritic structure is never strongly marked in the hand-specimens, and is frequently not noticeable.

Vesicular and amygdaloidal rocks are extremely common at Cape Flora. This is a point of some interest, when considered in connexion with Payer's remark that 'amygdaloidal varieties, so common in Greenland, were never found in Franz Josef Land.'<sup>1</sup> The cavities have been filled with various substances, such as calcite, analcime, natrolite, chacedony, quartz, and palagonite.

Under the microscope the constituents are seen to be plagioclase, augite, magnetite, olivine, interstitial matter, and various secondary products. The plagioclase occurs in forms giving lath-shaped sections, and also as aggregates of somewhat larger individuals, which mutually interfere with each other, and are more equally developed in the different directions. A broad type of albite-lamellation is common to both modes of occurrence, and the individuals of the larger aggregates often show, in addition, a zonal structure and twinning on the pericline-plan. The lath-shaped sections in a common type of rock measure about .5 mm. in length by .1 mm. in breadth; whereas the individuals which compose the larger aggregates may measure as much as 1 or 2 mm. in their longest diameters. There is a certain amount of variation in the dimensions of the feldspars in different specimens, but the above figures will give an idea of the scale on which they are commonly developed in those varieties which contain comparatively little interstitial matter.

When the powder of the rock, freed from the fine dust by washing, is placed in a diffusion-column of cadmium borotungstate, the feldspars form a fairly well-defined band, the centre of which corresponds to a specific gravity of 2.7. There is no great amount of scattering, and a fragment of labradorite floats in the centre of the band. The feldspar, therefore, agrees on the average with labradorite, but the optical characters of the zoned individuals, and the slight scattering of the grains in the diffusion-column, indicate deviations on both sides of the average. The central portions of the zoned individuals are more basic than the marginal portions, but the transition is not always continuous; so that in the life-history of individual crystals there has occasionally been a recurrence of the conditions which gave rise to the deposition of more basic material. The larger individuals frequently contain inclusions of brown glass, with or without bubbles. These inclusions are as a rule limited to the central portions.

Augite is abundant in all the rocks, and forms, with feldspar, the greater portion of the mass in the majority of cases. Generally only one type of augite is present. In thin sections this is pale brown, more rarely yellowish green, sometimes almost colourless. It is usually without any trace of crystalline form, and occurs as grains or patches, which are often penetrated by the lath-shaped sections of plagioclase. As a rule, several individuals having

<sup>1</sup> 'New Lands within the Arctic Circle,' German ed. p. 267.

different orientations occur in juxtaposition, so that the ophitic structure, though present, is not so marked as it is in many of the holocrystalline dolerites from Iceland, the Færøe Islands, and the West of Scotland. It resembles in character and mode of occurrence the augite of the Tynemouth and related dykes in the North of England.<sup>1</sup>

One rock-specimen, obtained from the underside of an iceberg found, tilted up, off Eira Cottage, which otherwise belongs to the common type, contains more or less idiomorphic phenocrysts (see Pl. XXXVII, fig. 3) of pale greenish augite, with peripheral inclusions, in addition to the ordinary augite above described. A few grains of this mineral were isolated, and the presence of chromium established. It is therefore, as was suspected from its appearance under the microscope, a chrome-diopside; and the fact is of some interest from the point of view of correlation, because Scharizer has proved the occurrence of this mineral under similar conditions in the basalts of Jan Mayen.<sup>2</sup> It will be shown subsequently that the basalts of Franz Josef Land have other points of resemblance with those of Jan Mayen.

The iron-ore occurs as grains, crystalline aggregates, and skeleton-crystals. It is strongly magnetic, and is often present in sufficient quantity to make the rock magnetic. The felspar and augite are as a rule remarkably free from inclusions of this mineral, which certainly does not in these rocks belong to the earlier phases of consolidation, as it does in so many rocks of intermediate composition. In many cases it is found only as skeleton-crystals in the interstitial matter (Pl. XXXVII, fig. 4), and in some the iron-oxides have remained wholly undifferentiated in a deep brown glass.

Olivine is by no means constantly present, and rarely occurs in sufficient quantity to give a marked character to the rocks. It occurs as grains, and occasionally as more or less idiomorphic crystals. When fresh it is colourless in the thin sections; but it is sometimes represented only by green, or more rarely by brown, alteration-products. The occurrence of olivine in sparsely-scattered grains or crystals seems to be a special character of this class of basalts. Its absence from any particular section does not prove that it is entirely absent from the rock, for if several sections be prepared from one specimen it may be found in some and not in others.

In addition to the mineralogical constituents above described, the rocks invariably contain a certain amount of interstitial matter, which assumes different forms in different cases. It may occur as a brown glass comparatively free from microlites, as palagonite arising from the alteration of this brown glass, or as a fine-grained matted aggregate of microlites of augite, magnetite, and felspar, with which some colourless base may possibly be associated. Transitions from the condition of brown glass to the microlitic type may sometimes be observed, and under these circumstances the gradual bleaching of the glass by the separation of ferriferous

<sup>1</sup> 'Petrological Notes on the North-of-England Dykes,' *Quart. Journ. Geol. Soc.* vol. xl. (1884) p. 209. See pl. xii. fig. 6.

<sup>2</sup> 'Ueber Mineralien u. Gesteine von Jan Mayen,' *Jahrb. d. k.-k. geol. Reichsanst.* vol. xxxiv. (1884) p. 707.

constituents is clearly shown. The amount of interstitial matter varies considerably in different specimens. It is very small in amount in the massive varieties, but in some of the vesicular forms it becomes an important constituent.

The most interesting type of interstitial matter is the palagonitic. Palagonite is especially abundant in the amygdaloidal varieties, where it occurs not only wedged in between the crystalline constituents, but also as the infilling material of some of the amygdaloids. It is a soft black or greenish-black substance, which can be readily scratched with the finger-nail and cut with a knife. The powder has a soft unctuous feel when rubbed between the fingers. Heated in a closed tube it gives off a large amount of water. It is readily acted upon by hydrochloric acid, and fragments leave behind a white siliceous pseudomorph. Under the microscope, in very thin sections, it is usually seen to be of a deep brown colour; but occasionally it contains green zones arranged parallel with the boundaries of the space which it occupies. In its general appearance, and in the presence of this zonal structure, it resembles the palagonite from deep-sea deposits described by Messrs. Murray & Renard.<sup>1</sup> When viewed with crossed nicols the palagonite is seen to be doubly-refracting. It appears to be formed of minute interlacing fibres or scales of a brown or, more rarely, of a green colour. The double refraction of the deep-brown palagonite enables us at once to distinguish it from the isotropic paler brown glass with which it is sometimes associated, and out of which it has been formed by hydration. The following analysis of this substance was made. Analyses of palagonite and of the closely-related 'hullite' are quoted for comparison:—

	I.	II.	III.	IV.	V.
SiO <sub>2</sub> .....	35.48	41.26	44.73	46.76	39.44
Al <sub>2</sub> O <sub>3</sub> .....	8.30	8.60	16.26	17.71	10.35
Fe <sub>2</sub> O <sub>3</sub> .....	12.30	25.32	14.57	1.73	20.72
FeO .....	14.60	...	...	10.92	3.70
MnO .....	...	...	2.89	0.44	trace
CaO .....	1.04	5.59	1.88	11.56	4.48
MgO .....	7.10	4.84	2.23	10.37	7.47
Na <sub>2</sub> O .....	3.92	1.06	4.50	1.83	...
K <sub>2</sub> O .....	trace	.54	4.02	0.17	...
H <sub>2</sub> O or loss on ignition ...	16.80	12.79	9.56	...	13.62
	<u>99.54</u>	<u>100.00</u>	<u>100.64</u>	<u>101.49</u>	<u>99.78</u>

- I. From amygdules in basalt at Cape Flora, Franz Josef Land (Teall).
- II. Palagonite from Palagonia, Sicily. The insoluble residue (10.99 %) is deducted and the remainder calculated to 100. Quoted from Zirkel, 'Lehrbuch der Petrographie,' 2nd ed. vol. iii. (1894) p. 689.
- III. Palagonite from South Pacific. Analysis by Sipőcz, *Challenger* 'Report on Deep-Sea Deposits,' p. 307.
- IV. Basic glass from the centre of the mass from which the palagonite (III) was obtained.
- V. 'Hullite' from Carnmoney Hill, near Belfast. Analysis by Hardman. Quoted from Sollas & McHenry, 'On a Volcanic Neck of Tertiary Age in Co. Galway,' *Trans. Roy. Irish Acad.* vol. xxx. (1896) p. 734.

<sup>1</sup> 'Report on Deep-Sea Deposits,' *Chall. Exp.*, p. 304.

The published analyses of palagonite differ considerably from each other, and the one which must now be added to the list does not entirely agree with any one of them. It is often stated that the iron present is wholly in the condition of ferric oxide. If this be taken as an essential character the present substance is certainly not palagonite, for most of the iron is in the ferrous condition. The discovery of so large an amount of ferrous oxide was quite unexpected, and a second determination was made with special care. The results in both cases were identical. It may, therefore, be taken as certain that the present substance, which so closely resembles palagonite in its microscopic character, mode of occurrence, and relation to basic glass, is rich in ferrous oxide. As the other analyses differ widely in some respects, no great harm will be done by extending the use of the term so as to include this substance.

The 'hullite' of Hardman has been shown by Profs. Cole<sup>1</sup> and Sollas<sup>2</sup> to occur, like the palagonite of Cape Flora, as interstitial matter, and as the infilling of amygdaloids. Mr. Hardman's analysis shows that the two substances have decided chemical affinities. Both are remarkable on account of the large amount of iron. Under these circumstances it became important to compare them as regards specific gravity. Mr. Hardman gives the specific gravity of hullite as 1.76, and Prof. Sollas confirms this somewhat extraordinary result. Five small pieces of palagonite were taken from two amygdules occurring in a specimen collected from the talus near Cape Flora, and placed in a solution of methylene iodide. After twenty-four hours' immersion it was found that two sank, one remained suspended, and two floated in a liquid of specific gravity 2.433; four sank and one remained suspended when the specific gravity of the liquid was lowered to 2.409. The specific gravity is therefore not constant, but it is somewhat greater than 2.4.

On comparing the analysis of the Cape Flora palagonite with that of Palagonia it will be noted that there is a close agreement so far as the total amount of iron is concerned, but an important difference as regards its state of oxidation. There are further important differences as regards the total amount of lime and the relative proportions of lime and magnesia.

The two analyses quoted from the *Challenger* Report are especially interesting. One represents the palagonitic crust, and the other the nucleus out of which it has been formed. They indicate, as the authors point out, that the change is accompanied by hydration, elimination of lime and magnesia, oxidation of the ferrous iron, and addition of alkalis.

More interesting results will be obtained if, instead of considering the palagonite of Cape Flora in relation to more or less allied substances from other localities, we consider it in relation to the rock in which it occurs. This is a basalt with a specific gravity

<sup>1</sup> 'On Hullite,' Rep. Belfast Nat. Field Club 1894-95, p. 1.

<sup>2</sup> 'On a Volcanic Neck of Tertiary Age in Co. Galway,' Sollas & McHenry, Trans. Roy. Irish Acad. vol. xxx. (1896) p. 739.

of about 2·9. The palagonite has arisen from the hydration of the glass formed by the consolidation of the mother-liquor out of which the other constituents, mainly labradorite and augite, have crystallized. If we assume that the only chemical change which has taken place is that of hydration, then the percentage composition of the mother-liquor would be as follows:—

SiO <sub>2</sub> .....	42·88
Al <sub>2</sub> O <sub>3</sub> .....	10·03
Fe <sub>2</sub> O <sub>3</sub> .....	14·86
FeO .....	17·65
CaO .....	1·26
MgO .....	8·58
Na <sub>2</sub> O .....	4·74
	100·00

In view of the researches of Lemberg<sup>1</sup> and the observations of Murray & Renard the above assumption is not warranted. Alkalies may have been added, and lime and magnesia removed. There is, however, no reason to believe that the relative amounts of alumina and iron have been appreciably changed, and we are therefore able to draw the important conclusion that in a magma of the type to which these basalts belong—that is, a basic magma poor in alkalies—progressive crystallization leads to the formation of a mother-liquor poor in silica and alumina and rich in iron. It is possible that the relative amounts of lime and magnesia have not been seriously modified by the hydration, and if so we see that crystallization may, at any rate in its earlier stages, tend to increase the relative amount of magnesia. The partial separation of the lime, alumina, and silica from the iron and magnesia is of course effected by the crystallization of basic feldspars, which in this class of rocks precede the augites and sometimes even the olivine.<sup>2</sup>

This concentration of the iron, and to a certain extent magnesia, in the mother-liquor of basic magmas does not appear to have attracted the attention which it deserves. It shows that progressive crystallization in these magmas sometimes leads to a result, the opposite of that observed in the case of intermediate magmas in which ferri-ferous compounds separate out during the early phases of consolidation.<sup>3</sup> The synthetic experiments of Messrs. Fouqué & Lévy<sup>4</sup> indicate that the formation of magnetite is not limited to one period in the history of the consolidation of silicate-solutions, and the

<sup>1</sup> Lemberg examined the effect of water and solutions of alkaline carbonates on volcanic glasses. He says:—'Fassen wir alles zusammen, so werden basische Gläser (Palagonitglas, Tachylyt) schon durch reines Wasser hydratisirt; durch Alkalicarbonate werden auch saure Gläser sehr rasch umgewandelt; dabei wird Wasser aufgenommen, Alkali gegen andere starke Basen ausgetauscht, Kieselsäure zum Theil ausgeschieden' ('Zur Kenntniss der Bildung und Umwandlung von Silicaten,' Zeitschr. Deutsch. geol. Gesellsch. vol. xxxv. 1883, p. 557).

<sup>2</sup> See W. W. Watts, 'Guide to the Collections of Rocks and Fossils in the Museum of Science and Art, Dublin,' 1895, p. 78.

<sup>3</sup> 'On some Quartz-felsites and Augite-granites from the Cheviot District,' Geol. Mag. 1885, p. 106.

<sup>4</sup> 'Synthèse des Minéraux et des Ro. hes,' Paris, 1882.

same fact has been established by Vogt in his work on slags. The last-mentioned author has made a special study of the conditions under which magnetite is formed and has established the fact that in basic slags in some cases magnetite precedes olivine, in other cases it crystallizes simultaneously with olivine, and in yet others it is formed after olivine.<sup>1</sup>

If we take the analysis quoted above, *minus* the water and alkali, as representing the composition of the mother-liquor formed after the separation of labradorite and augite, it is clear that we have still the material necessary to form olivine, magnetite, and spinel (hercynite).

In view of the evidence thus furnished of the concentration of iron, one is tempted to speculate as to the results that might follow if the process were carried still further. Magnetite forms the matrix of the cumberlandites of Rhode Island and Taberg, in which olivine and feldspar occur as phenocrysts.<sup>2</sup> It is found as interstitial matter in the ultrabasic 'schlieren' in the banded gabbros of Drüim an Eidhne.<sup>3</sup> Magnetite and a green spinel (hercynite?) are intimately associated in the pyroxenites from Scourie. Metallic iron associated with graphite occurs as interstitial matter in certain basalts in Greenland.<sup>4</sup>

Can it be that in some, at least, of these cases we see the extreme results of the process indicated above?

We have now described the principal constituents of the common type of basalt. The different specimens vary somewhat as to the relative proportions of the several constituents, and still more striking differences are due to the presence or absence of amygdaloids. The massive varieties are of medium grain, and contain comparatively little palagonite or other form of interstitial matter; the amygdaloidal varieties are usually of somewhat finer grain, and contain a considerable amount of palagonite. The mutual relations of the constituents are illustrated in Pl. XXXVII, figs. 1, 2, 3, & 4. The labradorite formed first, and the larger individuals sometimes contain glass-inclusions in their central portions. The separation of labradorite probably left the mother-liquor poorer in alumina, lime, and soda, and this facilitated the formation of augite. The common augite occurs in irregular grains and patches which are often penetrated by the feldspars. The chrome-diopside belongs to an earlier phase of consolidation. Magnetite has formed at different stages, but it is commonly associated with the interstitial matter, and in many specimens the feldspar and augite are almost entirely free from inclusions of this mineral. The bulk of the magnetite belongs to a

<sup>1</sup> 'Beiträge zur Kenntniss der Gesetze der Mineralbildung in Schmelzmassen,' Archiv für Math. og Naturvidensk. Kristiania.

<sup>2</sup> See 'Lithological Studies,' by M. E. Wadsworth, Mem. Mus. Comp. Zool. Harvard, vol. xi.

<sup>3</sup> 'On the Banded Structure of some Tertiary Gabbros in the Isle of Skye,' Geikie & Teall, Quart. Journ. Geol. Soc. vol. 1. (1894) p. 645.

<sup>4</sup> 'On the Existence of Nickel-iron . . . in the Basalt of North Greenland,' K. J. V. Steenstrup, Min. Mag. vol. vi. (1886) p. 1.

comparatively late period in the history of consolidation. Its distribution in the rock is in accordance with the view that progressive crystallization has tended to concentrate the iron-oxides in the mother-liquor. In some specimens there is no recognizable magnetite, the whole of the iron-oxide, except that which occurs in the augite, remaining undifferentiated in the brown glass. Microscopic sections of the amygdaloidal varieties show the connexion between the interstitial palagonite and that which partially or wholly fills the vesicular cavities. There is perfect continuity between the two kinds. In cases of partial infilling the central portion of the cavity is occupied by calcite (Pl. XXXVII, fig. 2).

Many specimens of more or less decomposed basalt from the talus at Cape Flora contain beautiful, radiating, fibrous aggregates of natrolite, and the same mineral occurs in a more compact form in concentric concretions filling large, irregular cavities. It is found also in joints in rotten basalt. Analcime occurs in detached crystals, sometimes measuring more than 1 cm. in diameter, and also as aggregates of smaller crystals. The analcime of these rocks appears to be wholly of secondary origin, and does not occur as in the monchiquites and analcime-basalts.<sup>1</sup>

Agates are also represented in the collection, and one large specimen of chalcedony and quartz which was evidently formed in a hollow cavity measures about  $20 \times 12 \times 10$  cms.

Calcite is abundant in the altered varieties, and frequently forms the infilling material of the amygdules, occurring either alone or in association with palagonite.

The specimens of basalt on which the above description is based were mainly collected near Cape Flora. The collection includes a few from Hooker Island which belong to the same type, but which are all massive.

Two or three points still remain uncertain with reference to the basaltic formations of Franz Josef Land. Judging from analogy with other districts of similar character, we should expect to find both lava-flows and intrusive sills. Tuffs and agglomerates are rare in regions of plateau-basalt, but they occasionally occur as necks and as beds interstratified between successive lava-flows. Then again old river-gravels and lake-deposits are sometimes found between the different outpourings of basalt.<sup>2</sup> Have we evidence of similar phenomena in Franz Josef Land? Unfortunately there is no petrographical character by which sills can be in all cases distinguished from lavas in the Brito-Arctic province. The sills are usually coarser in grain, columnar, holocrystalline, and ophitic in structure, but none of these characters can be relied upon as distinctive. Lavas are often amygdaloidal, but amygdaloids are not uncommon in sills and dykes.

<sup>1</sup> 'On the Monchiquites or Analcite Group of Igneous Rocks,' L. V. Pirsson, Journ. Geol. Chicago, vol. iv. (1896) p. 679.

<sup>2</sup> See Sir A. Geikie's paper on the 'Tertiary Basalt-plateaux of N.W. Europe,' Quart. Journ. Geol. Soc. vol. lli. (1895) p. 331. Future observers in Franz Josef Land would do well to study this paper.

We cannot, therefore, separate the specimens into two groups, lavas and intrusive sills. Nansen speaks of basalt interstratified with the underlying sediments, and the collection that we are describing contains specimens of amygdaloidal basalt 'from lowest rock (6 feet deep) having 3 feet layer of sandstone above it.' They were collected from the watercourse running down the talus. It is a well-known fact that the basalts of the West of Scotland are often intercalated between Jurassic strata,<sup>1</sup> and this fact led the early observers to conclude that they were of Jurassic age; but it is now universally admitted that this intercalation is the result of intrusion along planes of bedding, and that the basalts in question are post-Cretaceous.

The existence of tuffs cannot be positively asserted from the evidence before us, but there are one or two specimens of highly altered rocks which may be tuffs. The evidence that pauses occurred during the formation of the plateau-basalts is of a more satisfactory character. This is furnished by a specimen of a conglomeratic rock, mainly composed of basaltic débris and containing rounded pebbles, 'found in dolerite some 50 feet above lowest rock' near Cape Flora.

We are indebted to Mr. Fisher for the following table, giving the lowest level at which the main mass of basalt could be seen at several localities; the base, however, was often hidden by talus:—

	feet.
Cape Flora .....	600
Cape Gertrude .....	700
Cape Stephen .....	650
Tween Rocks .....	450 at one place, 200 at another.
Cape Grant .....	400 to 500
Cape Crowther .....	700 on one side, and sea-level on the other.
Cape Neale .....	500

#### IV. DISTRIBUTION OF BASALTS OF SIMILAR TYPE.

We will now conclude this account of the ordinary basalts with some remarks on the general distribution of rocks of the same type. Specimens brought home by Payer were described by Prof. Tschermak. He says, 'It [the dolerite] is a medium-grained, dark yellowish-green, crystalline, massive rock. Plagioclase forms the principal mass, although it only exceeds the augite by a small amount. The crystals of plagioclase are frequently 1 mm., sometimes 3 mm. long. They consist sometimes of thin and sometimes of thick lamellæ. The augite is greenish grey, shows no crystalline outlines, but forms grains which are often 1 mm. in diameter. Inclusions of the other minerals are frequent, and also gas-pores. Olivine forms grains which are smaller than the augite and only seldom show crystalline faces. These grains are frequently surrounded with a border of a yellowish-brown mineral (eisenchlorit). The titaniferous iron-ore occurs in long plates or fills the space

<sup>1</sup> Sir A. Geikie, *op. cit.* p. 375.

between the other minerals.' The resemblance of this rock to the dolerites of Spitsbergen is pointed out, and it is also stated that 'amygdaloidal varieties, so common in Greenland, were never found in Franz Josef Land; while the rocks in the south were aphanitic and thus like true basalts, those in the north were coarse-grained and nepheline-bearing.'<sup>1</sup> From this description we may conclude that the rocks brought home by Payer from the eastern portion of the archipelago resemble the massive olivine-bearing varieties of the Jackson-Harmsworth collection. Prof. Tschermak makes no mention of the occurrence of palagonitic material as interstitial matter, but he refers to an iron-chlorite which he regards as arising from the alteration of olivine. It is possible that this substance may in part represent the palagonite so common in the rocks from Cape Flora. He speaks of the 'titaniferous iron-ore' as 'sometimes filling the space between the other minerals.' The magnetite in the specimen that we examined contained only traces of titanitic acid, and in none of our rocks does it actually occur as interstitial matter. It either crystallizes out during the later stages, or else remains undifferentiated in the residual glass. Specimens from the northern part of the archipelago have not as yet been examined in detail, but both Payer and Nansen agree that more coarsely crystalline varieties occur in this region. It would be interesting to know the exact nature of the evidence on which nepheline has been stated to occur.

The more or less allied rocks of Spitsbergen have been described by A. E. Nordenskiöld<sup>2</sup> as hyperite, and by Drasche<sup>3</sup> as diabase. They frequently occur as sills in rocks of very variable age. Both authors appear to regard them as contemporaneous with the strata in which they are found, and Drasche comments on the remarkable nature of the fact that rocks so uniform in character should be associated with strata of all ages from pre-Carboniferous to Tertiary. The remarkable nature of this fact disappears if we regard the rocks as intrusive sills.

A curious difference of opinion has arisen between Bäckström<sup>4</sup> and Nathorst<sup>5</sup> as to these Spitsbergen rocks. At the conclusion of his paper on the liparites of Iceland, Bäckström calls attention to the widespread distribution of basalts in the Arctic province which 'extends on the one side to Spitsbergen and Franz Josef Land, on the other to Greenland, and in the south to Scotland.' Nathorst, in commenting upon this statement, points out that basalt has not been found in Spitsbergen, but that post-Triassic diabases occur both as dykes and sheets (Decken). Whether the Spitsbergen rocks should be termed basalts or diabases is a matter of comparatively slight

<sup>1</sup> 'New Lands within the Arctic Circle,' German ed. p. 267.

<sup>2</sup> 'Sketch of the Geology of Spitsbergen,' Stockholm, 1867.

<sup>3</sup> 'Petrographisch-geologische Beobachtungen an der Westküste Spitzbergens,' Tscherm. Min. Mitth. 1874, p. 261.

<sup>4</sup> 'Beiträge zur Kenntniss der islandischen Liparite,' Geol. Fören. Stockholm Förhandl. vol. xiii. (1891) p. 671.

<sup>5</sup> 'Einiges über die Basalte des arktischen Gebietes,' *ibid.* vol. xiv. (1892) p. 69.

importance; it is certain, however, from Drasche's description that some of them are substantially identical with rocks described as basalt from other portions of the Brito-Arctic province. It is often not clearly recognized by Continental authors that the basalts and dolerites of this province are more closely allied in composition and structure to the pre-Tertiary diabases of the Continent than they are to the Tertiary basalts of the same region. We may safely conclude that the so-called 'diabases' of Spitsbergen described by Drasche are of the same general character, and approximately of the same age, as the basalts of Franz Josef Land.

The rocks of Jan Mayen have been described by Reusch<sup>1</sup> and Scharizer.<sup>2</sup> The descriptions of these authors show that rocks closely allied to those of Franz Josef Land occur on this island. Thus Reusch speaks of the occurrence in one of the specimens examined by him of hollow cavities 'encompassed by a zone of glass,' and Scharizer records the presence of a chrome-diopside. In the British Isles the rocks which most closely resemble the vesicular basalts of Cape Flora are those of Carnmoney Hill, near Belfast, and of Bunowen Tower, in County Galway.<sup>3</sup> Both these rocks are ophitic dolerites which contain brown glass or its hydrated alteration-product (hullite). The rocks of the Tynemouth and related dykes<sup>2</sup> also resemble the basalts of Franz Josef Land, but the interstitial matter which also occurs in some of the amygdules is always devitrified.

It is evident, therefore, that the basalts of Cape Flora and Hooker Island are similar to types widely distributed in the Brito-Arctic volcanic province. They differ from the more common holocrystalline ophitic dolerites in containing a small quantity of interstitial matter. The general result of this examination is to confirm the conclusions of Payer, Etheridge, and others that Franz Josef Land belongs geologically to an extensive region of plateau-basalts, including such widely separated localities as Jan Mayen, Iceland, Green and, the Færøe Islands, the West of Scotland and the North of Ireland.

The second type of basalt is represented by some small angular fragments obtained from the underside of an iceberg in De Bruyne Sound. It differs from the common type above described, both in macroscopic and microscopic characters, and is, therefore, considered by itself. The rock is dark grey in colour, compact, and of so fine a grain that extremely thin sections and high powers are required to reveal its true character. The specific gravity is 2.977. The principal constituents are granules and microlites of augite ( $\cdot 008$  mm. and  $\cdot 008 \times \cdot 04$  mm.), microlites of feldspar ( $\cdot 004 \times \cdot 04$ ), and crystals or grains of magnetite ( $\cdot 008 \times \cdot 02$ ).<sup>4</sup> It is possible that a

<sup>1</sup> 'Det Norske Nordhavs-Expedition, 1876-1878,' Christiania, 1882, p. 27.

<sup>2</sup> 'Ueber Mineralien u. Gesteine von Jan Mayen,' Jahrb. d. k.-k. geol. Reichsanst. vol. xxxiv. (1884) p. 707.

<sup>3</sup> See papers, already quoted, by Profs. Cole and Sollas.

<sup>4</sup> The figures are merely intended to give an idea of the scale on which the different constituents are developed.

small quantity of colourless interstitial matter (? analcime) may be present. The rock contains a few scattered feldspars, somewhat larger than the microlites, and also grains of quartz and patches of calcite. A special feature is the occurrence of aureoles of slender augite-microlites round some of the patches of quartz and calcite (Pl. XXXVII, fig. 5). These microlites are larger than those of the main mass of the rock, and show a rough tendency to a radial arrangement with reference to the nucleus.

The occurrence in basaltic rocks of quartz-grains surrounded by aureoles rich in augite-microlites has been frequently described,<sup>1</sup> and a discussion has arisen as to whether the quartz is indigenous or exotic. In this case the aureoles surrounding quartz are precisely similar to those surrounding calcite.

The microscopic section also shows many groupings of augite-microlites similar to those surrounding the grains of quartz and calcite, but without a central nucleus. This may be, and doubtless is in some cases, due to the fact that the section does not pass through the centre, but the occurrences appear to be too frequent to be entirely explained in this way. This type of basalt appears to be rare in the volcanic province to which Franz Josef Land belongs. We are unable to refer to any rocks from this province with which it can be said to be closely allied.

#### V. FOSSILS AND SEDIMENTARY ROCKS OF FRANZ JOSEF LAND.

The greater number of the fossils have been collected in the immediate neighbourhood of Elmwood, the depôt of the Jackson-Harmsworth party, and around Cape Flora; but others have been obtained farther afield, during some of the longer expeditions. Each of the localities, with the fossils there found, will be first noticed, and their relations to each other afterwards considered.

The little settlement of Elmwood is on the south side of Cape Flora, on the island of Northbrook; it is placed on a raised beach at an elevation of about 40 to 50 feet above the sea. Behind the settlement are extensive talus-heaps, above which steep cliffs rise to a height of about 1100 feet above the sea, and this is capped by 100 feet of ice. The lower 500 or 600 feet appears to be chiefly clay, interstratified with shales and bands of ironstone, lignite, etc., and almost hidden by the talus, while the upper 500 is basalt.

#### 1. North of Cape Flora.

The highest fossiliferous bed said to be *in situ*, of which the collection has representatives, is that discovered by Dr. Kœttlitz on the north side of Cape Flora, where a bed of shale, broken into innumerable fragments and containing impressions of plants, was found lying across a mass of dolerite, protruding through the west side of a glacier at a height of about 700 feet above the

<sup>1</sup> 'On a Group of Volcanic Rocks from the Tewan Mountains, New Mexico, and on the Occurrence of Primary Quartz in certain Basalts,' J. P. Iddings, Bull. U.S. Geol. Surv. no. 66, 1890.

sea. This plant-bed therefore would seem to be included in the thickness of the basalt. A number of specimens were collected at this point by Dr. Kœttlitz and subsequently by Dr. Nansen. The last-named gentleman submitted his collection to Dr. Nathorst, the well-known Scandinavian authority on fossil plants, and a very interesting account of them is given in Dr. Nansen's 'Farthest North,'<sup>1</sup> together with some woodcuts of certain of the specimens. According to Dr. Nathorst the most abundant remains were needles and seeds of coniferous plants, which he refers to *Pinus* and *Taxites*; but the most interesting among his specimens are leaves of the genus *Ginkgo*, only one species of which is now living, in Japan. This genus, however, is very characteristic of certain Oolitic deposits in Europe, and several species have been found in the Jurassic, Cretaceous, and Tertiary strata of Spitsbergen, Greenland, and Eastern Siberia. One of the forms from Franz Josef Land is believed by Dr. Nathorst to be a new species, for which he proposes the name of *Ginkgo polaris*. It is said to be a near ally of *G. flabellata* from the Jurassic of Siberia, and is not unlike the *G. digitata* from British Oolitic strata.

A few ferns were included in Dr. Nansen's collection, and these are said to represent four types, but to be too imperfect for specific determination. One of these is referred to the genus *Cladophlebis*; two others are said to suggest the genera *Thyrsopteris* and *Onychiopsis*, while the fourth seems closely allied to the *Asplenium petruschinense* described by Heer from Jurassic strata in Siberia.

#### PLANTS IDENTIFIED BY DR. NATHORST.

- Pinus* like *Nordenskiöldi*, but probably another species.
- " species with narrow needles.
- " seeds, resembling those of *Maakiana*.
- Taxites* nearest to *T. gramineus*, Heer.
- Fieldenia* (= *Torellia*) sp.
- Ginkgo polaris*, Nath.
- " sp.
- Czekanowskia*.
- Cladophlebis*.
- Thyrsopteris*?
- Onychiopsis*?
- Asplenium*, near to *A. petruschinense*.

A goodly number of examples of these plant-impressions collected by Dr. Kœttlitz have been sent home, and although small and fragmentary, as indeed were all the specimens found at this locality, they represent most of the forms mentioned by Dr. Nathorst. There are many of the winged seeds of *Pinus*, varying in form, and possibly representing more than one of the species alluded to in the above list (Pl. XXXVIII, figs. 6-8). With these are numerous pine-needles, both broad and narrow, as well as a portion of a branch and a small cone. A few fragments may belong to the genus *Fieldenia* [*Torellia*] (Pl. XXXVIII, fig. 11). The peculiar form *Ginkgo* is represented by many specimens, some of which are

<sup>1</sup> Vol. ii. p. 484.

referred to Dr. Nathorst's new species, *G. polaris* (Pl. XXXVIII, figs. 1-3); but there are others rather larger, with more slender divisions to the leaves, and with seven or eight ribs on each blade, which are very like *G. siberica*, Heer (figs. 4 & 5), if they are not identical with that species.

Ferns are represented by several specimens which, although small, are well preserved, and in some the venation of the pinnules is particularly well shown. There is some variation in the form of the pinnules of these specimens, but this is not greater than might be expected in different individual plants, or perhaps even in parts of the same frond. The only genus mentioned by Dr. Nathorst to which these could belong is *Thyrsopteris*, and there is much resemblance between the present specimens and *Th. Murrayana* and *Th. Maakiana*<sup>1</sup> (Pl. XXXVIII, figs. 13 & 14), which occur in the Jurassic rocks of Eastern Siberia and of England.

The pinnules of these ferns also bear much resemblance to the figures of *Adiantites amurensis* as given by Heer,<sup>2</sup> but it seems to me best, for the present, to leave them in the genus *Thyrsopteris*. In none of these forms, however, is the venation so clearly shown as it is in some of these Franz Josef Land specimens, and in the latter also the bifurcation of the veins in the pinnules seems to be more regular and definite.

Dr. Nathorst found no cycads among his specimens; there are, however, in our series one or two long lanceolate leaves, not quite perfect, which so closely resemble some of those that have been called *Podozamites lanceolatus* that they are provisionally referred to that species (Pl. XXXVIII, fig. 12).

We have a few examples of long, slender, regularly-tapering leaves (?), with few strongly-marked longitudinal ridges; these are broken across in such a way as to resemble a jointed stem, and remind one of a slender *Equisetum* (Pl. XXXVIII, fig. 10). The true affinities of these specimens are not clear, but they bear some resemblance to *Baiera* and *Czekanowskia*.

With regard to the probable geological age of these plants, we could not do better than quote the opinion of Dr. Nathorst; but, as we are not permitted to do so, we can only refer our readers to 'Farthest North' (p. 487), and say that on the whole this flora resembles that of the Upper Jurassic beds of Spitsbergen, and indicates a cool climate, but one much more genial than that which obtains in Franz Josef Land at the present day.

## 2. East of Elmwood.

The second set of specimens to be noticed are labelled 'East of Elmwood and above Sharp's Rock.' These are specimens of some thin beds of shale which were found exposed *in situ* just below the basalt, but in which no fossils were found. Taken in descending order, these are:—

<sup>1</sup> Heer, 'Flora Fossilis Arctica,' vol. iv. Beiträge zur Juraflora Ost-Sibiriens, etc. pl. i.

<sup>2</sup> *Ibid.* pl. xxi. fig. 6.

(i) Black shale 4 inches thick, from just below the basalt. There is no appearance of this shale having been heated to any extent by contact with the basalt.

(ii) Black material like the preceding, but broken into fine particles and powder,  $1\frac{1}{2}$  inch thick.

(iii) Greenish-grey shale, 3 inches thick.

(iv) A lighter-coloured brownish clay-shale, the thickness of which is not recorded.

### 3. Elmwood.

In a watercourse at the back of Elmwood the rock is uncovered at a point about 50 feet below the basalt, and from this exposure of 'clay sandstone' a small, well-preserved ammonite was obtained (Pl. XXXIX, fig. 5).

Unfortunately this ammonite is the only specimen which was found in place at this spot, but in the same watercourse below the exposure of rock, and apparently fallen from the rocks above, a number of other specimens were collected, chiefly in blocks of clay-ironstone. Among these are ammonites identical with that found in place, as well as others which are referable to *A. macrocephalus* and *A. modiolaris*.

The number of species found at this locality is not great, and they will now be considered in detail.

AMMONITES (CADOCERAS) TCHEFKINI ?, d'Orb. (Pl. XXXIX, figs. 4-6.)

To this species is referred provisionally the one ammonite (fig. 5) found *in situ* 50 feet below the basalt at Elmwood, as well as several other specimens found in the watercourse below this exposure and two others from the side of the glacier at the western end of Cape Flora.

The ammonite found *in situ* is about 22 mm. in diameter, and 7 mm. thick; the umbilicus is 6 mm. in diameter. The ribs are sharply defined and regular in thickness, having no enlargements or tubercles; they pass outwards from the umbilicus, and in most cases bifurcate about the middle of the side, then with a definite flexure forwards pass over the back, which is narrow but not sharp. Most of the other specimens above noted agree so closely with the one just described as to need no further mention, but one of them (fig. 4) is nearly twice the size (35 mm.) and shows that the forward flexure of the ribs becomes less marked as the shell grows larger. The outer part of this specimen is crushed, so that its form is uncertain.

On comparing these ammonites with young examples of *A. Tchekf-kini* from Russia their agreement is found to be so close that, for the present, they are referred to that species; but at the same time there are small points of difference which leave some doubt. None of the Franz Josef Land specimens are large enough to show signs of the lateral expansion which characterizes the adult *A. Tchekf-kini*, but the largest of them retains the same character of the ribs on the outer whorls that it has on the inner whorls—that is to say, the ribs merely bifurcate, and consequently those around

the umbilicus are of the same size as those near the back. Now, in all the larger specimens of *A. Tchefkini* available for comparison, the ribs around the umbilicus are distinctly larger than those on the back, and only one third or perhaps one fourth as numerous. The figures of *A. Tchefkini* given by De Verneuil<sup>1</sup> and Nikitin<sup>2</sup> show this same character.

In the Museum of Practical Geology there are several specimens from the Kellaways Rock of Chippenham which come very near to the Arctic ammonites, and these have been regarded as a variety of *A. Mariæ*.

AMMONITES (CADO CERAS) MODIOLARIS, Luid. (Pl. XXXIX, figs. 7-10.)

The specimens from this locality referred to the above species are two fragments of whorls, which show the lobes and saddles very clearly, and in form and markings agree closely with examples of *A. modiolaris* from the Kellaways Rock (figs. 7 & 8). A cast from the umbilicus of one of these fossils also agrees with this species, and there is a similar cast from the talus of the western end of Cape Flora which just fits the umbilicus of one of the Kellaways Rock specimens in the Museum of Practical Geology.

One specimen from the talus near Elmwood (Pl. XXXIX, fig. 9), embedded in ironstone and partly crushed, so as to give the appearance of a sharp back, has a much wider umbilicus than is usual in *A. modiolaris*; but as this agrees with the figures given by Prof. S. Nikitin of a specimen from Elatma,<sup>3</sup> which is regarded as *A. modiolaris*, the Cape Flora specimen is likewise referred to this species.

Another specimen, from below where the rock was found *in situ*, is more compressed, and in this respect somewhat resembles *A. Elatmæ*<sup>4</sup>; but, while the ribs are quite as strong as in the latter species, there is no evidence of the large tubercles around the umbilicus.

A better-preserved example of this variety was obtained from the side of the glacier at the west point of Cape Flora (Pl. XXXIX, fig. 10).

AMMONITES (MACROCEPHALITES) MACROCEPHALUS, Schloth. (Pl. XXXIX, figs. 1-3.)

The specimens from the present locality referred to this species are not good, but a much better example is that received in the earlier consignment and noted by Mr. G. Sharman in the Geographical Journal,<sup>5</sup> a further examination of which has convinced us that it is the true *A. macrocephalus* (fig. 1). In these specimens the ribs pass directly outward from the small umbilicus, and, after

<sup>1</sup> 'Géologie de la Russie d'Europe,' vol. ii. (1845) pl. xxxv.

<sup>2</sup> Mém. Acad. Imp. Sci. St. Pétersb. ser. 7, vol. xxviii. (1881) no. 5, pl. iii.

<sup>3</sup> Nouv. Mém. Soc. Imp. Nat. Moscou, vol. xv. (1885) pl. xi. fig. 48.

<sup>4</sup> Nikitin, *op. cit.* vol. xiv. (1881) pl. xi. fig. 21.

<sup>5</sup> Vol. vi. (1895) p. 518.

bifurcating, run over the back without any forward flexure; they agree with British and Continental examples of this species, and attention may be especially directed to Prof. Nikitin's<sup>1</sup> figures of specimens from Kellaways beds near Elatma, in Central Russia.

Another specimen found upon the talus-heap, which includes about half the shell, has rather more rounded whorls; but, as it resembles some of the inflated forms which have been referred to *A. macrocephalus*, it is provisionally allowed to remain here (Pl. XXXIX, fig. 3).

#### BELEMNITES PANDERI, d'Orb. (Pl. XXXIX, figs. 11-14.)

Fragments of several belemnites have been collected at No. 3 locality, but only a few of them can be determined with any certainty; on comparing them, however, with better fragments from the talus, there is no doubt as to their being the same species. These belemnites belong to the group in which the radiation, seen on the cross-section of the guard, is excentric, as in the well-known *B. lateralis*. In the specimen now under consideration the guard is not flattened dorso-ventrally, as in the last-named species, but to a slight extent laterally, and there is a distinct though not very deep ventral groove near the apex, and extending a short distance along the guard. The most perfect specimen (Pl. XXXIX, fig. 11) was found on the talus at the western end of Cape Flora: it is only about 2 inches long, and shows nothing of the alveolar cavity. Other examples retaining this cavity show that it is excentric (fig. 12).

A comparison of these belemnites with a series from Russia, in the possession of Mr. Lamplugh and named by Prof. Alexis Pavlow, left no doubt as to their agreement with examples of *B. Panderi*, a species which has been recorded from the Middle Kellaways and passes upward to the Kimeridge Clay.<sup>2</sup>

#### PECTEN *cf.* DEMISSUS.

The mould of a small *Pecten* evidently indicates a shell closely allied to, if not identical with, the common Oolitic *Pecten demissus*, which is one of the species recognized in the Upper Jurassic rocks of Spitsbergen.

#### GORGONIA (?). (Pl. XXXIX, fig. 15.)

On one of the ironstone-blocks is to be seen a long cylindrical body, about 1 mm. in diameter and 70 mm. long, the nature of which is by no means clear. Only part of this now remains, and it seems to be entirely replaced by iron pyrites. Externally it is almost smooth, with a few transverse, very fine lines. This fossil calls to mind the rod of the living *Pennatula* and that of the *Graphularia* from the London Clay; but it is not now a continuous rod: there are regular intervals here and there, reminding one of the interrupted condition of the stem in the genus *Isis* and its

<sup>1</sup> Nouv. Mém. Soc. Imp. Nat. Moscou, vol. xv. (1885) pl. viii. fig. 44.

<sup>2</sup> S. Nikitin, 'Ueber die Beziehungen zwischen der russischen u. der west-europäischen Juraformation,' Neues Jahrb. vol. ii. (1886) p. 205.

allies. These intervals may, however, be due to breakage before being embedded in the rock.

PHOSPHATIC NODULES. (Pl. XXXVII, fig. 6.)

Rounded and ovoid nodules of a pale brown colour externally, but black or dark brown internally, occur with these fossils, and apparently at almost all the horizons from which fossils have been collected; mostly they seem to have been free in the clay, but sometimes they are included in the clay-ironstone. These nodules vary much in size, some being less than an inch in diameter, others 3 or 4 inches in length and perhaps 2 inches in diameter. Thin sections under the microscope show for the most part a mass of fine débris with nothing definable; but some specimens show in parts small masses of minute oval bodies, with a long diameter of 1 mm., which agree in form and size with the small coprolites described by Mr. A. Strahan<sup>1</sup> from the Phosphatic Chalk of Taplow, and indeed there can be little doubt that they are the droppings of some small animal. And further, upon closer examination with the microscope, these minute ovoid bodies may be seen pressed closer and closer together, until at last they form one mass; but in most cases the separate pellets may be still distinguished. A number of these nodules have been tested, and in all cases they proved to be rich in tricalcic phosphate.

The following forms have been identified from this horizon at locality No. 3:—

- Ammonites (Macrocephalites) macrocephalus.*  
 " (Cadoceras) *Tchefkini?*  
 " " *modiolaris.*  
 " " " var.  
*Belemnites Panderi.*  
*Pecten cf. demissus.*  
*Gorgonia?*  
 Phosphatic nodules.

Precisely similar forms have been found in the talus at other points near Elmwood, and on the side of a glacier-slope at the western point of Cape Flora.

This series of fossils, although small, is of the greatest interest, inasmuch as it contains ammonites which give no uncertain indication of the horizon to which they must be referred. *Ammonites modiolaris* is distinctly a Kellaways Rock form, although extending into the true Oxford Clay. The occurrence with this of *A. macrocephalus*, which not only occurs in the lowest Oxford Clay and Kellaways Rock, but is perhaps the most characteristic ammonite of the Cornbrash, shows very clearly that beds of lowest Oxfordian age occur at Cape Flora at a height of about 400 or 500 feet above the sea, and doubtless correspond to some extent with the '*macrocephalus*-beds' which are now known to have so vast an extent throughout the northern hemisphere, if, indeed, they do not also occur in Australia (see references on p. 515).

<sup>1</sup> Quart. Journ. Geol. Soc. vol. xlvii. (1891) p. 356.

## 4. Windy Gully.

The next exposure of rock to be noticed is that which was found at the southern end of Windy Gully, a valley north-east of Elmwood, running nearly north and south. Near the southern end of this valley there is a projecting shoulder of rock, and on this, at a height above the sea of about 300 feet,<sup>1</sup> a number of fossils were obtained, nearly all of them being in hard concretions or in phosphatic nodules. Dr. Kœttlitz is satisfied that they were *in situ*; but even if not actually in place, they could only have been weathered out of the rock on which they rested.

These beds seem to be lower in the series than those of No. 3, unless the strata are less horizontal than we understand them to be, and they have yielded a different set of fossils; the most striking of these are some ammonites which are believed to be varieties of *A. Ishmæ*, a species described by Keyserling from Ishma in Petchora Land.

AMMONITES (MACROCEPHALITES) ISHMLÆ, Keys., var. ARCTICUS.  
(Pl. XL.)

Several examples of this ammonite were found, but they vary somewhat in form. The most typical specimen is also the most perfect (Pl. XL, fig. 1); it is about  $2\frac{3}{4}$  inches in diameter, and its greatest thickness measures  $1\frac{1}{2}$  inch. The ribs, which are sharply defined, pass outwards, with a distinct inclination forwards. At a distance from the umbilicus of about one-third the height of the whorl, the ribs bifurcate, and then pass over the back. Occasionally there is a single rib interposed. The umbilicus is very small, less indeed than is usually the case in *A. macrocephalus*, although it is equally small in some specimens that have been referred to the latter species. In nearly all the above points our specimen resembles *A. macrocephalus*, but on closer examination it is found that the whorls do not increase so rapidly, and as at the same time they are more involute, the outer whorls are much more encroached upon by the whorl which precedes it; so that while in *A. macrocephalus* the last whorl is encroached upon for less than half its height, in the present form the encroachment is always more than half the height, thus indicating a different mode of growth. And further, the sides of this species are less inflated around the umbilicus, and more so towards the back, so that the entire shell has a different aspect.

If this specimen be compared with Keyserling's figure of *A. Ishmæ* from Petchora Land,<sup>2</sup> it will be seen that in most of those points in which our specimen differs from *A. macrocephalus* it approaches *A. Ishmæ*; but at the same time the inner whorl of *Ishmæ* does not encroach so much upon the outer one as is the case in the Arctic specimen. This encroachment of the whorls, involving, as it does, a different growth of the shell, may perhaps be thought sufficient for the establishment of a new species, and if so

<sup>1</sup> [Dr. Kœttlitz says 'over 400 feet.']

<sup>2</sup> 'Reise in das Petschora-Land,' 1846, p. 331, pl. xx. figs. 8 & 9.



collected a number of fragmentary fossils which had been washed out from the rock. These fossils are mostly either pieces of belemnites or parts of a large species of *Avicula*, but there is one fragment of an ammonite allied to *A. Gowerianus*, which is as yet undetermined.

#### BELEMNITES sp.

Most of the fragments of belemnites from this locality are so much broken and decomposed that it is hopeless to think of specific determination, nevertheless there are a few points which may be noticed. There are evidently two if not three forms, but none of them can be referred to *B. Panderi*, as they do not show the marked excentric radiation of the transverse section characteristic of that species. One form is compressed, with a well-marked groove near the apex and a slightly excentric radiation.

A second form is similar, but much more compressed, and there seems to have been a deep groove extending from the apex some distance up the guard.

The third form is cylindrical, concentrically radiated, and with a comparatively acute apex.

Some of these belemnites may be the same as those from locality 4.

#### AVICULA sp. cf. INÆQUIVALVIS. (Pl. XL, fig. 4.)

There are several of these large aviculas, but all are more or less crushed and broken; some of them, probably on account of breakage, look more equilateral than others, and at first sight remind one of *Pecten*; but the large wing on one side shows that they do not belong to that genus.

The best-preserved specimen (fig. 4) in its present condition is  $1\frac{3}{4}$  inch in length; but, with the exception of the umbo and a piece of the hinge, all the margins are broken away, and, judging from other fragments, the species must have reached 3 or 4 inches in diameter. One valve is moderately convex, while the opposite valve is concave. Strong ribs radiate from the umbo to the margin; between these are finer ribs, and a third still smaller series are to be seen between each of these, giving the shell much the appearance of a well-marked *A. inæquivalvis*, but in that species the ribs are not nearly so strong. The concave valve is less distinctly marked than the other. The hinge is long, and the posterior wing is much larger than the anterior. Some of the specimens appear to be more equilateral than others, but this is believed to be due to crushing, and as all have similar markings they are regarded as one species.

The small height above the sea at which this exposure of rock is situated, to the west of Elmwood, shows that it occupies a position at about 250 feet below the bed with *Ammonites Ishma* var. *arcticus* at Windy Gully, but the specimens give no idea of their age.

## 6. Cape Gertrude.

Cape Gertrude, which is some 2 or 3 miles east of Cape Flora, rises to a height of about 1100 feet above the sea. Mr. Fisher, who has carefully examined this locality, says that the uppermost 100 feet is basalt, columnar above, but more irregular underneath. From the base of this basalt to the sea-level the face of the cliff is almost wholly hidden by talus; but at one place the débris has been cleared away, apparently by ice or rock falling from above, exposing a series of sedimentary beds more than 200 feet high by about 100 feet wide, the highest part being between 300 and 400 feet above the sea. Dr. Kœttlitz, with Mr. Fisher, measured the section thus exposed, and they found as many as seventy beds of sand, flaggy sandstone, pebbly sand, shales, lignite, etc., varying in thickness from 3 inches to 25 feet. The extraordinary number of thin beds of diverse character shown in this section points to rapidly-varying conditions of deposition, and possibly to oscillations of level; while the beds of lignite indicate, to some extent at least, a freshwater origin.

With the exception of this lignite, and some wood found embedded in the lower part of the basalt, no fossils have been obtained from this section, and consequently the beds cannot be correlated with those at Cape Flora. The lignite-seams at the latter locality, and the few indications there seen of the nature of the beds, appear to indicate many rapid alternations of thin beds, similar to these at Cape Gertrude; and, judging from this and the height of the beds above the sea, it is likely that the Cape Gertrude section corresponds to part of the Jurassic series present at Cape Flora.

Much interest attaches to the discovery above mentioned of the masses of wood in the lower part of the basalt; for Mr. Fisher says that it is of precisely the same character as the silicified wood which has been found so abundantly on the talus at Cape Flora and also at Cape Gertrude; but this is the one place where it has been found *in situ*, and is the only clue that we at present possess as to its place of origin.

## 7. Cape Stephen.

We have now to travel some 20 miles west of Cape Flora to Cape Stephen. At this point, and also between here and Cape Grant, a hard calcareous sandstone was met with, near the sea-level and under the raised beach. This bed, which is *in situ*, contains an abundance of carbonized plant-remains, but they are not well preserved, and in none of them can the details of structure be seen. Consequently their determination cannot be settled with that degree of certainty which could be wished. Although the stems of Equisetaceæ and some other forms are not unlike species with which we are familiar in the Yorkshire Lower Oolites, yet these Arctic specimens seem to agree best with the flora described by Prof. Schmalhausen from Petchora and Tunguska.<sup>1</sup>

<sup>1</sup> Mém. Acad. Imp. St. Pétersb. ser. 7, vol. xxvii. (1880) No. 4.

PHYLLOTHECA (EQUISETITES) *cf.* COLUMNARIS, Phil. (Pl. XLI, figs. 1-3.)

Several striated and jointed stems, such as we have long known under the name of *Equisetum columnare* in the Yorkshire beds, occur in these sandy deposits at Cape Stephen. These stems vary from  $\frac{1}{4}$  to perhaps  $1\frac{1}{2}$  inch in diameter. In two instances, what looks like an outer sheath of a joint is preserved, showing at one end the oval spaces to which the whorl of spikelets or perhaps branches was attached. There is also one portion of a 'disc' with the spikelets still attached.

RHIPTOZAMITES? *cf.* GÖPPERTI, Schmalh. (Pl. XLI, figs. 6 & 7.)

The cycadaceous leaves of various shapes and sizes from Northern Siberia which are referred by Prof. Schmalhausen to the above genus and species seem to find their counterparts among the plant-remains on these slabs from Cape Stephen. Some of these leaves are slender and lanceolate, others broader and more oval, but each leaf, as far as can be seen, has fine ribs running nearly parallel from end to end. A portion of what may be a large oval woody leaf of this form, in its present broken condition, measures nearly 2 inches in width.

ANOMOZAMITES? (Pl. XLI, fig. 8.)

A fragment of what appears to have been a large leaf of a Cycad allied to *Anomozamites* shows what seems to be a broad midrib and on one side three unequally divided portions of the leaf, thus resembling the genus *Anomozamites*; it is introduced here for the sake of calling attention to the possible presence of this genus, but the specimen is not sufficient for certain identification.

ZAMIOPTERIS? *cf.* GLOSSOPTEROIDES, Schmalh. (Pl. XLI, figs. 4 & 5.)

There are a number of more or less fragmentary leaves to be seen on these slabs, which, while varying in size, agree in being broadly lanceolate and in having a venation which passes obliquely outwards from the middle line forward to the periphery, but without a definite midrib. The venation of these leaves certainly appears coarser than those shown in the figures given by Schmalhausen, but as it is possible that this may be due to their bad state of preservation, I have provisionally referred them to *Zamiopteris*.<sup>1</sup>

ASPLENIUM *cf.* WHITBIENSE, Brongn. (Pl. XLI, fig. 9.)

A portion of the frond of a fern with pinnulæ short and pointed, with entire margins and with a base attached by its whole width, is believed to represent this species, which, besides its original home, the Yorkshire Oolites, is said to occur in the north of Siberia. The venation of the Franz Josef Land specimen is entirely obliterated, and consequently the determination can be regarded as only doubtfully correct.

<sup>1</sup> [Compare also with *Gangamopteris*. See Seward, Quart. Journ. Geol. Soc. vol. liii. (1897) p. 324.]

## List of Fossils from Cape Stephen.

*Phyllothea* cf. *columnaris*, Phil.  
*Rhizozamites*? cf. *Gæpperti*.  
*Anozamites*?  
*Zamiopteris* cf. *glossopteroides*.  
*Asplenium* cf. *whitbiense*.  
 Bituminous shale.

The striking resemblance between this series of plant-remains from near Cape Stephen, and those described and figured by Prof. Schmalhausen from Lower Tunguska, can only lead to the inference that they are approximately of the same age. This Tunguska flora was at one time supposed to be Palæozoic, but Prof. Schmalhausen afterwards regarded it as of Oolitic age, and even referred it to the Great Oolite.<sup>1</sup>

There is no stratigraphical evidence available which might indicate the position of these plant-beds at Cape Stephen, and the distance between them and Cape Flora prevents any correlation with the strata there exposed, as we know nothing of the possibilities of change of dip or faulting which may occur in the 20 miles which intervene. At the same time it may be remembered that the probable north-easterly dip of the beds in Franz Josef Land would, if correct, bring these beds some little distance below horizon No. 5 at Cape Flora, where indeed beds of Lower Oolite age might be expected to occur.

Bituminous paper-shales occur in close relation with these sandstone plant-beds, at the locality between Cape Stephen and Cape Grant sometimes called 'Tween Rocks,' but it is not known whether they are merely in restricted patches or occur as regular beds. This shale contains a large amount of combustible matter, and burns with a good flame.

Near the spot at Tween Rocks where the plant-bed was found, a bed of coaly lignite was discovered at a height of about 100 feet<sup>2</sup> above the sea; this, Mr. Fisher tells us, was undoubtedly *in situ*. A stream of water had cut a channel for itself in the almost perpendicular cliff and had exposed this stratum, a good-sized block of which has been sent home, but is now split into many pieces, a consequence, probably, of its having been frozen. This coal burns with a good flame, and was recognized by the discoverers as a possible supply of fuel; it is not merely a lignitized tree-stem, but is composed of crushed and compacted vegetable matter. One point of interest about this coal is that in parts macrospores can be seen with a lens, reminding

<sup>1</sup> [Mr. Seward, in the August number of this Journal (vol. liii. 1897, p. 325), says that the rocks described by Schmalhausen are probably of Permian age (see Zeiller, Bull. Soc. géol. France, ser. 3, vol. xxiv. 1896, p. 466). If this be so, then the series of plant-remains from Cape Stephen, which are so similar to those from the Tunguska deposits, may prove to be of the same age. But an Oolitic facies in the case of Permo-Carboniferous plants is so remarkable that, in the absence of some characteristic form, such as the *Sigillaria* described by Mr. Seward from the South African beds, it would hardly be safe to regard these Cape Stephen plant-beds as of Permian age.]

<sup>2</sup> Dr. Kœttlitz says that this bed is 300 feet above the sea.

one of the 'spore coal' so commonly met with in 'Coal Measure' coal; and on examination with the microscope this portion of the lignite was found to be largely made up of micro- and macrospores.

This coal-seam, so far as we can judge, occurs about 100 feet above the sandstone which has yielded the plant-remains, and it may be that it belongs to beds of about the same period. A similar lignite or coal was found on the moraine at Cape Richthofen, but it is not certain that it contains macrospores.

There is still a specimen from Cape Stephen which has to be noticed; but, as it was obtained from the talus at 300 feet above the sea, it is evident that it must have been derived from a bed situated at that or some greater elevation. The specimen is a slab about 10 inches square and  $1\frac{1}{2}$  inch thick, wholly composed of layers of plant-remains completely silicified; it is black throughout, but one surface is weathered white. The greater part of the plants are strap-like leaves from 4 to 9 mm. wide, and the longest piece measures about 110 mm., but none are perfect at the ends; the broadest leaf has 11 longitudinal ridges. They remind one of *Baiera* and *Podozamites*, but there is no evidence of their mode of attachment, and their true affinities are uncertain.

On this slab there is a fan-like leaf which is believed to be an undivided *Ginkgo*-leaf, like that of *G. integriuscula* from Jurassic beds in Spitsbergen,<sup>1</sup> but it has a still closer resemblance to *G. reniformis*, Heer, from Tertiary beds on the Lena.<sup>2</sup> As the identity of this *Ginkgo* is not established, it can only be taken as an indication of the possibility of the specimen being of Tertiary age, and the other plants on the slab do not seem to militate against this; the piece of a conifer-branch close to the *Ginkgo* might be of almost any age. It is quite possible, on the other hand, that this slab has been derived from a bed representing at Cape Stephen the Upper Jurassic plant-bed of Cape Flora. Finally, it may be that this silicified slab is of the same age as the silicified wood which is so abundant in Franz Josef Land; but the age of the wood has yet to be settled.

### 8. Cape Crowther.

Cape Crowther, which is some 12 miles north-west of Cape Grant, has been visited, but the only specimens that we have received from that locality are a piece of the ubiquitous silicified wood, a mass of silicified plant-remains, and some black-banded chert containing vegetable tissue. These fossils were not found in place, but were picked up from the highest raised beach.

### 9. Cape Neale.

About 6 miles still farther north-west is Cape Neale, the most westerly point from which we have received specimens. On the

<sup>1</sup> Heer, 'Flora Fossilis Arctica,' vol. iv. (1877) pt. i. p. 44 & pl. x. figs. 7-9.

<sup>2</sup> *Ibid.* vol. v. (1878) pt. ii. p. 32 & pl. viii. figs. 24-25.

summit of this headland, which reaches a height of 700 feet, there is a level plateau free from snow, and from here we have received some silicified wood which is stated to be part of a large block found protruding from the soil. With this wood were some black flinty specimens containing plant-remains, and likewise fragments of what looks like siliceous sinter. The upper 250 feet of Cape Neale is formed by basalt, and it was on this that the fossil wood was found.

#### 10. Hooker Island.

Hooker Island, which lies about 20 miles north-east of Northbrook, has been visited by Mr. Jackson with some of his party, and on the higher raised beach, as Mr. Fisher tells us, several small flints and cherty specimens were obtained from the 'soil,' which soil is formed of disintegrated basalt. The flints and cherty specimens all seem to contain traces of vegetable tissue, but this is very indistinct.

#### 11. Cape Richthofen.

During Mr. Jackson's journey to the north a number of specimens were collected and labelled  $80^{\circ} 51' N.$  and  $53^{\circ} 40' E.$ , which, according to the map, seems to be at or near Cape Richthofen. The specimens were found on the top of a lateral moraine which is said to be 300 feet high and 500 yards wide, but the height above the sea is not stated. The specimens are fragments of basalt, rotten vesicular basalt, brown sandstone, cherty nodules, lignite, friable sandy shale with plant-remains, and a small mass of compressed vegetable remains. About some of these a few words may be said, but it is unfortunate that they were not *in situ*.

One of the nodules (No. 345) is a grey-and-white cherty flint, which under the microscope is seen to be chalcedonic and contains some indistinct foraminifera which remind one of *Rotalia*, but they are not sufficient for determination and give no clue as to age. The latter remark may be also applied to the large sponge-spicules seen in a second cherty nodule, which look like one of the 'glass-rope' sponges.

Two of the pieces of lignite are really pieces of tree-stems or branches retaining the outward form, but they are so much altered and in so friable a condition that their microscopic structure has largely been obliterated. It is not quite certain what the wood is, but an appearance which may represent spiral fibres and single rows of discs points to the possibility of its being allied to the yew-tree.

Some of the lignite seems to be composed of fragmentary vegetable matter, and is not unlike that from near Cape Stephen, which contains the macro- and microspores.

There are several pieces of a sandy shale which is exceedingly friable and almost black with carbonized vegetable remains; but these are so altered that at present nothing distinct has been made out, and the nature of the plants is uncertain.

The compressed mass of plant-remains is very recent-looking;

it is mixed with a little muddy matrix, and readily breaks up on soaking in water; when this is done the mass separates into small pieces, perhaps  $\frac{1}{8}$  inch wide and, say, 1 inch or less in length, flat, and as thin as paper. With these are other fragments, broader, but, like the first, so much altered that nothing can be made out of them. Mr. Clement Reid, who is so familiar with Pleistocene plants, has seen these, and feels sure that they are not so recent as Pleistocene, but thinks that they are probably of Tertiary age.

### Raised Beaches.

The occurrence of raised beaches in many places in Franz Josef Land is well established. One was noticed by Mr. Leigh Smith at Gray Bay, west of Cape Grant, 90 feet above sea-level. Mr. Jackson's hut at Elmwood is on an old sea-beach 40 to 50 feet above the sea, while there are others at higher and lower levels. The bones of a whale (probably *Balena mysticetus*) are mentioned as being found near Mr. Jackson's hut. Similar raised beaches occur on Frederick Jackson Island, showing that the movement of upheaval is not confined to the southern parts of Franz Josef Land, where most observations have been made. At the northern end of Günther's Bay raised beaches were observed by Dr. Kœttlitz, and from the lower one pebbles of basalt and specimens of *Saxicava arctica* were collected; similar beaches were also seen by the Jackson-Harmsworth party at Cape Crowther, at Cape Stephen, at Hooker Island, and at Windy Gully; from the latter, *Trophon antiquus*, *Tr. gracilis*, *Mya arenaria*, and *Balanus concavus* were obtained.

### Silicified Wood.

The common occurrence of silicified wood has been noticed by all who have visited Franz Josef Land. Lieut. Payer alludes to it; Mr. Leigh Smith and Mr. Grant collected specimens; the first consignment of fossils from the Jackson-Harmsworth expedition contained some fine specimens; Dr. Nansen also notices it; and the present series of specimens from the Jackson-Harmsworth party includes many examples, some of which are large and formed part of a tree-stem.

This silicified wood is widely distributed in the Franz Josef archipelago, for Lieut. Payer's specimens must have been from the eastern islands, while we have evidence of it from Capes Flora, Crowther, Neale, and Gertrude. Mr. Leigh Smith's specimens seem to have been found on Mabel Island. In nearly every case this wood has been found on the talus-heaps, and the only place where it has been found *in situ* is at Cape Gertrude, where Dr. Kœttlitz and Mr. Child discovered a mass of it embedded in the lower part of the basalt at a height of more than 700 feet above the sea. On the plateau at the summit of Cape Neale, which is 700 feet above the sea, a large silicified tree-trunk was found projecting from the soil, and therefore above the 250 feet of basalt which there caps the Cape.

It is difficult to assign any age to this wood. It is possible that a Tertiary basalt overwhelmed forests of pines growing at that time, and that the same kind of trees subsequently grew on the surface of the sheets of basalt. Or it may be that some already existing plant-beds were invaded by the intruding basalt, in which case the moving mass might in some instances have passed over, and in others passed under, the plant-bed; or there may have been more than one such bed.

It is well-nigh certain that this silicified wood is not earlier than Upper Jurassic, for it almost certainly occupies a position above the Oxfordian fossil-bed; but of this we have no positive proof, seeing that the beds exposed at Cape Gertrude have yielded no fossils to indicate their age. It is quite possible, therefore, that some of this silicified wood may be of Upper Jurassic, Cretaceous, or Tertiary age. On the whole, it seems most in accordance with the known facts to regard it as of approximately the same age as the basalts, which are probably of Tertiary date.

Judging from the report of Mr. Leigh Smith's visit to Franz Josef Land,<sup>1</sup> and Mr. Etheridge's remarks in the discussion,<sup>2</sup> it was thought that the pine-cone, the silicified wood, and the plant-impressions there mentioned were all from one horizon; but no evidence was brought forward proving that such was the case. Mr. Carruthers, who examined the pine-cone, was of opinion that it was of Cretaceous age; and the presence of Cretaceous rocks in Franz Josef Land rests upon that opinion. It is by no means clear, however, that the silicified wood is Cretaceous, even if the evidence of the pine-cone be accepted; but there now seems to be some doubt as to the age of the cone.

The manner in which this silicified wood is preserved merits attention; in some cases the replacement by silica has been so brought about that the form of the finest tissues is extremely well preserved, and, being of a dark brown colour, sections under the microscope show their structure even better than recent wood (Pl. XLI, fig. 11). The large longitudinal cells of the woody tissue are clearly defined, as are also the medullary rays which cross them, but the feature which is the most striking and at the same time the most characteristic is the well-marked series of discs (dotted tissue) which are typical of coniferous wood, and are in this instance large, and arranged in single and double rows in the cells. Transverse sections show the usual annual rings.

There is much difference in the degree in which the finer tissues of this fossil wood are preserved, some examples, like that above described, seeming to have every feature of the original structure retained, while in others this is nearly or quite obliterated. Some sections of black flinty fragments which have been examined have traces of tissue so faint as to leave doubt concerning its vegetable origin; and there are many intermediate stages between the two extremes. It may be mentioned also that silicified masses

<sup>1</sup> Proc. Roy. Geogr. Soc. n. s. vol. iii. (1881) p. 135.

<sup>2</sup> *Ibid.* p. 147.

of vegetable matter other than wood have been collected, but these may not be of the same geological age. One such block, from the talus at Cape Stephen, on which there is a leaf of *Ginkgo* and a piece of a pine-branch, has already been noticed (p. 506).

The preservation of this wood in close relation to the basalt is of much interest, for it is not only in Franz Josef Land that there is this association, but it has been noticed in many other places. Under very similar conditions wood has been found interstratified with the basalts of Greenland; the same conditions are present in the Western Islands of Scotland, where *Pinus eiggensis*, sometimes silicified and sometimes preserved in carbonate of iron, occurs under the Scur of Eigg, as described by Hugh Miller in the 'Cruise of the *Betsy*'; and coniferous wood was found by Sir A. Geikie under the basalt in the Island of Canna.<sup>1</sup>

The common occurrence of silicified wood on the shores of Lough Neagh, Ireland, is well known, and is stated to be derived from clays which are there found under the basalt.<sup>2</sup> Silicified wood has also been met with in the basalt of the Giants' Causeway.

It would be interesting to know whether similar conditions have existed in other places where silicified wood has been so abundantly found, such as near Cairo, in Antigua, in Arizona, in Tasmania, etc. In some of these localities volcanic conditions do obtain, but further information as to the precise relation of the silicified wood to the volcanic rocks is desirable.

In addition to the specimens above described the collection contains material from the surface of a floe, 48 miles south of Bell Island, and from the under-surface of an iceberg found, tilted up, off Eira Cottage.

That from the floe is a brown mud composed of extremely fine, brownish, amorphous particles, with which a few diatoms are associated. A partial analysis gave the following result:—

SiO <sub>2</sub> .....	49·88
TiO <sub>2</sub> .....	·28
Al <sub>2</sub> O <sub>3</sub> .....	18·06
Fe <sub>2</sub> O <sub>3</sub> .....	9·14
CaO .....	3·00
MgO .....	2·20
Loss on ignition .....	13·88
	96·44

The material from the iceberg is a greenish sand, containing shells and fragments of *Mya truncata*, *Balanus concavus*, *Balanus porcatus*, and *Saxicava arctica*; also some small subangular pebbles. The sand is principally composed of quartz and felspar, but contains also hypersthene, zircon, iron-ores, rutile, tourmaline, and garnet.

<sup>1</sup> Quart. Journ. Geol. Soc. vol. lii. (1896) p. 362.

<sup>2</sup> See W. W. Watts, 'Guide to the Collections of Rocks and Fossils in the Museum of Science and Art, Dublin,' 1895, p. 69.

The subangular pebbles are formed of basalt, sandstone, and black radiolarian chert. A section of the chert has been examined by Dr. G. J. Hinde, F.R.S., who has kindly furnished us with the following description:—

‘The thin section of the small rolled pebble of light-coloured chert from Franz Josef Land is seen under the microscope to be filled with casts of radiolaria. The structure of these organisms, as is usually the case, is now entirely obliterated, and they appear as minute transparent bodies with circular, oval, or discoidal outlines in the cherty matrix. Most of them are smooth, but a few have projecting spines. They range from 0.06 to 0.19 mm. in diameter; in general, the forms are relatively smaller than those usually met with in chert. Judging from their outlines, several genera are represented in the section; the most numerous are the simple round and oval forms belonging to *Cenosphaera* and *Cenellipsis*, and the rarer spined ones may be probably referred to *Xiphostylus* and *Dorysphaera*. Though the horizon of the rock from which this pebble comes cannot be positively determined from these imperfectly preserved radiolaria, it is not improbably of Palaeozoic age. The character of the chert itself is precisely similar to that of the radiolarian chert of the Palaeozoic rocks of Devon, Cornwall, and the South of Scotland.’

It is a curious circumstance that among the few specimens brought from Joinville Island in the Antarctic region, south of the Falkland Isles, was one of radiolarian chert; thus this rock has been found, though not *in situ*, in the most northerly and most southerly lands yet visited.

Rocks showing cone-in-cone structure are very abundant near Cape Flora, and have been found at several localities. Numerous specimens have been collected, but unfortunately not one of them was found in place, so that the exact horizon from which they come cannot be determined. As they are found all round the Cape, and sometimes high up on the talus, it is probable that they form a band or bands situated not far below the basalt.

The rock is an argillaceous limestone, and the carbonate, which has produced the structure by its attempts to crystallize under unfavourable circumstances, is rich in lime and poor in iron and magnesia.<sup>1</sup>

## VI. THE RELATIONS OF THE VARIOUS FOSSILIFEROUS HORIZONS.

In order to give some idea of the relations of the various beds of fossils above noticed, and of their probable place in the geological sequence, a vertical section (fig. 4) has been made of the strata at Cape Flora, relying upon the various heights above the sea, at which the different beds are said to occur, for the position of these

<sup>1</sup> See G. A. J. Cole, ‘On some Examples of Cone-in-cone Structure,’ *Min. Mag.* vol. x. (1892) p. 136.

beds in the section ; but it must be remembered that the figures supplied to us are only approximately accurate, and are liable to correction by further measurements.

The sedimentary strata in the south of Franz Josef Land are believed to be regularly horizontal, with only a slight dip to the north-east, and consequently within the area of Cape Flora it is unlikely that there will be any serious variation in the height of the same bed at different parts of the cliffs.

Cape Flora is said to be 1100 feet high ; the upper 500 feet is basalt, while the lower 600 feet is made up of sedimentary rocks, covered for the most part by talus. The base of the basalt is thus placed at 600 feet above the sea, and the positions of some of the beds, as we shall see, are reckoned by their distance below the basalt. Thin beds of basalt are said to occur in the clay-beds, but as the exact position of these is not stated they are left out of the section ; and for the same reason the seams of coaly lignite, noticed in these clay-beds, are omitted.

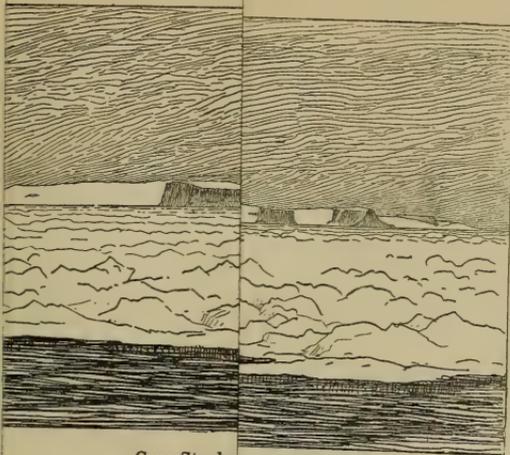
There is one horizon, however, the age and position of which are definitely known : it is that which occurs at the back of Elmwood, at about 50 feet below the base of the basalt. At this spot a bed (No. 3) was found *in situ*, and from it a small ammonite was obtained, which is probably *Ammonites Tchefkini*. In the watercourse below this exposure similar ammonites were found, together with *A. modiolaris* and *A. macrocephalus* (see p. 496). These suffice to settle the age as Lower Oxfordian and probably the equivalent of our own Kellaways Rock ; and although only one ammonite was really found *in situ*, yet it is sufficiently certain that the others, if not from the same place, came from beds but little lower in the series. Similar fossils to these occur in the talus at many places around Cape Flora, showing that the same beds in all probability occur all round the Cape.

The belemnites which were collected during the *Eira* Expedition by Mr. Grant, apparently on Mabel Island and said to be of Oxford Clay age, probably belong to this horizon.

How much of the beds above and below the *Ammonites macrocephalus*-horizon is to be included in the Lower Oxfordian one cannot say, no distinctive fossils having been found. The thin bands of shale (No. 2) which occur just above the *A. macrocephalus*-horizon and close under the basalt have yielded no fossils.

On the north side of Cape Flora, at a height of about 700 feet, the bed with plant-remains (No. 1) occurs ; it is said to be *in situ*, and overlying a mass of basalt projecting through a glacier. This locality is about a mile north-west of Elmwood—that is, on the supposed strike of the beds ; it is therefore included in the section at the height given. It is difficult to decide whether this plant-bed should be included in the Oxfordian or not. Dr. Nathorst's opinion, that it is of Upper Oolite age, carries great weight ; but if this be correct, then there would seem to be only 150 feet of strata between the Lower Oxfordian and the Upper Oolite. More-

OF THE WESTERN PA



Cape Stephen

Bell Island.

in the distant cliffs to the

DATA SUPPLIED, SAND.

1300 feet  
above  
sea-level.

1100 feet.

Glacier-slope.  
Plant-bed over basalt. 700 feet.

by talus.

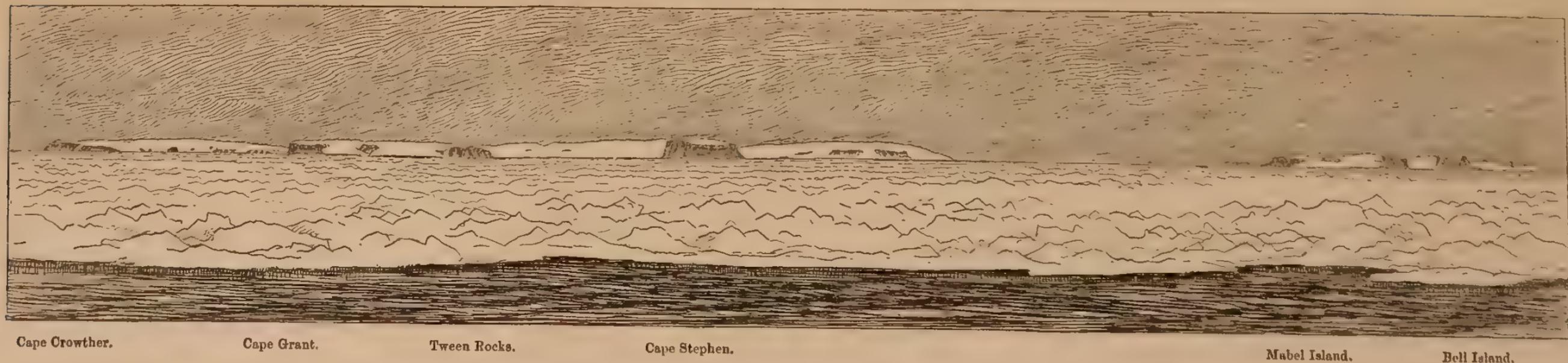
600 feet.  
East of Elmwood,  
bands of shale. bed.  
Elmwood water-  
course.

Windy Gully. 300 feet.

500 yards west 30 to 40  
of Elm- feet.  
wood.

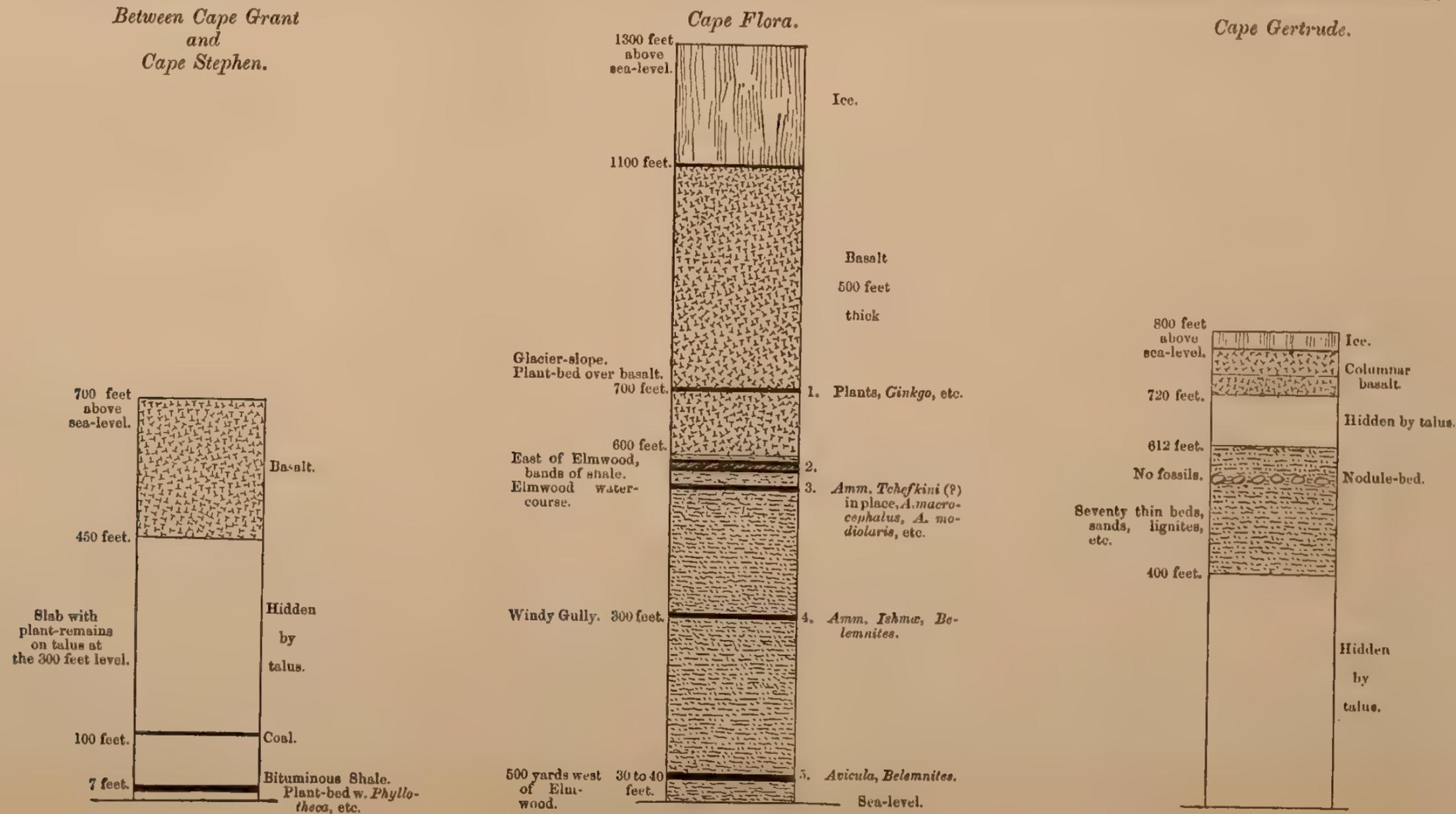


Fig. 3.—GENERAL VIEW OF THE WESTERN PART OF FRANZ JOSEF LAND. (From a sketch by Mr. Fisher.)



[Ice-pack extends from the distant cliffs to the sea in the foreground. The dark masses are basalt-crags.]

Fig. 4.—VERTICAL SECTIONS, COMPILED FROM DATA SUPPLIED, SHOWING THE PROBABLE STRATIGRAPHICAL SUCCESSION IN FRANZ JOSEF LAND.





over, if the basalt is intrusive, then the two beds (1 and 3) may originally have been nearer together than they are now. We must await further evidence before this point can be fairly discussed; in the meantime these plant-bearing shales are the highest fossiliferous horizon that has yet been found in place in Franz Josef Land.

The specimens of *Ammonites Ishmæ* discovered at Windy Gully, at 300 feet above the sea,<sup>1</sup> are believed by Dr. Kœttlitz to have been in place—that is to say, he is of opinion that they belonged to the bed on which they were found. This horizon, therefore, is placed in the section at 300 feet above the sea, and is thus 250 feet below the *Ammonites modiolaris*-bed, but this distance may be too great. The ammonites and belemnites of this bed are not of the same species as those found in the *Ammonites macrocephalus*- and *A. modiolaris*-horizon; and it is quite possible that we may have in this *A. Ishmæ*-bed a representative of another formation, perhaps of the age of the Cornbrash.

The lowest horizon seen at Cape Flora is the bed exposed at about 30 to 40 feet above the sea, a little to the west of Elmwood (No. 5). Except for the fact that this bed is situated some 250 feet lower in the series than the place where *A. Ishmæ* was found, there is nothing to give a clue to its geological horizon. The large *Avicula* has not been identified, and the belemnites, although resembling those found with *Ammonites Ishmæ*, are not perfect enough for identification.

The numerous thin beds (No. 6) at Cape Gertrude, that occur at a height of from 200 to 400 feet above the sea, having yielded no fossils to indicate their age, cannot be correlated with the section at Cape Flora, and it is only their elevation above the sea that points to a possible correspondence with the *Ammonites macrocephalus*- and *A. modiolaris*-series.

We now come to what seems to be the lowest horizon from which fossils have been collected in Franz Josef Land—namely, the plant-bearing sandstone at Cape Stephen (No. 7), which was also found exposed farther south-west, towards Cape Grant. As this locality is more than 20 miles west of Cape Flora and the structure of the intervening islands is not known, it is hazardous to attempt to correlate the beds at the two places. But, at the same time, if the strata of the south of Franz Josef Land are uniform in their north-easterly dip, then, as this plant-bed is near the sea-level at Cape Stephen, we should expect to find it or its equivalent at some distance below the sea at Cape Flora; and the possibly Lower Oolite age of the plants points to a similar position in the series. On the other hand, as already pointed out (p. 505), these beds may be of much greater antiquity.

The presence of a plant-bed at the top of these Oolitic strata of Franz Josef Land, and the occurrence of lignite-beds in many places below, show that estuarine, if not indeed freshwater, con-

<sup>1</sup> See footnote, p. 500.

ditions must have prevailed during a large part of the time when they were being deposited; but, on the other hand, the horizons with *Ammonites* and *Belemnites* point to times when marine depositions intervened.

Strata of Oolitic age have been met with in Spitsbergen by Prof. Nordenskiöld,<sup>1</sup> and the presence of *Ammonites triplicatus* would seem to indicate that they belong to higher beds than have been recognized in Franz Josef Land, unless indeed they correspond with the upper plant-bed of Cape Flora.

More recently two species of Jurassic ammonites have been recognized from Spitsbergen by Dr. Fraas,<sup>2</sup> namely *Ammonites triplicatus* and *A. cordatus*, from which one can only conclude that beds are present which in Britain would be called Upper Oxfordian.

Numerous Jurassic fossils were collected by Prof. Nordenskiöld in Novaya Zemlya and have been described by Prof. Tullberg.<sup>3</sup> Among these *Ammonites alternans* is found, thus indicating the presence of beds of Kimeridgian age in that country.

The question of the age of the silicified wood has already been alluded to (p. 509), and little further can be said. The occurrence of this wood below the basalt and near to probable Jurassic deposits shows that some of it may perhaps be of Jurassic age; but it may equally well be of Cretaceous or Tertiary date. Even if future discoveries confirm the supposed Cretaceous age of the pine-cone from Bell Island, this will not necessarily prove the silicified wood to be of the same age.

The possibility of Tertiary beds being present is shown by the silicified slab from Cape Stephen, the *Ginkgo* seeming to be the same as *G. reniformis*, which is from beds believed to be of Tertiary age.

The plant-remains found near Cape Richthofen may likewise be of Tertiary age, as already mentioned (p. 507), but the evidence is so slender that it must be taken rather as a suggestion of something to be looked for in the more northern parts of Franz Josef Land than as a proof of the presence of beds of so late a date. The fact that beds with abundant plant-remains of Tertiary age have been found in Spitsbergen shows that similar deposits may be expected here. It will be remembered that the specimens from Cape Richthofen were found upon a high lateral moraine, and therefore presumably were derived from beds directly above this moraine, or it may be were brought from a distance; in either case it is quite possible that they may yet be found *in situ*. The plant-remains themselves have a very recent look, but it is hardly likely that they can be more recent than the Glacial Period; indeed, Mr. Clement Reid's opinion (p. 508) goes far to show that they are of neither recent nor Pleistocene age, but must be referred to the

<sup>1</sup> 'Sketch of the Geology of Spitsbergen,' 1867, p. 27.

<sup>2</sup> Neues Jahrb. 1872, p. 203. See also Raymond & Dollfus, 'Géol. Spitsbergen,' Feuille des Jeunes Naturalistes, 1897, Nos. 286, 287, 288.

<sup>3</sup> 'Verstein. Nowaya Semlya,' Bihang till Svenska Vetenskap. Akad. Handl. vol. vi. (1880) pt. ii.

Tertiary period. These plants, however, are so poorly preserved, and their place of origin is so uncertain, that we can only hope for additional specimens which may throw light upon this interesting but obscure question.

## VII. CONCLUSION.

In conclusion, we may perhaps be allowed to sketch out briefly the salient features in the geological history of Franz Josef Land, so far as this can be done in the light of our present knowledge. Passing over the plant-bed at Cape Stephen, the age of which is uncertain, the first event of which we have any record is the deposition of a series of shales and sandstones containing plant-remains, beds of lignite, and other evidences of littoral or estuarine conditions. Intimately associated with these shallow-water deposits are some purely marine beds, the age of which is placed beyond all doubt by the occurrence of such well-characterized zonal fossils as *Ammonites macrocephalus* and *A. modiolaris*.

Owing mainly to the brilliant researches of Neumayr,<sup>1</sup> it is now generally recognized that the Jurassic sea reached its greatest extension in the present land-areas during the Callovian and Oxfordian periods. Hydrocratic and geocratic movements alternated during Jurassic times, with a decided balance in favour of the former, and a recession of the coast-line towards the north. Even in the North of Scotland we find no decided evidence of the proximity of land during the Oxfordian period, although the lower portions of the Jurassic formation are represented by littoral and estuarine deposits.<sup>2</sup>

Under these circumstances the discovery of *A. macrocephalus*-beds in Franz Josef Land in association with plant-bearing strata is of special interest. It extends the range of this ammonite several degrees towards the north, and shows, in all probability, that during the period of its existence a coast-line lay somewhere in this direction. Marine deposits of Callovian and Oxfordian age are now known to range from Sutherland to Cutch and from Franz Josef Land to the North of Africa; and *A. macrocephalus* is one of the most widely distributed of all Jurassic ammonites.<sup>3</sup> The soft Jurassic sediments were subsequently covered up and preserved from destruction by vast flows of basaltic lava; and it is not a little remarkable that rocks of the same general period have been preserved in the same way in districts so far removed from Franz

<sup>1</sup> 'Die geographische Verbreitung der Juraformation,' Denkschr. d. k. Akad. d. Wiss. Wien, vol. 1. (1885) pp. 57-142.

<sup>2</sup> J. W. Judd, 'The Secondary Rocks of Scotland,' Quart. Journ. Geol. Soc. vol. xxix. (1873) p. 164, & vol. xxxiv. (1878) p. 726.

<sup>3</sup> It not only occurs in Central and Southern Europe, Northern Russia, and Franz Josef Land, but also in Cutch (Waagen, Pal. Indica, ser. ix. vol. i. 1873) and Bolivia (Steinmann, Neues Jahrb., Beilage-Band i. 1881, p. 239). It has also been recorded from Western Australia (Moore, Quart. Journ. Geol. Soc. vol. xxvi. 1870, p. 226), but Neumayr throws doubt on the identification (*op. cit.* p. 118).

Josef Land as the North-west of Scotland<sup>1</sup> and Abyssinia.<sup>2</sup> We have already pointed out that Dr. Nansen refers the basalt in part to the Jurassic period; but in view of the fact that the basalts of the West of Scotland were at one time supposed to be of the same age, for reasons similar to those relied upon by him, this conclusion cannot be regarded as definitely established. At the same time it is important to notice that, if we except the North of Ireland, the Upper Cretaceous period is unrepresented, or but feebly represented, by sedimentary deposits in regions like the Deccan of India and the high plateaux of Abyssinia, where basalts are extensively developed. It is therefore quite possible that the vast outpourings of basic lavas which have given a special character to extensive areas of the earth's surface<sup>3</sup> may have commenced in pre-Tertiary times.

The present configuration of the archipelago of Franz Josef Land (see fig. 3, facing p. 512) conclusively proves that it is formed of the fragments of an old plateau. The land frequently ends off in high cliffs, capped with sheets of basalt which must have extended far beyond their present limits. When one compares the topography of this district with that of the Færöes and the West of Scotland, one is inclined, notwithstanding the immense tracts of water which now separate these localities, to ask whether they may not at one time have been continuous, and whether the northern portion of the North Atlantic, as suggested by Suess,<sup>4</sup> may not be of comparatively recent origin.

But whatever answer may be given to this question, it is clear that at the close of the volcanic period the various islands of Franz Josef Land were united and formed part of an extensive tract of land. This land was subsequently broken up, partly, in all probability, by the sinking of certain areas along lines of fault, and partly by denudation.

The final stages in the history of the district are represented by the raised beaches, which prove that this region, like so many other portions of the extreme north, has quite recently been under the influence of a geocratic movement.

## EXPLANATION OF PLATES XXXVII.-XLI.

### PLATE XXXVII.

Fig. 1. Basalt from talus, Cape Flora.  $\times 20$ . The figure shows labradorite, ophitic augite, and interstitial matter, with which some magnetite is

<sup>1</sup> J. W. Judd, 'The Secondary Rocks of Scotland,' Second Paper, Quart. Journ. Geol. Soc. vol. xxx. (1874) p. 220.

<sup>2</sup> Aubry, 'Observations géologiques sur les Pays Danakils, etc.,' Bull. Soc. géol. France, ser. 3, vol. xiv. (1886) p. 201.

<sup>3</sup> The Deccan traps cover an area of about 200,000 square miles, 'Geology of India,' 2nd ed. 1893, p. 256.

<sup>4</sup> 'Are Great Ocean-Depths Permanent?' Natural Science, vol. ii. (1893) p. 185.

associated. The magnetite cannot be distinguished from the interstitial matter in the figure. [F. 318.]

- Fig. 2. Amygdaloidal basalt from the talus, Cape Flora.  $\times 10$ . Labradorite, augite, palagonite, and calcite. In this case no magnetite can be recognized under the microscope; the whole of the iron-oxide appears to have remained undifferentiated. The interstitial matter occurs also as the infilling material of an irregular cavity, the centre of which is occupied by calcite. [F. 321.]
- Fig. 3. Olivine-basalt with chrome-diopside.  $\times 10$ . From the under-surface of an iceberg off Eira Cottage. The chrome-diopside occurs as a phenocryst with a zone of inclusions near the margin. The large black inclusion is of a greenish undetermined substance—not magnetite. Olivine is not seen in the figure. [F. 324.]
- Fig. 4. Another portion of the same section.  $\times 20$ . The interstitial matter in this rock has been devitrified during consolidation, and is crowded with grains and skeleton-crystals of magnetite, which can be recognized in the figure. [F. 324.]
- Fig. 5. Quartz-bearing basalt.  $\times 50$ . From the under-surface of an iceberg, found tilted up in De Bruyne Sound. Calcite surrounded by a zone of augite-microlites. The clear patch near the outer margin of the zone is also formed of calcite. The main mass of the rock is formed of microlites of feldspar, augite, and magnetite. [F. 343.]
- Fig. 6. Phosphatic nodule from Windy Gully, Cape Flora.  $\times 16$ . [F. 336.]

[The numbers in square brackets refer to the collection in the Museum of Practical Geology.]

#### PLATE XXXVIII.

Fossil plants from the north side of Cape Flora, Northbrook Island, Franz Josef Land, 700 feet above the sea.

- Fig. 1. *Ginkgo polaris*?  
 2. " "  
 3. " sp."  
 4. " *siberica*?  
 5. " ?  
 6, 7 & 8. Pine-seeds.  
 9. " cone.  
 10. *Baiera*?  
 11. *Fieldenia*?  
 12. *Podozamites*?  
 13 & 14. *Thyrsopteris* sp.

#### PLATE XXXIX.

Figs. 2, 3, 5, 7, 8 & 15 are of specimens from the watercourse in the talus at the back of Elmwood, Northbrook Island, No. 5 being found *in situ*.

Figs. 4, 6, 10, 11, 12, 13 & 14 are of specimens from the western end of Cape Flora. Figs. 1 & 9 from Cape Flora.

- Figs. 1 & 2. *Ammonites* (*Macrocephalites*) *macrocephalus*.  
 3. " " " var.  
 4 & 6. *Ammonites* (*Cadoceras*) *Tchefkini*?  
 5. " " " Found in place 50 feet below the basalt.  
 7, 8 & 9. *Ammonites* (*Cadoceras*) *modiolaris*.  
 10. " " " flattened variety.  
 11, 12 & 13. *Belemnites* *Panderi*.  
 14. " " " Piece of large specimen.  
 15. *Gorgonia*?

## PLATE XL.

Figs. 1-3. Ammonites from Windy Gully, east of Elmwood, Northbrook Island, found on a shoulder of rock 300 feet above sea-level, believed to be in place.

- Fig. 1. *Ammonites* (*Macrocephalites*) *Ishmæ*, var. *arcticus*.  
 2. " " " " inflated variety with coarser ribs.  
 3. " " " " The exterior of this shell is almost devoid of ribs.  
 4. *Avicula* sp., from west of Elmwood, 30 or 40 feet above sea-level, and believed to be in place. The outline shows the probable size. Other fragments indicate still larger shells.

## PLATE XLI.

Figs. 1-9. Plants collected from beds *in situ* near the sea-level, at a spot called 'Tween Rocks' between Cape Grant and Cape Stephen.

- Figs. 1-3. *Phyllothea* like *Equisetum columnare*, Phil.  
 4 & 5. *Zamipteris*? like *glossopteroides*. Margins imperfect.  
 6 & 7. *Rhipozamites*? near to *Gæpperti*.  
 8. *Anomozamites*?  
 9. *Asplenium* cf. *whitbiense*.  
 10. Portion of silicified slab of plant-remains from Cape Stephen, 300 feet up the talus, containing strap-like leaves with (a) *Ginkgo reniformis*? and (b) *Pinites*.  
 11. Magnified section of silicified wood from Northbrook Island, showing the discs of coniferous wood.

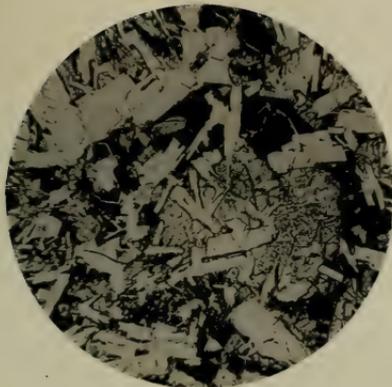
## DISCUSSION.

DR. J. W. GREGORY was glad that the Authors confirmed Mr. Etheridge's determination of the beds as Oxfordian—a conclusion based on the collections made by Mr. Leigh Smith. The simplicity of the series around Elmwood was probably due to its occurrence in the heart of a great plateau-area; whereas in Western Spitsbergen the series was more varied, owing to its having been formed on the oscillating border of the land-area. Hence it is probable that the outlying islands of the Franz Josef archipelago, such as Osear Land and Petermann Land, will yield a richer series of deposits.

The main interest of the stratigraphical portion of the paper was centred in the history of the Arctic Jurassic sea; but the speaker thought that Neumayr's fascinating theory, to which reference had been made, was now quite untenable. The relations of the Jurassic series in Franz Josef Land to those of the Northern Petchora basin were very significant. He understood that *Belemnites Panderi* was typically Kimmeridgian and Sequanian. He thought that all Fellows of the Society would be grateful to Mr. Harmsworth for his munificent generosity, and to the Authors for their very careful and thorough study of the material collected.

MR. W. W. WATTS enquired as to whether it was absolutely certain that the basalts were other than of Tertiary age. In

1.



2.



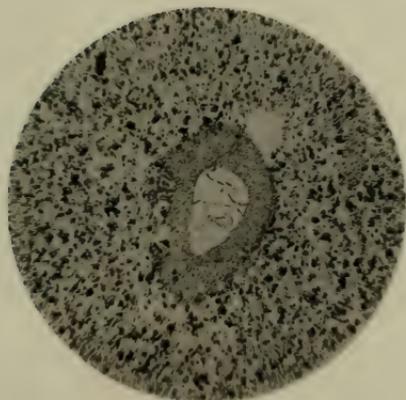
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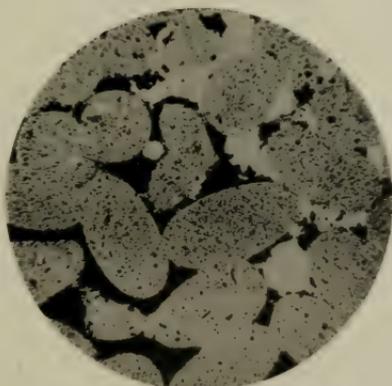
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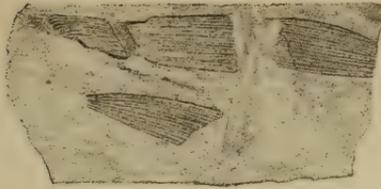


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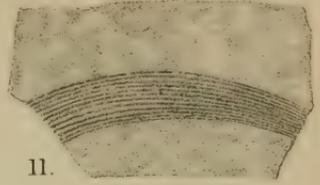


ROCKS FROM FRANZ JOSEF LAND.

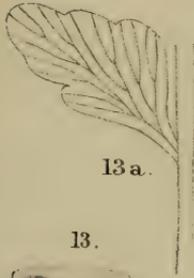




12.



11.



13a.

13.

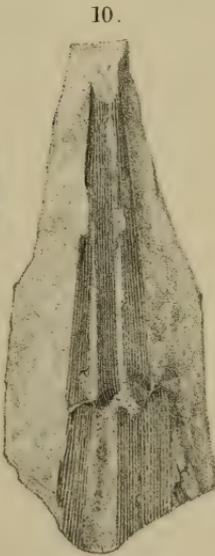
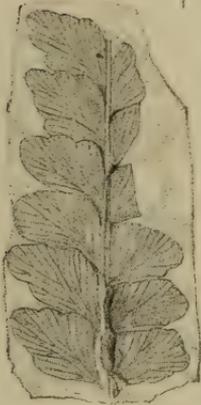


9.



14a.

14.



10.



7.



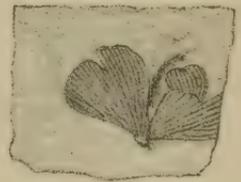
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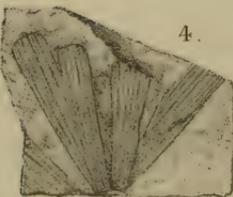
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6.



3.



4.



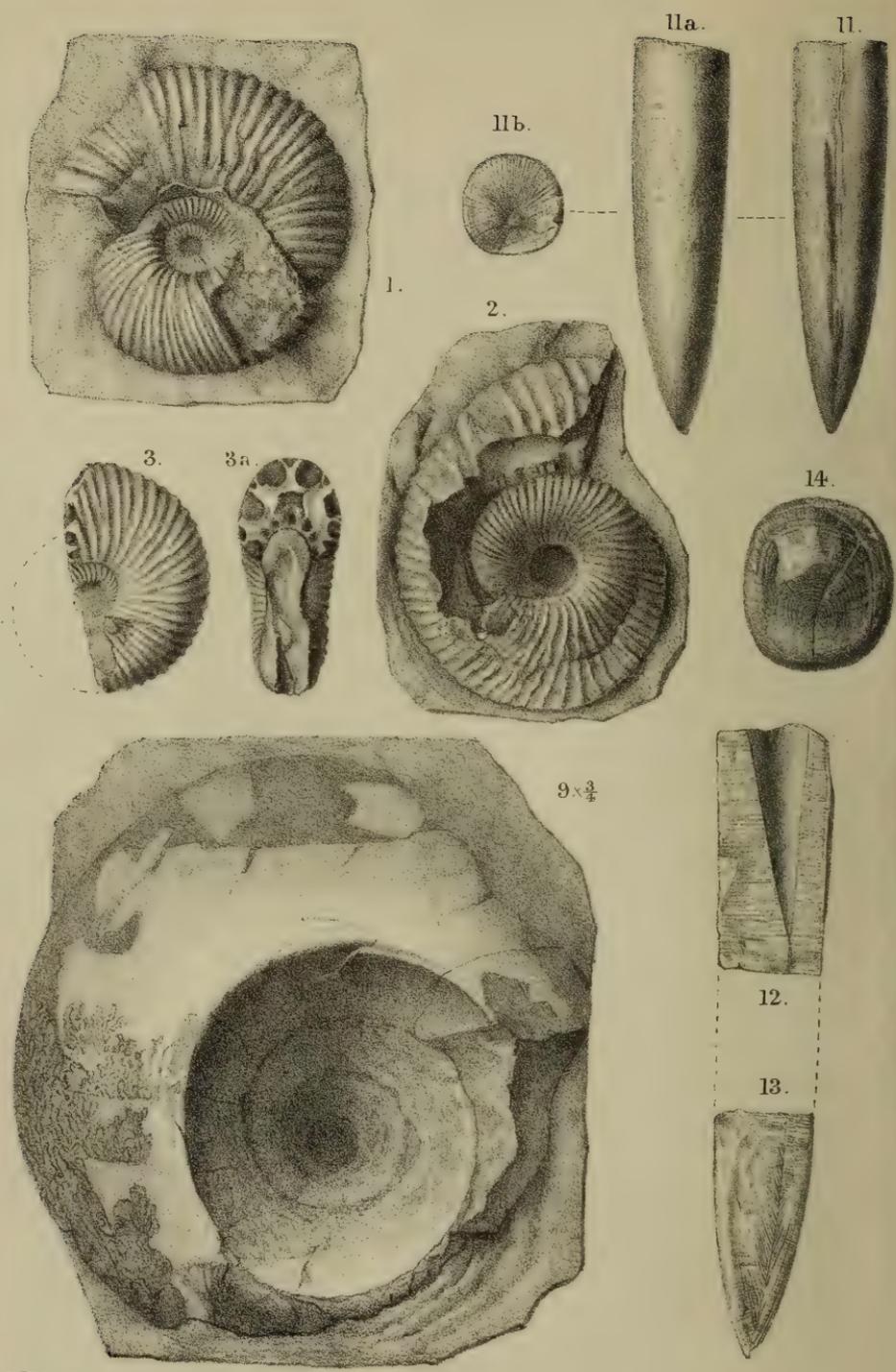
2.



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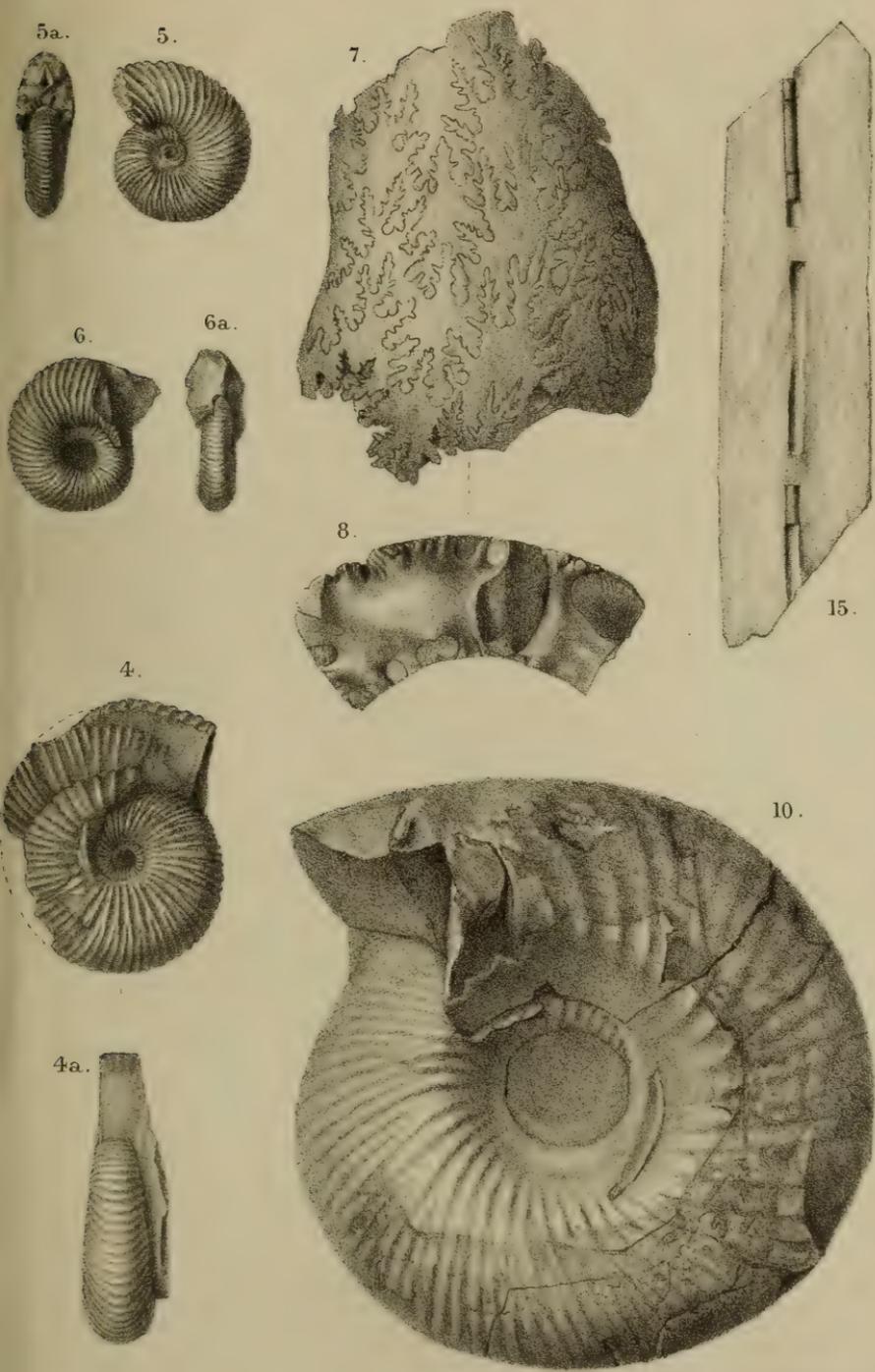






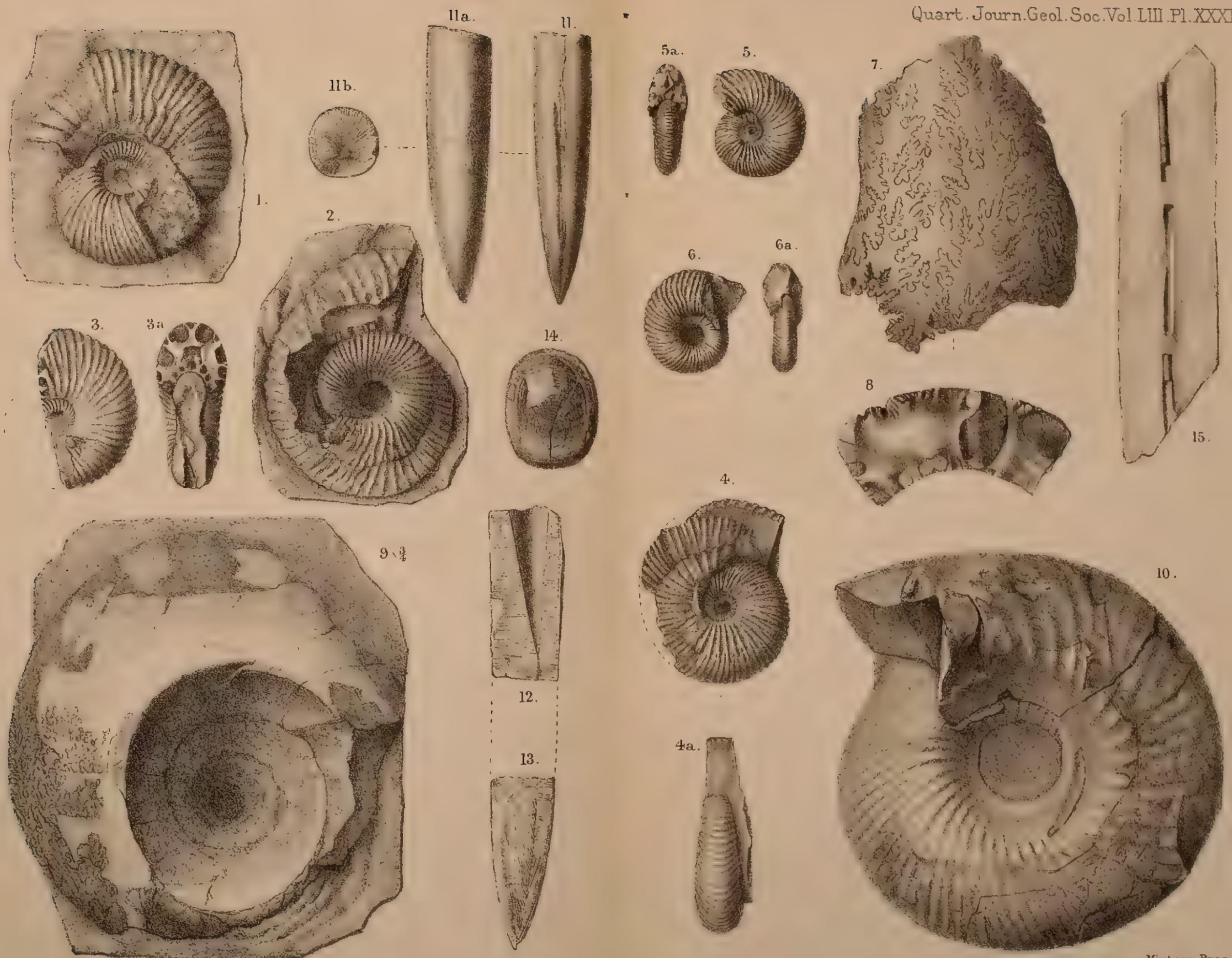
A.T.Hollick del. et lith.

FRANZ JOSEF LAND



Mintern Bros. imp.

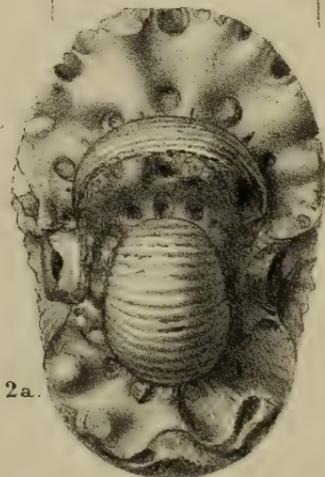
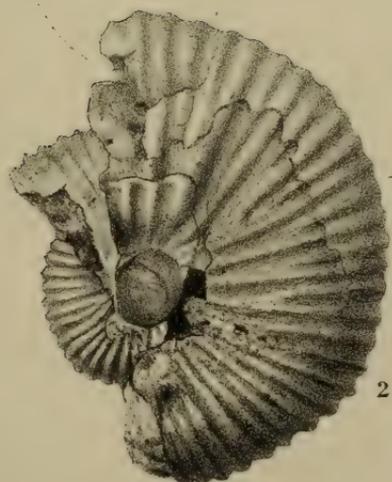
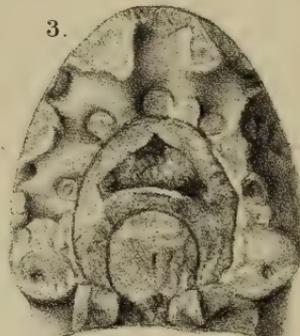
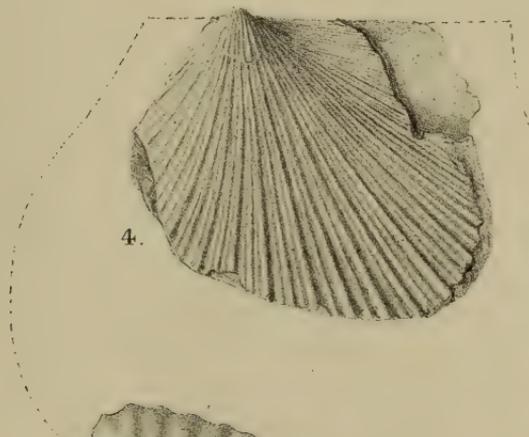
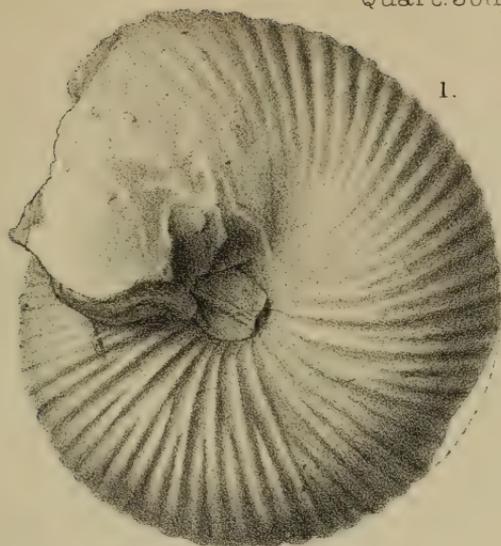




A.T. Hollick del et lith.

Mantern Bros. imp.



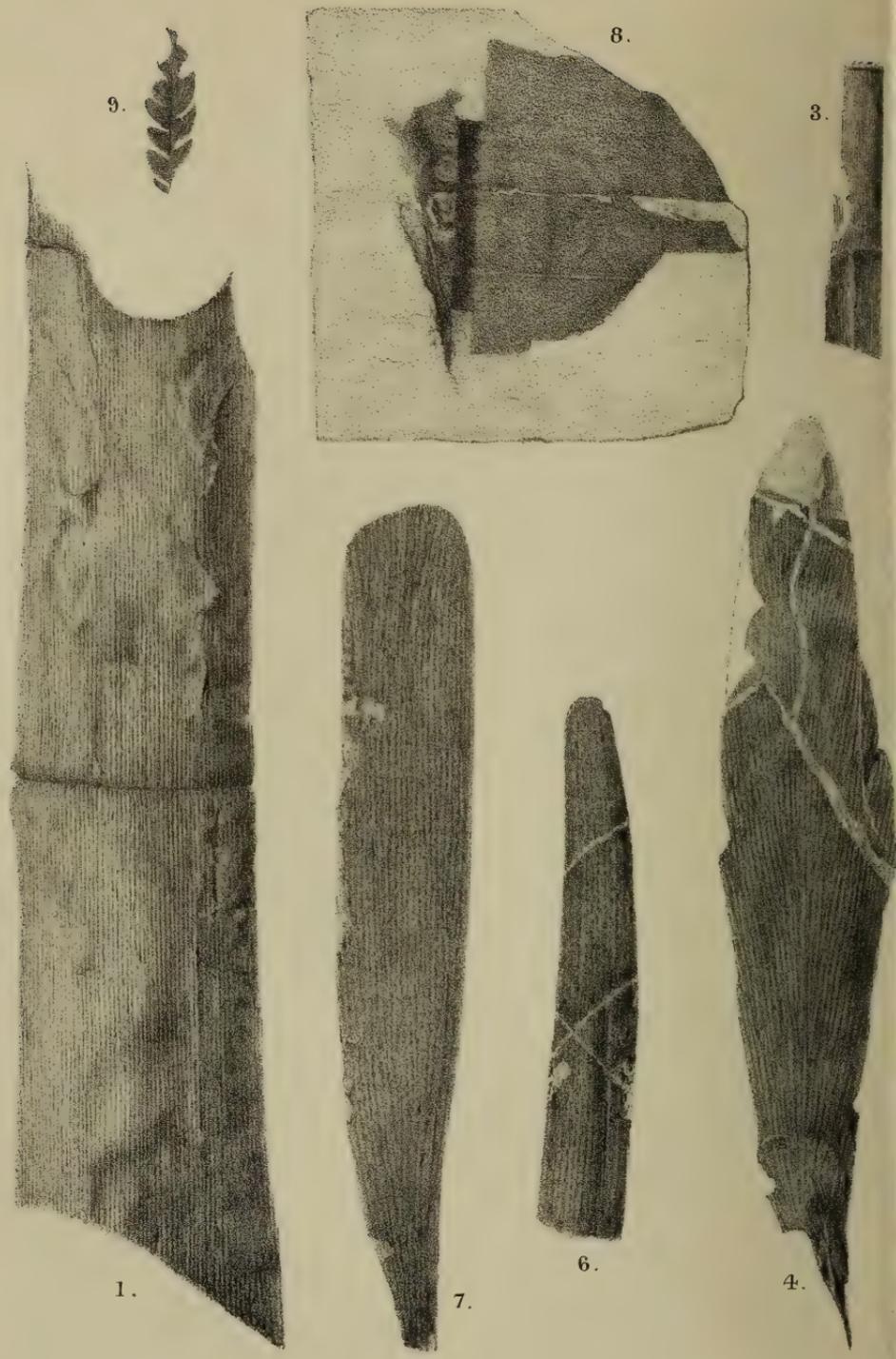


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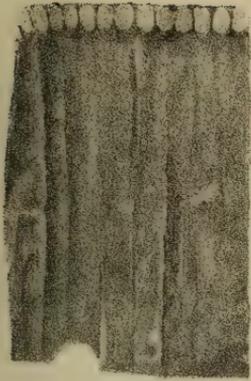




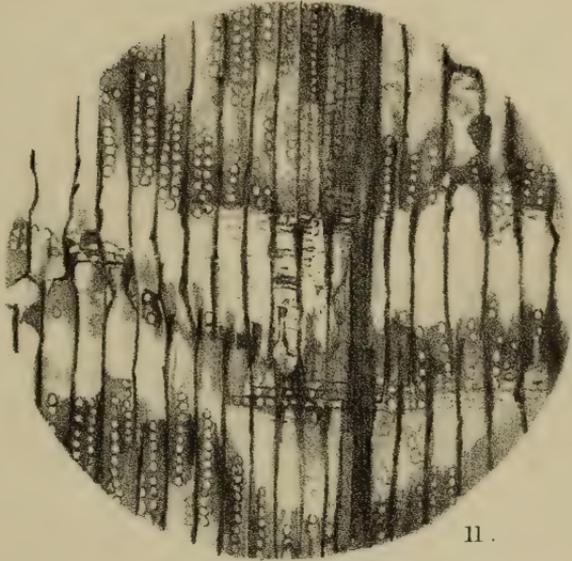


A.T.Hollick del.et lith.

FRANZ JOSEF LAND



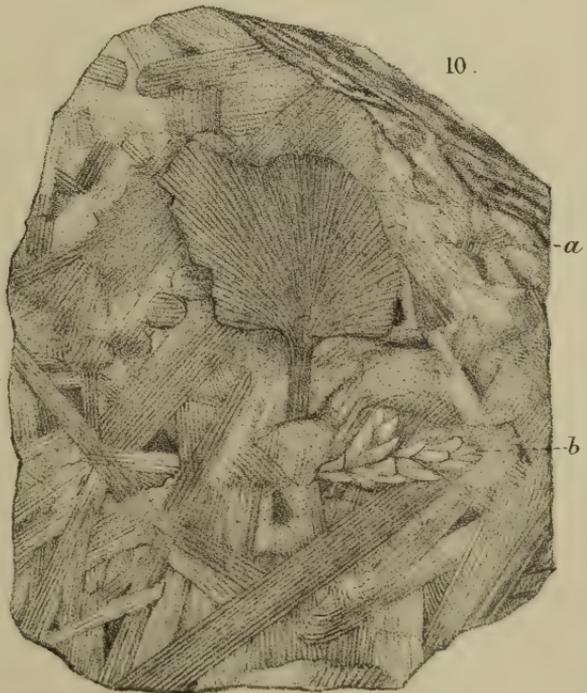
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11.



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a

b

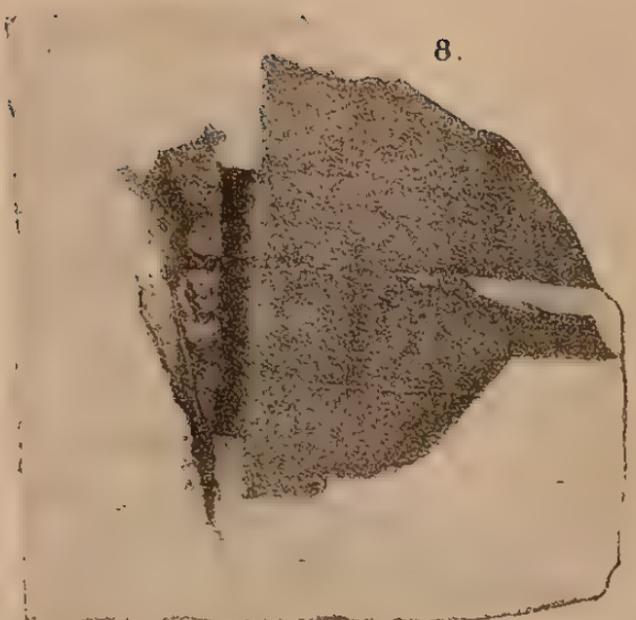
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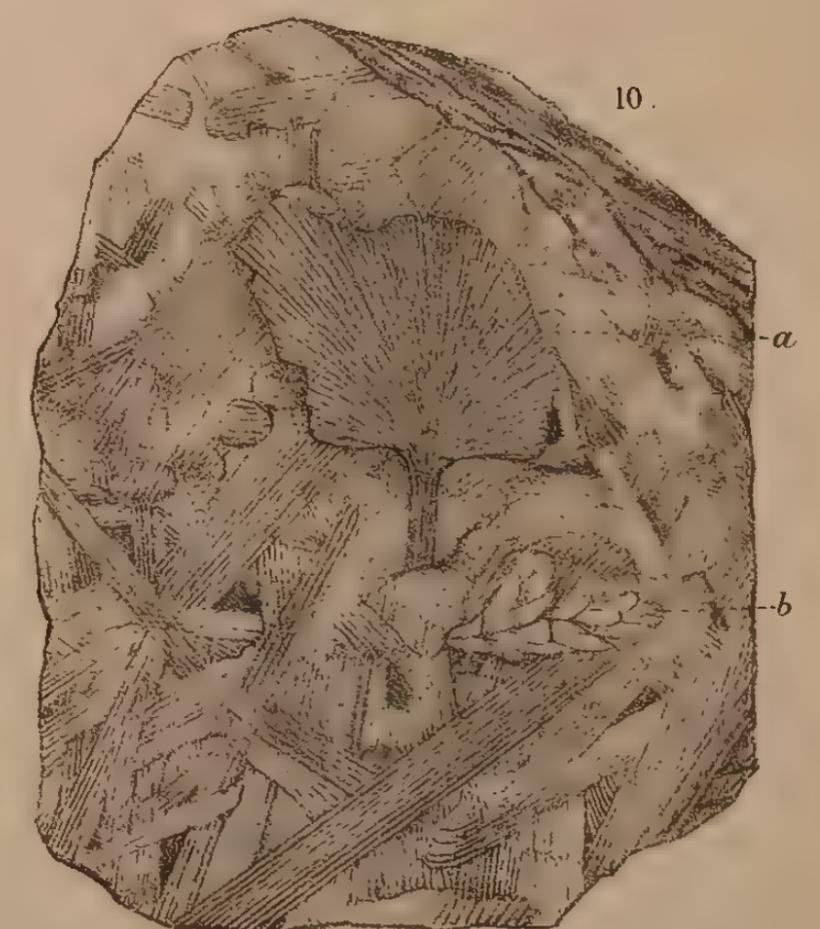
6.



4.



5.



10.

a

b



Spitsbergen, Ireland, and Scotland exactly similar lavas were of Tertiary age.

Mr. G. C. CRICK agreed with the Authors as to the age of the cephalopoda exhibited, and with regard to Dr. Gregory's question respecting the occurrence of *Belemnites Panderi* with the ammonites referred by the Authors to *A. macrocephalus* and *A. modiolaris*, suggested that possibly beds of a somewhat higher horizon than that indicated by the Authors were also present.

The PRESIDENT, Prof. H. G. SEELEY, Dr. G. J. HINDE, Mr. A. MONTEFIORE BRICE, and Prof. LAWSON also spoke.

The AUTHORS, in reply, said that they did not suggest that the basalts were of Jurassic age. They thought that these were probably related to the Jurassic rocks in the same way as in the north of Skye. They were quite aware of the probable occurrence of faults in the district, but could not give any direct evidence on this point.

With regard to the Upper Jurassic age of the higher plant-bearing beds, they were pleased to be able to support the view of Dr. Nathorst. They thought that the range of *Belemnites Panderi* would prove greater than was supposed.

In conclusion, they desired to express their appreciation of the careful way in which the specimens had been collected and labelled—a result doubtless in large measure due to the energy and organizing skill of the Hon. Secretary of the Expedition, Mr. Montefiore Brice.

35. *An Account of the PORTRAINE INLIER (Co. DUBLIN).* By C. I. GARDINER, Esq., M.A., F.G.S., & S. H. REYNOLDS, Esq., M.A., F.G.S. *With an APPENDIX on the FOSSILS* by F. R. COWPER REED, Esq., M.A., F.G.S. (Read June 9th, 1897.)

## [PLATES XLII &amp; XLIII.]

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## I. INTRODUCTION.

THE coast of County Dublin is well known for the variety and interest of the rocks exposed along it, but there is probably no part of it more interesting than that in the neighbourhood of the village of Portraine, some 14 miles north of Dublin itself. Here occurs an inlier of pre-Devonian rocks which prove the occurrence in the district, during Bala times, of much volcanic action and of reef-building corals. The interest attaching to the rocks and the difficulty of interpreting their meaning are increased by the great amount of disturbance which has gone on and has given rise to extensive developments of conglomerate-like beds.

Volcanic rocks, which are certainly of the same age as those at Portraine, and coarse conglomerates, occur on Lambay Island, some 3 miles out to sea, and we hope to give some account of these at no distant date.

We were led to examine the beds at Portraine from a wish to compare them with the Bala Beds occurring in the neighbourhood of Kildare, which we described last year.<sup>1</sup>

The Portraine area has, perhaps, hardly received so much attention from geologists as it deserves. The first description is that given by H. B. Medlicott<sup>2</sup>; a brief account is given by G. V. Du Noyer, in the Memoirs of the Irish Geological Survey, the memoir including

<sup>1</sup> Quart. Journ. Geol. Soc. vol. lii. (1896) p. 587.

<sup>2</sup> Journ. Geol. Soc. Dublin, vol. v. (1853) p. 265.

a list of some fifty fossils determined by W. H. Baily<sup>1</sup>; later Prof. Cole writes of the area in his articles on 'County Dublin, Past and Present'<sup>2</sup>; while the most recent account is that by Prof. Sollas, written for the visit of the Geologists' Association to the district in 1893.<sup>3</sup>

## II. DESCRIPTION OF THE AREA AND ITS GEOLOGICAL STRUCTURE.

The area with which we are concerned forms a blunt-ended promontory, limited on the north by the estuary on which Rush is built, and on the south by that on which Malahide is situated. The pre-Devonian rocks are bounded on the east by the sea; on the north by the waters of the Rush estuary; on the west by a coarse conglomerate, referred by the officers of the Geological Survey to the Old Red Sandstone period; and on the south by an area of blown sand. Our account of them deals mainly with the coast-section, for inland exposures are scanty, the country being much covered by drift.

Two martello towers have been built on the promontory, the northern one being used as a Coastguard station, and they will be frequently referred to, as they form convenient landmarks. (See Map, Pl. XLIII.)

Geologically the rocks forming the inlier are divisible into several well-marked groups. At the northern end is an area of volcanic rocks, succeeded to the south by an area of limestone and shale, which is followed by an exposure of grits. Then comes a smaller development of limestone and shale, and, finally, at the southern end of the inlier occurs a second area of volcanic rocks. Owing to the great amount of faulting and folding which has taken place, the area has been made very complicated. Not one of the groups of rocks that we have mentioned can be seen to rest conformably on another, the junction being apparently in every case a faulted one. The divisional plane between the grit series and the limestone-and-shale series is, wherever visible, a thrust-plane, marked by the development of most interesting conglomerates due to earth-movements.

Although we have no definite proof of their age, the grit series apparently forms the newest group, and the volcanic rocks the oldest, of the inlier, the district as a whole forming a much denuded half-syncline.

## III. THE IGNEOUS AND ASSOCIATED ROCKS AT THE NORTHERN END OF THE INLIER.

'At the north-western corner of the inlier the coarse quartzose conglomerate mentioned above is seen dipping N.W. at 35°, and from beneath it appear with a south-easterly dip a series of purple and green andesitic rocks which form the foreshore up to, and just beyond,

<sup>1</sup> Explan. Mem. Sheets 102 & 112 Geol. Surv. Irel., 2nd ed., Dublin, 1875.

<sup>2</sup> 'Irish Naturalist,' vol. i. (1892) p. 31.

<sup>3</sup> 'The Geology of Dublin and its Neighbourhood,' Proc. Geol. Assoc. vol. xiii. p. 91.

the farm at the north-eastern corner of the area. These rocks in a hand-specimen are seen to have a compact groundmass, and frequently show porphyritic feldspars of no great size. They are often slightly and sometimes extremely amygdaloidal, the amygdules being formed of pink calcite. Veins of epidote are of frequent occurrence, and jaspers are numerous at certain spots.

Some twenty sections of rocks from this portion of the coast have been examined microscopically. They are all seen to be from andesites which have undergone considerable alteration, accompanied by the formation of various secondary minerals.

The groundmass is always fairly prominent, and in some cases very prominent indeed; it is invariably much altered, its original constituents being replaced by chlorite and epidote. In many sections the groundmass contains numerous needle-shaped crystals of feldspar which extinguish approximately parallel to their lengths, and occasionally show well-marked flow-structure. Iron-ores are abundant, some slides showing magnetite, others leucoxene or hæmatite, while in some iron pyrites occurs as well.

The porphyritic constituents are (1) feldspars, probably labradorites, occurring as fair-sized crystals, which, though much altered, worn, and replaced, still at times show twinning; (2) augites, now entirely replaced by calcite or by a brown mineral traversed by veins of chlorite; and (3) apatite, which has been observed in only one section of a rock from this area, though it has been frequently found in similar andesitic rocks occurring on Lambay Island.

The amygdules, as previously mentioned, are formed for the most part of calcite, but some contain chlorite enclosing little patches of silica.

Immediately north of the farm, at the point where the coast-line turns to the south, two somewhat different types of rock occur, one of which probably forms a dyke in the andesites, as its strike does not run in the same direction as do those of the andesites.

The dyke, a foot or so in breadth, runs in an east-and-west direction, is of a light green colour, and shows large, greenish-white, platy feldspars. It is identical in character with some of the Lambay porphyrites, which are sometimes intrusive and sometimes interbedded. Under the microscope it shows an extensive groundmass, composed of a yellow decomposition-product and feldspar-microlites, and porphyritic feldspars, fairly fresh but much worn at their edges.

The second rock, whose strike, like those of the other andesites, is south-west and north-east, is noticeable from the very large amount of red iron-oxide which is aggregated round the feldspars and vesicles. Small feldspars are to be seen in the groundmass, most of them much altered. Porphyritic feldspars are scarce, while patches of a light orange-brown material probably represent porphyritic augites.

A little farther on, just at the east side of the corner, is a second

mass of coarse rock, similar in character to the dyke above mentioned. It appears to be intruded into the surrounding andesites, portions of which are caught up and included in it. It contains in some parts numerous jaspers.

Farther to the south-east a small thickness of light-green andesite is seen dipping S.E., at an angle of about  $45^\circ$ ; and then, after a gap in the exposures, about 2 feet in width, there comes on a remarkable conglomerate which occupies the foreshore for the next 150 yards. The dip of this bed is to the S.E. at  $45^\circ$ , that is, in the same direction and at the same angle as the andesite below it, and this fact, together with the absence of any trace of crushing in either rock near their junction, makes it practically certain that the conglomerate is not faulted against the andesite.

The conglomerate has a matrix which is at first a dark ashy shale, including many angular fragments, of various sizes, of ash, andesite, and shale; and here and there small veins of calcite traverse the rock. The large included blocks consist mainly of limestone or ash, very few pieces of grit or of lava being seen in the lower portions of the rock. Several varieties of limestone occur—a red, somewhat horny type, an earthy type, crowded with fossils, and an ashy type. The ashes are mostly of a calcareous nature, several degrees of coarseness being represented. These larger blocks are always well rounded, and are most of them from 6 to 9 inches long.

Interbedded with the conglomerate there occurs at one point a thin band of limestone, and a few feet below it there is a lenticular mass of black shale.

On going southward, and therefore on ascending the series, the matrix of the conglomerate is seen to become more distinctly ashy and yellowish green in colour, while the blocks of limestone and ash first decrease in number, and then blocks of a coarse porphyrite and fine andesites become numerous. Occasionally blocks of very large size are met with towards the centre of the bed, one (of ash) measuring 5 feet in length.

About 150 yards before the martello tower is reached there occurs on the foreshore a narrow band of limestone dipping beneath a few feet of black shale, the latter bed containing very poorly-preserved graptolites, identified by the officers of the Geological Survey as *Diplograptus pristis*. Among the specimens that we collected *Climacograptus Scharenbergi* (Lapw.), *Diplograptus*, and *Dicellograptus* have been identified for us by Miss E. M. R. Wood.

The strike of these bands appears to be more nearly east and west than that of the beds to the north; but farther out to sea the previous north-easterly and south-westerly strike is maintained, and certain well-marked bands of ash are clearly traceable. The ashes found here were of very varied types. Some were fine, some coarse, some calcareous, some non-calcareous. Immediately north of these graptolitic shales the officers of the Geological Survey draw a fault and state that the beds are there reversed in their dip, but we

could obtain no evidence of this, though at this point signs of disturbance begin which become more marked as we proceed southward.

Beyond the graptolitic shale the rock is still an ashy conglomerate containing numerous blocks of coarse porphyrite, of ashes of various types, and of fine andesites, and then as the martello tower is approached thin bands of limestone, often ashy in their nature, come to be interbedded with the ashy conglomerate, while bands of dark-grey calcareous shales also occur, and have yielded, at the spot marked A in the map (Pl. XLIII), fossils which have been identified for us by Mr. F. R. Cowper Reed as *Orthis simplex*, M'Coy?, *Orthis* sp., *Rafinesquina expansa*, Sow., *Plectambonites sericea*, Sow., and fragments of trilobites.

Farther out to sea the ashes, with the interbedded limestones, are covered by fine green and purple andesites.

The martello tower, forming the Coastguard station, stands on a mass of limestone which is shaly in places, especially at its base, and yielded, at the spot marked B in the map, *Orthis testudinaria*, Dalm., and *Plectambonites sericea*, Sow. Though the evidence is not very clear, this mass of limestone seems to dip landward, and to be separated by a thrust-plane or fault, with a low hade, from the volcanic series, whose general dip is, as mentioned above, seaward. A thrust- or fault-conglomerate of considerable width is seen at the junction between the limestone and the volcanic series, both to the east and north-east of the martello tower, while to the south-east it is not seen.

The volcanic series in the neighbourhood of this plane of thrust or fault is exceedingly disturbed, the evidence of crushing obtained in the field being corroborated by microscopic examination, which shows that, though no mineralogical reconstruction has gone on, yet displacement of the particles in the groundmass has occurred. South-east of the martello tower the general strike becomes more nearly north-north-east and south-south-west than north-east and south-west. Due south of the tower, exposed only at low tide, is a band of dark-grey earthy shales, apparently belonging to the volcanic series. This is indicated in the map (Pl. XLIII) by the term 'trilobite-shale,' and yielded

*Agnostus agnostiformis*, M'Coy.  
(=*trivodus*), Salt.

*Ampyx* sp.

*Asaphus radiatus*, Salt.?

*Cheirurus juvenis*, Salt.?

*Cybele*, sp.?

*Lichas laxatus*, M'Coy.

*Phacops Brongniarti*, Portl.

*Trinucleus seticornis*, var. *portrainensis*, var. nov.

*Orthis* sp.

*Hyolithus* sp.

*Glyptocystites* cf. *Logani*, Billings.

Owing to the thrust-plane or fault above mentioned, and a break in the continuity of the exposure in the sandy bay south of the tower, it is clear that no regular succession can be traced at the northern end of the Portraine section between the volcanic series as a whole and the limestone series.

As will be seen below, a well-marked thrust-conglomerate occurs at

two points on the coast south-east of the martello tower mentioned above, and, for reasons which we give, we consider it to be due to earth-movements. It was natural, therefore, that the idea should suggest itself that this conglomerate north of the martello tower, which we have just described, should be due to similar causes. But the observations which we made in the field and under the microscope forbade us maintaining that idea.

In the first place, there occur in the conglomerate the two bands of limestone and accompanying shale which we have mentioned. Now, if the conglomerate owed its existence to earth-movements, it is difficult to see how these thin bands of limestone and shale would have preserved their continuity and have shown such slight signs of being greatly squeezed and fractured, while hard igneous rocks and compact ash-beds were broken up into fragments.

The very definite nature of the blocks forming the conglomerate at different points is another objection to the idea. We have mentioned that the blocks are at first chiefly of the nature of ashes and limestones, while at the top of the conglomerate they are largely of the nature of porphyrites and andesites. The bed on which the conglomerate rests is an andesite, yet very few blocks of andesite are found in the lower parts of the conglomerate. No squeezing or drawing out of the blocks is to be seen in the main mass of the rock. Microscopic investigation points in the same direction. No mineralogical alteration is apparent, though this is not a point on which much stress can be laid, considering the very slight traces of such alteration that can be observed in the undoubted thrust-conglomerates along the coast. But the microscope does not reveal either any such crushing or drawing out of the materials of which the groundmass is made as might be expected if this were a thrust-conglomerate. The groundmass is seen to be of the nature of an ash, being formed of angular fragments of lavas.

It is true that near the martello tower disturbance does begin to be visible, and the finer beds overlying the conglomerate show signs of bending, but this phenomenon appears to be very local and to be connected with the movement which brought the limestone-and-shale series under the martello tower into its present position.

If the conglomerate were due to earth-movements, it is difficult to see why the overlying bands of limestone and ash were not bent and fractured, so that a passage between the two beds could be observed.

These are the most important reasons that led us to conclude that this conglomerate is not one due to earth-movements, but is a sedimentary conglomerate, with a matrix largely made up of angular fragments of lava.

#### IV. THE IGNEOUS ROCKS AT THE SOUTHERN END OF THE INLIER.

##### (a) Those exposed along the Shore.

At the southern end of the area, near the southern martello tower, igneous rocks are again exposed on the foreshore. These rocks are

similar in character to the igneous rocks described above, though they are much altered, and, especially to the south-west of the tower, are cleaved and much veined with quartz.

The rocks south of the tower were mapped by the officers of the Geological Survey as ash; but, though some ash perhaps occurs, they consist mainly of altered lavas. North of the tower they are certainly all lavas. In the field they are seen to be green and purple rocks, the most marked type being a coarse porphyrite with a purple groundmass and large green porphyritic feldspars. This is described by the Geological Survey as being faulted against the rocks to the south, the latter being also described as altered when they come in contact with the coarse rock, but we found no evidence of either the fault or the alteration.

Sections of these rocks show a prominent groundmass, as a rule much altered, but showing small acicular feldspars and generally much iron ore; ilmenite and magnetite are most plentiful, but hæmatite and pyrites are sometimes abundant, while chalybite occurs in one slide. The porphyritic constituents are (1) feldspars, probably labradorite, generally replaced partly or wholly by epidote, calcite, or chlorite—the alteration having gone so far that sometimes it is barely possible in polarized light to distinguish between the porphyritic feldspars and the groundmass; and (2) augites, also much altered.

In many of the rocks calcite has come in largely, and often permeates the groundmass as well as fills the vesicles. Other vesicles are filled with chlorite or with chlorite and quartz, while some contain a mineral which is probably serpentine.

The lavas, then, are, like those at the northern end of the section, mainly augite-andesites.

The junction between the igneous and sedimentary rocks is seen in the sandy bay south of St. Kenny's Well; its character is not clear, but it is probably a faulted junction, like that between the igneous and sedimentary rocks at the northern end of the section. It will be described more fully in dealing with the sedimentary rocks.

### (b) Those exposed Inland.

The igneous rocks at the southern end of the section exposed inland occur in the neighbourhood of Balcarrick House. They consist of augite-andesites, sometimes amygdaloidal, and similar in the main to those forming the foreshore, but often in a much fresher condition, the porphyritic augites being in some cases specially well preserved. In the groundmass, too, fresh augite-granules are well seen, and some of the rocks are more nearly holocrystalline than are any of those on the foreshore. One rock, grey-green in colour, with numerous large augites visible in a hand-specimen, occurs in the farmyard of Balcarrick House; this rock, under the microscope, is seen to have a not very prominent groundmass, somewhat decomposed, but still showing small feldspar-needles and augite-granules. Scattered about in this groundmass are numerous porphyritic

felspars, now so much replaced as to show no trace of twinning, and also many very fresh porphyritic augites of large size. A little chloritic material has come in, filling up vesicles.

In the 1-inch Geological Survey map the igneous masses at the northern and southern ends of the section are connected by a strip of igneous rocks running along the north-western boundary of the inlier. No trace of this is to be seen now, that part of the country being drift-covered, though round the Pigeon House are several exposures of ashy shales and calcareous ash.<sup>1</sup>

## V. THE LIMESTONE SERIES.

### (a) The Coast-section North of the Grits.

The limestone series is exposed along the coast from the northern martello tower on the north to Priest's Chamber on the south, a distance of about  $\frac{1}{3}$  mile in a straight line, though if the indentations of the coast be followed the distance would be far greater.

Owing to the enormous amount of faulting and folding to which the beds have been subjected, it is impossible to ascertain their thickness with accuracy, but the general succession from above downward is:—

3. Thin-bedded limestone with shaly partings.
2. Beds of compact, grey, crystalline limestone with many fossils.
1. Thin-bedded limestones with shaly partings, the upper beds being in places crowded with corals, while the lower beds become more shaly.

The beds may best be described by following the coast-exposure in some detail, and understood by referring to the section (Pl. XLII).

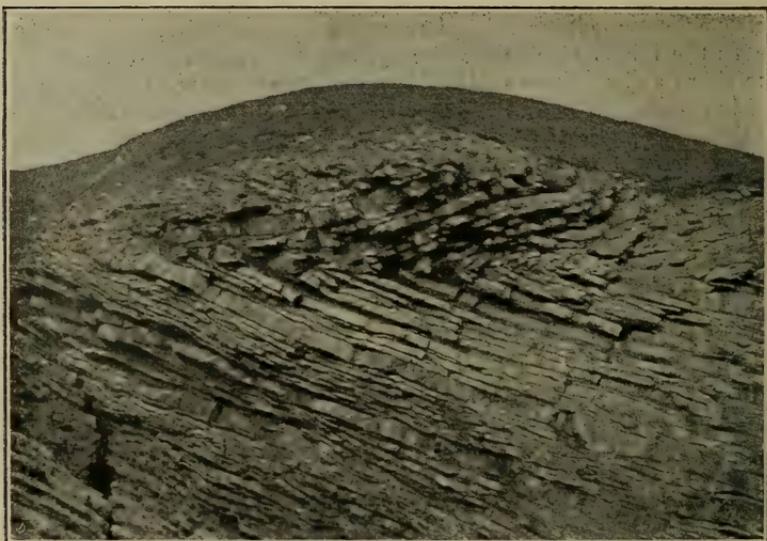
The most northerly exposures are two knolls of black fissile shales which project into the sandy bay south of the northern martello tower. They are considerably crushed and contorted, but have yielded obscure traces of graptolites, are probably bounded by faults on either side, and are succeeded on the southern boundary of the bay by brown shales with thin limestone-bands. These beds are very much faulted, crushed, and folded (see fig. 2, p. 528), and every stage can be traced between a continuous limestone-band and one which has been broken up into small rounded fragments, so as to present precisely the appearance of a conglomerate. To this type of rock we propose to restrict the term 'crush-conglomerate,' applying the term 'thrust-conglomerate' to a conglomerate formed along a thrust-plane.

In spite of the disturbance to which these beds have been subjected, remains of fossils (crinoids and corals) can be detected in the limestone.

Before long the shales become less plentiful, and the series passes up into a fairly compact band of limestone, perhaps 30 feet thick, and having an easterly dip. This bed forms the coast till close to

<sup>1</sup> In a small excavation in the railway-cutting immediately south of Donabate Station, about 2 miles to the west, we saw an exposure of a very coarsely porphyritic rock with a green groundmass and large white porphyritic felspars.

Fig. 1.—*Overfolded Bala Limestone and Shale.* (Close to the spot marked *C* in the map, Pl. XLIII.)



[From a photograph by Mr. S. H. Reynolds.]

Fig. 2.—*Limestone-and-shale bands, beginning to be broken up by pressure, in the bay south of the northern martello tower.*



[From a photograph by Mr. H. Preston.]

the end of the point south of the Old Limekiln. Here thin-bedded limestones with shaly partings come on again below the compact bed, and, as might be expected, the signs of disturbance become more marked, the thin bands of limestone being often crushed so as to form what look like bands of nodules or pebbles embedded in shale, while excellent examples of overfolding may be seen (see fig. 1). At the head of the bay, south-west of the Limekiln, the limestone is traversed by two or more faults and shows signs of much disturbance; but at the western end of this bay the beds are undisturbed, and consist of thin regular bands of limestone alternating with shales.

Resting upon these limestones and shales we again find the compact limestone, which is here very hard and forms a prominent rampart-like mass at the top of the cliff. This bed and the underlying shaly limestone occupy the coast as far as the next point, and it is along here that the limestone has proved most fossiliferous. A small quarry has been opened at the top of the cliff in the compact limestone, at the spot marked C in the map (Pl. XLIII), and from it we obtained the fossils enumerated in the Appendix (p. 535). Of these, *Cheirurus bimucronatus*, *Pseudosphærexochus subquadratus*, *Sphærexochus mirus*, *Cybele rugosa*, *Trinucleus seticornis*, and *Stawocephalus* are worth mentioning here. A portion of this limestone was dissolved in acid, and 4·3 per cent. of it was insoluble: this residue, when examined under the microscope, being seen to consist chiefly of small pieces of pumice and a little pyrites.

The limestones interbedded with shales are at this spot crowded with corals, excellent specimens of which, weathered out by the sea, were readily procured. *Halysites catenularia* and *Heliolites megastoma* were the most numerous forms, and a complete list is given in the Appendix. From the abundance of coral life which existed here one is justified in regarding this as a coral bank.

The next small bay is divided into two by a tongue of rock, through the landward end of which the sea has forced a passage. The signs of disturbance here are very great indeed. The more northerly of the two little bays shows interbedded shale- and limestone-bands, all much crushed, the rock showing an excellent overfold at one place. The Point is also formed of these much-crushed limestones, the bands being so much broken and the resulting fragments so much rounded as to form a crush-conglomerate, this being especially well seen below high-water mark on the south-western side of the tongue of land mentioned above.

Here, too, a compact grey limestone is seen underlying the shaly limestone, but it did not prove fossiliferous.

The more southerly of the two portions of the small bay is cut into much disturbed beds of limestone and shale, but at its south-western boundary the compact limestone again comes on, being separated from the limestone and shale by a wedge-shaped mass of a conglomerate formed of limestone-pebbles, all much rounded, in a calcareous matrix—obviously a conglomerate due to earth-movements.

Greatly disturbed limestone, with a mass of shale faulted in, occupies the coast by the next little inlet up to the succeeding point; but there we again come upon compact limestone which occupies the next projecting part of the coast; and finally, as one reaches the little bay known as Priest's Chamber, the compact limestone is overlain by bedded limestones with shaly partings, and this becomes more and more disturbed, passing into a thrust-conglomerate which, as we mentioned before, occurs here at the junction of the limestone with the grit series.

### (b) The Coast-section South of the Grits.

Limestone-beds are exposed along a strip of coast, some 250 yards long, south of the grits in the sandy bay near St. Kenny's Well. They are not nearly so calcareous as the beds just described, but are of the nature of soft argillaceous limestones. It is due to this fact, no doubt, that they have been so much denuded away, and that they are now only exposed in isolated patches projecting through the sand.

The lowest beds are exposed at low tide at a spot about 150 yards S.S.E. from the Gamekeeper's Lodge. They consist of calcareous shales, and rest on igneous rocks. The latter show signs of much crushing, while the former are cracked and veined with quartz, and this renders it probable that the junction is a faulted one. Other exposures of the rock occur, and it appears to pass up into a black limestone with shaly partings: this becomes nodular in its upper parts, and is separated from the grit series by a thrust-conglomerate, as is the case with the limestones of Priest's Chamber. The dip of these limestones is about  $30^{\circ}$  S.E. No fossils were found in them.

### (c) Exposures Inland.

South-west of the northern martello tower are several exposures of calcareous rocks, most of them close to the Pigeon House and the Tower which have been built in the Deer Park. Though limestone-bands interbedded with shales occur, the majority of the exposures are in calcareous or shaly ashes.

Some of these ashly limestones contain perfectly-rounded pebbles of compact andesites, light green in colour. South-west of the Pigeon House occurs a fossiliferous limestone with included fragments, resting on a calcareous ash which overlies a calcareous conglomerate containing corals; all these beds dip at a high angle ( $? 60^{\circ}$ ) to  $10^{\circ}$  south of east. A calcareous conglomerate also occurs near the Tower itself, and under it are limestones with shaly partings and ash-bands, dipping at about  $45^{\circ}$  S.E.

The Pigeon House is built on coarse ashes, but nodular and shaly limestones occur here also. The fossils which were found in these calcareous beds indicate that their age is the same as that of the limestones of the shore, and there can be no doubt that we are dealing here with lower beds of the same series.

## VI. THE GRIT SERIES.

Between Priest's Chamber and St. Kenny's Well, a distance of about 600 yards, the coast is formed of green and brown grits and slates, which dip, on the whole, E. 20° S., but roll slightly. The coast-line in the main follows the strike, and only about 220 feet is seen. There is a marked discordance, as observed by the officers of the Geological Survey, between the dip of the series and the dip of the cleavage of the interbedded slate-bands. These beds yielded no fossils, and are separated by a mass of thrust-conglomerate from the underlying limestone series, so that we have no direct evidence of their age, but their resemblance to the grits and slates which occur near Balbriggan, some 8 miles to the north, is worth noting. These latter beds contain bands of black slate yielding *Monograptus Becki*, *M. triangulatus*, *M. Hisingeri*, *M. jaculum*, *Diplograptus tamariscus*, and *Petalograptus palmeus*, and apparently therefore belong to the Middle or Lower Birkhill Series.<sup>1</sup>

Two small exposures of grit occur a short distance inland, and the spring at St. Kenny's Well is probably thrown out at the base of the series.

## VII. THE CONGLOMERATES DUE TO EARTH-MOVEMENTS.

The strip of coast which we are describing has been subjected to so much disturbance that conglomerate-like rocks produced by earth-movements occur almost wherever the lithological character of the beds admits of their being formed.

These beds, as already noted (p. 527), we divide into two classes: (a) crush-conglomerates and (b) thrust-conglomerates.

The crush-conglomerates, in this area, are those formed by the separation of a bed of limestone into parts, the parts having been subsequently rounded. All stages in the formation of such beds may be traced. Compact bands of limestone may be seen, at first cracked, but not displaced; then, a short distance farther along, the cracks become more obvious; and at length the portions of what must have been a continuous band have become separated one from another by a gap, now filled with the shaly material derived from the shale-bands above and below.

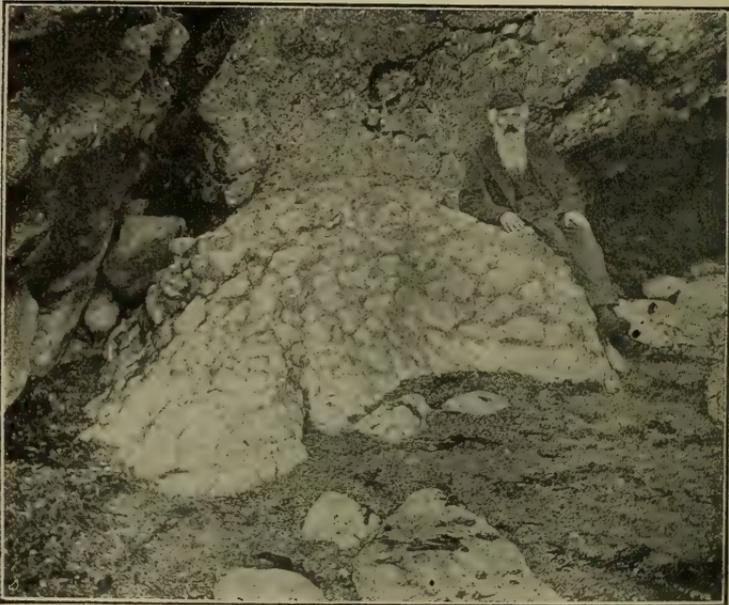
It is very clearly seen on the south side of the bay, just south of the northern martello tower, that where the bands of limestone differ in thickness the wider bands, here about 10 inches thick, have merely been cracked, their portions having suffered no displacement; while the intermediate bands have not only been fractured, but their fragments have undergone a certain amount of displacement; and the narrower bands, here some 2 or 3 inches thick, have been cracked, and their fragments are now separated by several inches of shale. These fragments are now thoroughly rounded, and pre-

<sup>1</sup> These graptolites have been determined for us by Miss E. M. R. Wood and Miss G. L. Elles.

sent the exact appearance of limestone-pebbles embedded in shale; and were it not for the gradation, visible at so many points, between the uneracked limestone and these beds of limestone-pebbles, the origin of the latter would be hard to prove.

The shale-bands intervening between the limestone-bands also show signs of disturbance—cracks, now filled with infiltrated material, being numerous. This, too, is evidence of the agent which has probably brought about the present rounded form of the originally angular fragments of the limestone-bands. There can hardly have been sufficient friction between the limestone-fragments and the

Fig. 3.—*Thrust-conglomerate at Priest's Chamber.*



[From a photograph by Mr. H. Preston.]

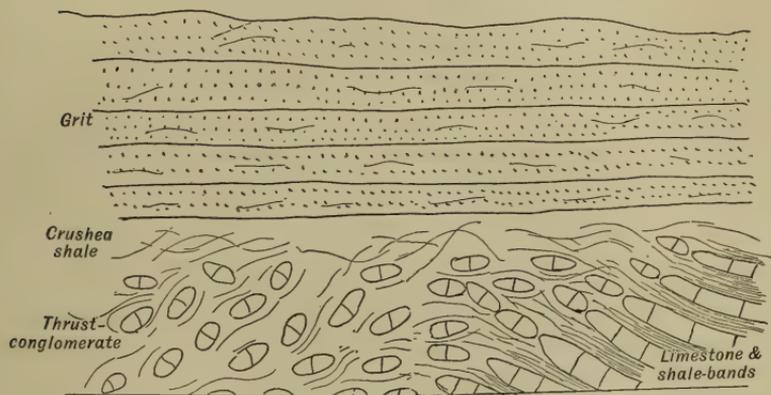
shale to bring about the rounded appearance of the latter, and it is to the dissolving agency of infiltrating water that one must look to explain the rounded appearance of the fragments. This type of conglomerate due to earth-movements may be seen frequently along the coast; but the other type, namely, the thrust-conglomerate, is to be seen only at the places where the thrust-plane between the grit series and the limestone series is visible, that is, at Priest's Chamber and near St. Kenny's Well.

The Point north-east of Priest's Chamber consists of compact limestone overlain by bands of limestone and shale, these bands being about 6 inches thick. They pass both laterally and vertically into shale interbedded with bands of rounded blocks of limestone,

and as Priest's Chamber is reached the rock becomes a thrust-conglomerate formed of well-rounded blocks of limestone and calcareous ash varying greatly in size, embedded in a matrix formed of fragments of the same material and of crushed shale (see fig. 3). Some of the blocks of ashy limestone contain uncrushed corals and brachiopoda, and sections from these blocks show under the microscope no straining or evidence of crushing.

Over this conglomerate lie the grits with much-crushed black slates at their base (see fig. 4).

Fig. 4.—Diagram of the cliff at Priest's Chamber, looking north-west.



It is an interesting fact that, both at this point and at others where the disturbance has obviously been very great, sections of the matrix, as well as sections from the included blocks, show very little sign of it. At Priest's Chamber the matrix is seen under the microscope to resemble, on the whole, the ashy limestone exposed inland in the neighbourhood of the Pigeon House, though traces of crushing are to be seen, and sericite is occasionally developed.

On the shore south of St. Kenny's Well there is a larger exposure of thrust-conglomerate, but no cliff-section. The uppermost beds of the limestone series consist here of calcareous shales passing up into a black limestone with shaly partings. The upper bands become nodular, and the series dips S.E. at about  $30^{\circ}$ . Above comes a bed chiefly composed of limestone-blocks sometimes a foot or more in length, and usually rounded and arranged in layers, the limestone of the blocks being similar to that of the underlying beds.

The matrix in which these blocks are embedded is sometimes an ordinary black shale, showing evidence of having been much crushed, and forming patches quite discontinuous one from another; but more often it is a crushed limestone or a crushed calcareous ash, sometimes containing much pyrites. We estimated the thickness

of this bed to be about 30 feet; it is sometimes overlain by a bed of a finer character, which, though it is to a considerable extent calcareous, contains no large limestone-pebbles, and is mainly made up of small fragments of lava and grit. Above this bed come the unaltered grits.

This thrust-conglomerate has obviously been formed by the thrusting of the grits over the limestone series; and the bulk of it has been derived from the latter, the tough grits not lending themselves readily to its production. The limestone before the disturbance must in some places have been of an ashy type, and in others have had shaly partings.

### VIII. SUMMARY AND CONCLUSIONS.

In spite of the break between the limestone and the igneous series, there seems to be sufficient evidence to prove the general succession of the rocks.

The igneous series, of which the lowest beds seen are of the nature of lava-flows, is overlain by a coarse ashy conglomerate, some of the blocks in which were derived from a neighbouring limestone, while others were derived from lava-flows and ash-beds. This bed becomes finer in texture as it is traced upward, and passes up into finely calcareous ash-beds with intervening bands of ashy limestone and shale, which have yielded fossils bearing a Middle Bala facies. One of the highest beds of the series is a bed of earthy shale which has yielded fossils, all of which occur in the Middle Bala of Great Britain.

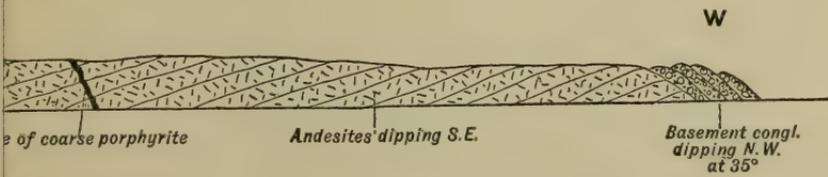
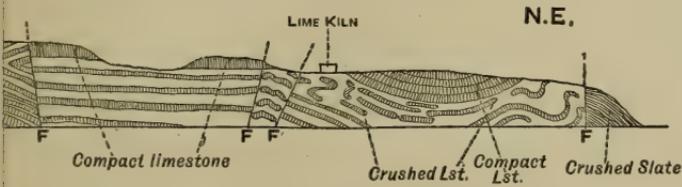
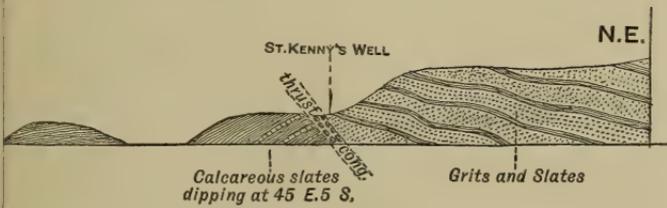
The limestone series has at its base many small bands of shale, and when the thick bands of limestone come on they are seen to be of a distinctly ashy type. The coral-bed in the series is shown by its fossils to be, in all probability, of Middle Bala age, and is covered immediately by the compact crystalline limestone, which, as noted in the Appendix (p. 538), is closely comparable to the Shoeshook Limestone of South Wales, and is mentioned by Mr. Cowper Reed as being very probably of Upper Bala age.

The succession, though broken, appears therefore to be obvious, the break having occurred in the ashy-calcareous rocks intervening between the ashy conglomerate and the limestone-beds, but how much of the ashy-calcareous rocks has disappeared there is no means of telling. There is also no evidence as to the former relation in time or in space of the grits between Priest's Chamber and St. Kenny's Well to either of the other two series.

The Portraine Limestone, though it has yielded no new species, is an important rock, and is comparable to the Chair of Kildare Limestone on the one hand, and on the other to the *Staurocephalus*-, Keisley, and Shoeshook Limestones of Great Britain.

The igneous rocks, in spite of their being much altered, show, though not so well as do those of Lambay Island, that there was an active vent in this neighbourhood—apparently in Middle Bala times. Where the exact situation of this vent was we have no evidence at

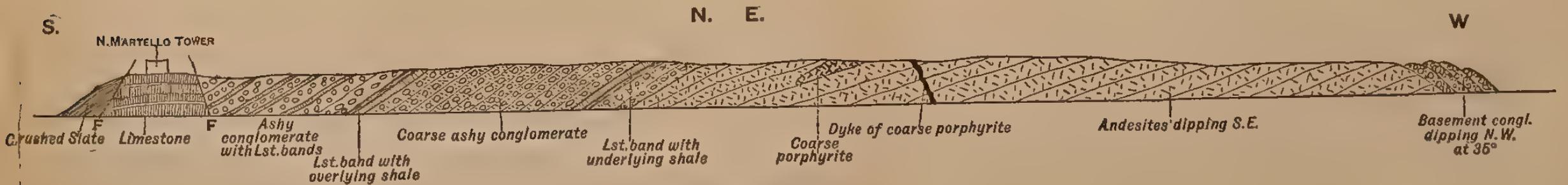
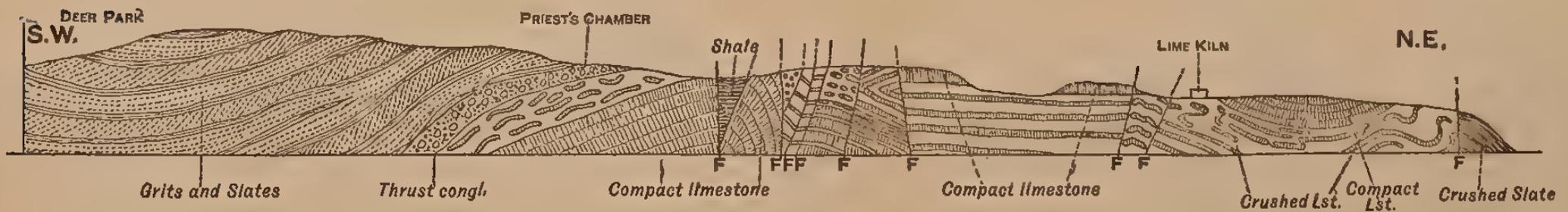
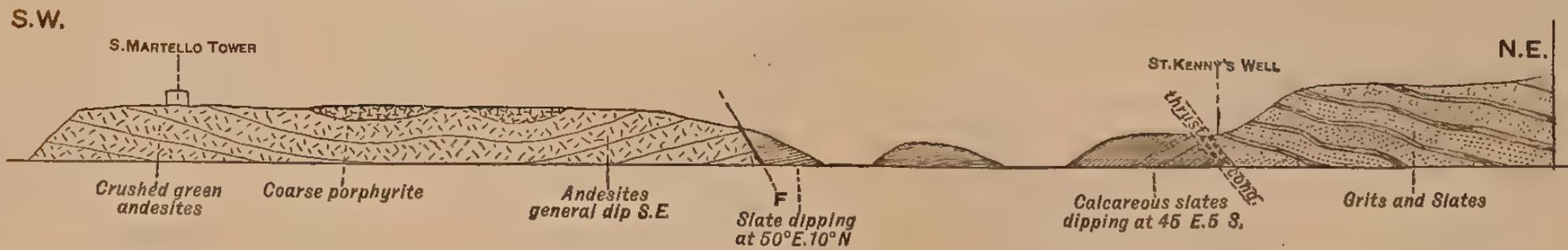
RAINE (Co. DUBLIN).



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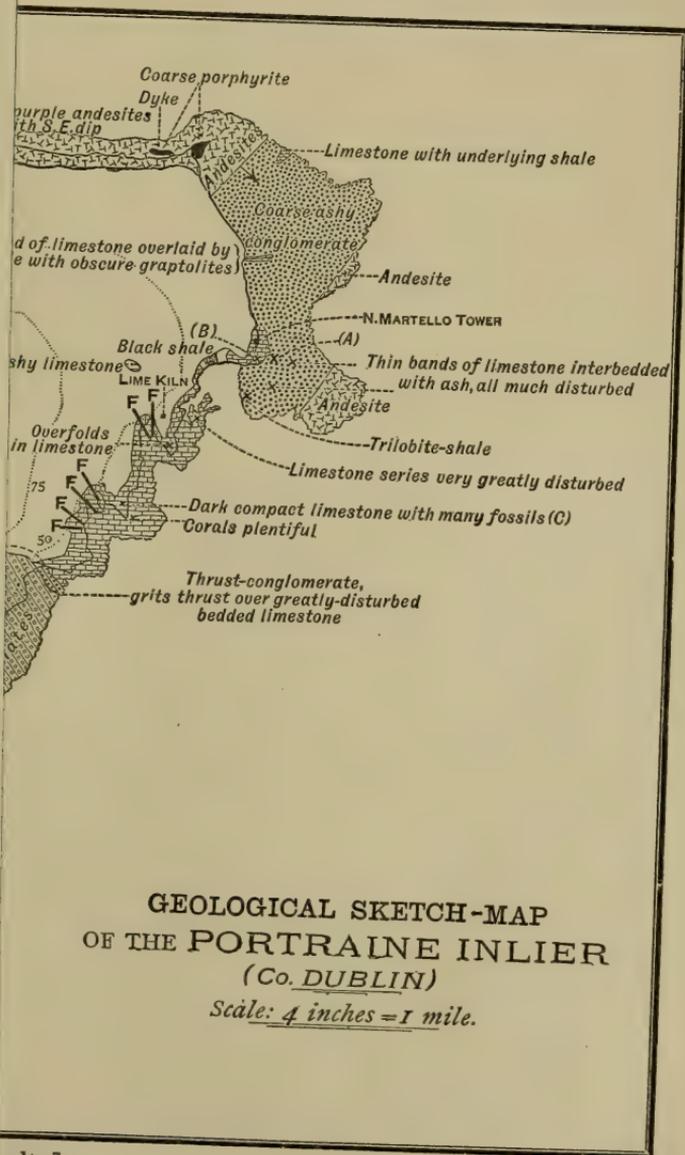


SECTION ALONG THE COAST, PORTRAINÉ (CO. DUBLIN).



[Scale: 12 inches = 1 mile.]





GEOLOGICAL SKETCH-MAP  
OF THE PORTRAIRIE INLIER  
(Co. DUBLIN)

Scale: 4 inches = 1 mile.

faults.]







Portrairie to show, but the coarse breccias and tuffs of Lambay Island seem to indicate that one of the centres of vulcanicity lay to the east.

While the interest attaching to these Bala beds and to their relation to English and Welsh rocks is great, the importance of the area as a whole is enhanced by the presence of rocks of a conglomeratic nature formed at a later date.

In a paper read before this Society in 1895 by Messrs. Lamplugh & Watts attention was drawn to crush-conglomerates in the Isle of Man, and there seem to be many points of resemblance between the Portrairie and the Isle of Man conglomerates. In both cases hard beds which occur among beds of shale have been cracked, pulled asunder, and converted into a conglomeratic deposit; in the one case these hard beds are formed of limestone, and in the other of sandstone. In both cases, too, shearing has taken place, and along the thrust-planes conglomerates have been developed. But the amount of actual deformation of the broken pieces of the hard beds at Portrairie seems to have been quite trifling when compared with that which has occurred in the Isle of Man, and this appears to be a very important point. The amount of mineralogical reconstruction seems also very small. Either the nature of the beds at Portrairie did not readily lend itself to alteration, or the time occupied in the formation of the conglomerate was long; and thus the heat engendered had time to be conducted away before the rocks had arrived at a sufficiently high temperature for mineralogical alteration. The occasional occurrence of sericite is the only evidence of mineralogical reconstruction due to the crushing.

In conclusion, we wish to express our sincere thanks to Mr. F. R. Cowper Reed, F.G.S., for his assistance in the identification of our fossils and for writing the Appendix to this paper. At the same time we would thank Miss Elles and Miss Wood for having identified our graptolites; Mr. Alfred Harker, F.G.S., for looking over some of our rock-sections; Mr. W. W. Watts, F.G.S., for having assisted us in many ways; and Mr. H. Preston, F.G.S., for having allowed us to make use of his photographs of the coast. We also gratefully acknowledge the kindness of the authorities of the Irish Geological Survey in giving us every facility for examining their collection of fossils.

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APPENDIX. By F. R. COWPER REED, Esq., M.A., F.G.S.

(a) Fossils from the Limestone at point C in the Map.

TRILOBITA.—The fauna of this limestone consists principally of trilobites, which both in species and individuals form the majority of the fossils. The following is the list of the trilobites, but the extremely fragmentary condition of most of the specimens rendered their identification a matter of much difficulty:—

*Calymene Blumenbachi*, Brongn.  
*Cheirurus bimucronatus*?, Murch.  
 — *juvenis*, Salt. (? *clavifrons*, Dalm.).  
 — [*Pseudosphærexochus*] *subquadratus*, Reed.  
*Cybele rugosa*, Portl., var.  $\alpha$ .  
 — —, var. *attenuata* nov.  
*Harpes*, 2 spp.  
*Illænus Bowmani*, Salt.  
 — —, sp.  $\alpha$ .

*Illænus Bowmani*, sp.  $\beta$ .  
 — —, cf. *oblongatus*, Ang.  
*Lichas* sp.  
*Remopleurides* sp.  
*Sphærexochus mirus*, Beyr.  
*Staurocephalus* sp.  
*Stygina latifrons*, Portl.  
*Trinucleus seticornis*, His.  
 — —, var.

Of the above the *Illæni* are the most abundant. Besides *I. Bowmani* there are fragments of a form (sp.  $\alpha$ ) possessing an ornamentation of small pits distributed with some regularity over the shell, with a very finely-punctated surface. But the specimens are too imperfect to determine the species.

Another form has the general appearance of *I. Bowmani*, so far as the fragments allow one to distinguish its characters, but the pygidium is seen to be bluntly pointed behind when the shell is removed and the cast of the under surface displayed to view.

The remaining form, represented by one imperfect pygidium in this collection, has the shape and prominent axis of *I. oblongatus* (Angelin), with which it may be compared; but it is not quite clear whether the specimen has not suffered crushing and distortion.

*Calymene Blumenbachi* and *Sphærexochus mirus* are represented by several pygidia and head-shields which call for no remarks.

*Trinucleus seticornis* of the typical Swedish form, without the long head-spines of *T. Bucklandi*, occurs in the limestone, so far as one can judge from portions of the fringe and general expansions. But in one specimen the three or four uppermost rows of pits on the convex portion of the fringe immediately in front of the glabella are situated in regularly radiating grooves, giving a very distinctive appearance to this part. In other respects the specimen resembles the typical *T. seticornis*, and can only be considered a variety of it.

*Cybele rugosa* appears to occur, for I can only regard the two imperfect pygidia of a *Cybele* as belonging to this species. In 'variety  $\alpha$ ' three pairs of small tubercles are situated on the axis, just at the inner termination of the incomplete transverse furrows which mark out the rings on the axis. This specimen closely resembles that figured by Nicholson & Etheridge in their 'Monograph of the Girvan Silurian Fossils' (pl. xiv. fig. 13); while var. *attenuata* has the long attenuated axis of M'Coy's figure ('Syn. Brit. Pal. Foss.' pl. i. c, fig. 8), but there are three pairs of small tubercles on the axis as in the other variety, and the ribs on the lateral lobes are narrower, except the outer one, which is flattened and pitted so as to give a somewhat wide margin to the upper part of the outer edge of the pygidium. Otherwise it is similar to M'Coy's figure. It may be designated as var. *attenuata*. Fragments of the head-shields of *Cybele* are abundant.

*Harpes* is represented by two fragments belonging to the punctated border of two species. The punctures in one specimen are much coarser and more irregular than in the other, which is uniformly covered with fine minute pits.

Of *Remopleurides* I have been able to identify only one portion of a free cheek and eye, of which the species is doubtful.

The species of *Cheirurus* are badly preserved, with the exception of *Ch.* [*Pseudosphærexochus*] *subquadratus*, one excellent specimen of which I have discovered.

*Staurocephalus* appears rare, but I have chipped out one specimen of the globate portion of the glabella. Whether it belongs to *St. Murchisoni* or *St. globiceps* is doubtful.

*Stygina latifrons* is represented by one pygidium.

#### ENTOMOSTRACA.

*Primitia M'Coyi*, Salter, occurs sparingly in this limestone.

#### BRACHIOPODA.

The following brachiopoda have been identified among the specimens handed to me. There are fragments of some others which, however, are much too imperfect for identification. But brachiopoda on the whole seem to be far from common; *Orthis biforata*, *Plectambonites sericea*, and *Rafinesquina deltoidea*, var. *undata*, are the most abundant species.

*Orthis biforata*, Schloth.  
 — *elegantula*, Dalm.?  
 — *testudinaria*, Dalm.  
 — —, var.  
*Plectambonites sericea*, Sow.

*Rafinesquina deltoidea*, Conr.  
 — —, var. *undata*, M'Coy.  
*Strophomena*, sp.?  
*Triplexia insularis*, Eichw.

#### MOLLUSCA.

*Bellerophon* sp.  
*Cyclonema* sp.

*Modiolopsis* sp.  
*Orthoceras audax*, Salter.

The only shell of which I am able to identify the species is *Orthoceras audax*, which is found at Rhiwlas, and probably at the Chair of Kildare.

POLYZOA. *Ptilodictya lanceolata*, Goldf.

ACTINOZOA. *Heliolites* sp. and *Halysites* sp.

This species of *Heliolites* resembles, in the paucity of cœnenchymal tissue, etc., the description and figures of *Palæopora* [*Lyopora*] *favosa*, M'Coy, in M'Coy's 'Synopsis of British Palæozoic Fossils' (pl. i. c, fig. 3, p. 15), but Nicholson & Etheridge have declared M'Coy's account to be apocryphal. The larger corallites are, moreover, smaller and closer together than in typical specimens of *L. favosa* from Scotland.

CONCLUSION.—The fauna of this limestone has undoubtedly a Bala facies, but judging from the presence of *Stygina latifrons*, *Pseudosphærexochus subquadratus*, *Trinucleus seticornis*, *Cybele rugosa*, and species of *Remopleurides*, *Harpes*, *Staurocephalus*, and *Primitia M'Coyi*, I should be inclined to associate it more closely with the

*Staurocephalus*-, Chair of Kildare, and Keisley Limestones, and especially with the Shoeshook Limestone of South Wales, than with the typical Middle Bala. So that, on the whole, its horizon may be with much probability considered to lie near the base of the Upper Bala.

- (b) Fossils from the Limestone-bands immediately beneath the Compact Limestone from which the preceding were obtained.

The whole fauna appears to consist of corals, most of which are in an inferior state of preservation.

<i>Favosites aspera</i> , d'Orb.	<i>Lindstræmia</i> sp.
<i>Halysites</i> cf. <i>escharoides</i> , Lam.	<i>Stenopora fibrosa</i> , Goldf.
— <i>catenularia</i> , Linn.	<i>Streptelasma europæum</i> , Röm. ?
<i>Heliolites megastoma</i> , M'Coy.	—, 2 spp.
— sp.	<i>Cybele</i> sp.
<i>Lindstræmia subduplicata</i> , M'Coy.	

The Middle Bala facies is obvious.

- (c) Fossils from the Grey Shales marked in the Map as Trilobite-Shales.

These fossils are poorly preserved. By far the most abundant form is *Trinucleus seticornis*, var. *portrainensis*.

#### TRILOBITA.

<i>Agnostus agnostiformis</i> , M'Coy (= <i>trinodus</i> , Salt.).	<i>Cybele</i> sp. ?
<i>Ampyx</i> sp.	<i>Lichas laxatus</i> , M'Coy.
<i>Asaphus radiatus</i> , Salt. ?	<i>Phacops Brongniarti</i> , Portl.
<i>Cheirurus juvenis</i> , Salt. ?	<i>Trinucleus seticornis</i> , var. <i>portrainensis</i> nov.

BRACHIOPODA. *Orthis* sp.

MOLLUSCA. *Hyolithus* sp.

ECHINODERMATA. *Glyptocystites*, cf. *Logani*, Billings.

The general facies of the fauna appears to indicate a lower horizon than the limestone at the spot marked C. None of the species are characteristic Upper Bala forms, and nearly all occur in the Middle Bala of Great Britain.

TRINUCLEUS SETICORNIS, His., var. PORTRAINENSIS NOV.

Head-shield as in the type-form of Hisinger's species, with the exception of the limb. Genal angles of limb flattened out, and not produced backward behind the head, as in the type-form. Limb divided in front into two parts by an encircling striated groove, but not so markedly as in the type-form.

On the inner portion of the flattened expansions of the limb at the

genal angles, the pits are arranged as in the type-form, but the pits in the two outer concentric rows lie in short, regular, radiating grooves with intervening ridges, thus resembling *Tr. fimbriatus*, but differing therein that the grooves do not extend to the edge of the limb.

In front of the glabella the pits of the three outer rows lie in these radiating grooves, but behind them, and also on the upturned portion of the limb, lie one or two independent rows of pits not in grooves. In front of the glabella and cheeks the inner convex portion of the limb also has three or four concentric rows of pits arranged in similar radiating grooves, as in the variety of *Tr. seticornis* from the limestone at the spot marked C.

#### EXPLANATION OF PLATES XLII & XLIII.

##### PLATE XLII.

Section along the coast, Portrairie (Co. Dublin), on the scale of  
12 inches to 1 mile.

##### PLATE XLIII.

Geological Map of the Portrairie Inlier on the scale of 4 inches to 1 mile.

#### DISCUSSION.

Mr. LAMPLUGH was, in the main, able from personal observation, under the guidance of Mr. McHenry, to corroborate the Authors as to the effect of earth-movement in these sections. The readiness of the thin-bedded limestones to break up into crush-conglomerate was striking. In areas affected by shearing, he thought that the origin of every conglomerate should be carefully investigated, and was glad to find that this was the attitude of the Authors. Though the lower ashy conglomerate might have been an originally fragmental deposit, he thought that it had undergone some subsequent modification. To distinguish between the original and the superimposed structure in such cases was, as he knew by experience, difficult. He doubted whether the distinction drawn by the Authors between crush-conglomerate and thrust-conglomerate could be generally maintained.

Mr. W. W. WATTS also spoke, and Mr. C. I. GARDINER replied.

36. *The CRETACEOUS STRATA of COUNTY ANTRIM.* By DR. W. FRASER HUME, F.G.S. (Read June 9th, 1897.)

[PLATES XLIV & XLV.]

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I. INTRODUCTORY AND DESCRIPTIVE.

ALTHOUGH, during the last twenty years, the Upper Cretaceous strata of England and the Continent have been the objects of detailed investigation, the deposits of the same age, which form so conspicuous a feature in the North-east of Ireland, have been practically neglected. Two observers only, Prof. R. Tate<sup>1</sup> and Dr. C. Barrois,<sup>2</sup> have seriously attempted to classify these formations on definite palæontological principles, but the results at which they respectively arrived differ in several material particulars. The present paper is the outcome of two excursions carried out in the summers of 1895 and 1896: the first connected with, and following on, the Geologists' Association's visit to County Antrim, under the guidance of Mr. A. McHenry; the second aiming at a more detailed examination of the stratigraphy of the same district. The first and second parts will be devoted to the consideration of the various sections visited, together with an account of the results obtained by applying the methods of analysis and microscopical examination previously employed by me in considering the Upper Cretaceous zones of the South of England. In the third and fourth parts it is proposed to examine the theoretical questions arising out of these researches, dealing with the zonal classification of the Irish Cretaceous strata, the probable distribution of the land-masses, and the sequence of physical changes during the period under consideration.

<sup>1</sup> Quart. Journ. Geol. Soc. vol. xxi. (1865) pp. 15-44 & pls. iii.-v.

<sup>2</sup> 'Recherches sur le Terrain Crétacé Supérieur de l'Angleterre et de l'Irlande,' Lille, 1876.

My thanks are due to the following members of the Belfast Naturalists' Field Club, who have freely placed their local knowledge and experience at my disposal:—Miss Sydney Thompson; Mr. A. McHenry, M.R.I.A.; Mr. S. A. Stewart, F.L.S.; Mr. W. Swanston, F.G.S.; Mr. J. St. J. Phillips; Mr. R. S. Bell; and Mr. McLean. Messrs. A. Smith Woodward, F.G.S.; G. C. Crick, F.G.S.<sup>1</sup>; A. J. Jukes-Browne, F.G.S.; R. B. Newton, F.G.S.; Dr. J. W. Gregory, F.G.S.; Dr. G. J. Hinde, F.R.S.; and Mr. F. Chapman, A.L.S., have also rendered valuable special assistance in the examination and identification of the organic remains, the last-named contributing a special report on the foraminiferal casts. I am also much indebted to Prof. J. W. Judd, C.B., F.R.S., for enabling me to carry out my chemical and microscopical work in the Research Laboratory of the Royal College of Science, and for having placed the whole of his Irish collection at my disposal.<sup>2</sup>

It will not be necessary to recapitulate the results arrived at by writers previous to the year 1865, as this has already been done by Tate and Barrois in the works previously referred to. Tate was the first to clearly recognize the lithological divisions of the Cretaceous system as they are developed in the neighbourhood of Belfast, and seeing that these will be constantly referred to in the sequel, it may be convenient to define them at once. They are in descending order:—

1. White Limestone or Hard Chalk.
2. Chloritic Chalk.
3. Chloritic Sands and Sandstones.
4. Grey Marls and Yellow Sandstones with Chert.
5. Glauconitic Sands.

The White Limestone is practically a hard white chalk, in general containing well-marked layers of flint.

The term 'Chloritic Chalk' has become so well established in the literature of the subject that to attempt to alter it would tend to confuse rather than to simplify the nomenclature. At the same time, it must not be forgotten that the green grains in the rock which were formerly believed to be chlorite would probably now be classed with glauconite. Typically, Chloritic Chalk is a pink-coloured limestone, having minute green grains of glauconite scattered through it.

The 'Chloritic' Sands and Sandstones are among the most variable members of the series, and are thus described by Tate (*op. cit.* p. 23):—'The beds between the Grey Marls and the White Limestone are generally siliceous sands in a calcareous paste, and contain disseminated chloritic grains. The compactness of this zone

<sup>1</sup> To Mr. Crick I am especially indebted for assistance in the examination and identification of the cephalopoda mentioned in this paper, most of the notes appended on this subject being the result of my conversations with him.

<sup>2</sup> For the beautiful photograph of the conglomerate at Murlough Bay I have to express my hearty thanks to Mr. J. R. Welch, of Belfast.

varies with the locality. On the whole, I find that, in ascending the bed, it becomes more and more compact, by the predominance of the calcareous paste, and the siliceous and chloritic elements become less and less in amount, finally passing up insensibly into the condition of a white compact limestone.' Apart from the use of the term 'chloritic' instead of 'glaucinitic,' the above description accurately states the character of this interesting set of beds.

The Yellow Sandstones are normally of a brown to yellow colour, frequently containing well-marked bands of chert. Marly layers may occur throughout, but are especially developed at the base.

Finally, the Glaucinitic Sands are of a deep green colour, and in many localities mainly consist of glaucinitic grains.

Tate further subdivided the lithological divisions into zones which were named after the characteristic fossils. Thus the White Limestone became the zone of *Ammonites gollevillensis*, while the Chloritic Chalk included a Spongiarian zone and that of *Ananchytes gibbus*, a band containing the latter species being taken as the base of the Upper Chalk or Senonian.

On the other hand, the Chloritic Sands (including the two zones of *Exogyra columba* and *Inoceramus Crispi*), the Yellow Sandstones (zone of *Ostrea carinata*), and the Glaucinitic Sands (zone of *Exogyra conica*) were all classed as members of the Cenomanian. The general conclusion, therefore, is that a palæontological hiatus must have existed between the Chloritic Chalk and Chloritic Sands: the whole of the Turonian, and a good part of the Senonian beds being unrepresented in the series.

Barrois re-examined the strata in the light of his researches on the English Cretaceous zones, and came to the conclusion that the Turonian, or Middle Chalk, was clearly represented in the Irish district, certain bands, rich in *Inoceramus*-fragments, being especially characterized by Turonian fossils. These, according to him, showed the existence of the higher zones, namely, *Holaster planus* and *Terebratulina gracilis*, that of *Inoceramus labiatus* being unrepresented. He further believed all the Senonian divisions to be present, whereas Tate placed the zone of *Ananchytes gibbus* on a level with that of *Belemnitella quadrata*, in the Upper Senonian. The zones of *Ostrea carinata* and *Exogyra conica* were referred by him to the Cenomanian.

Neither of the two authors above mentioned have made any reference to the remarkable conglomerates which form the base of the White Chalk where the latter rests upon beds of more ancient date, such as the Trias, Carboniferous, or metamorphic rocks of a still older period (mica-schists, etc.). These beds were recognized and carefully examined by Portlock.<sup>1</sup> He also divided the Cretaceous

<sup>1</sup> 'Report on Geol. Londonderry, etc.' 1843. See especially pp. 115 & 749, and generally pp. 90-140, where many references to the White Chalk and its subjacent beds will be found.

into three subdivisions: (1) the Upper Chalk, (2) the Lower Chalk, (3) the Arenaceous or Glauconous or Greensand; but under these names are included beds, mainly of Senonian age, which differ chiefly in their lithological characters. The officers of the Irish Geological Survey have recorded these from many localities, as at Slieve Gallion, in county Derry, and at Murlough Bay, near Ballycastle.

In the Irish Survey Memoirs 7 & 8, by Symes, Egan, & McHenry; 12, by Nolan & Egan; 14, by Symes & McHenry; 18, by Nolan & Egan; 20, by Symes; 21, 28, & 29, by Prof. E. Hull; 27, by Egan; and 36, by Hull, Warren, & Leonard, the lithological characters of the rocks are discussed and the nature of their distribution considered in some detail, but otherwise no important information is added to that given in the previously quoted works.

In the Proceedings of the Belfast Naturalists' Field Club, 1876-77, pp. 251-262, Mr. W. Gault, a local collector, expressed his views on the Cretaceous beds of the district south of Belfast. This paper, while arriving at conclusions with which, on many points, the present writer finds himself in accordance, cannot be trusted always, so far as the identification of fossils is concerned. The association of *Belemnitella mucronata*, *Actinocamax* [*Belemnitella*] *plenus*, *Ammonites* [*Acanthoceras*] *rotomagensis*, and *Micraster* spp., in the same beds may be cited as an example of the need of caution in considering the bearings of the paper. The most important points raised in it are the recognition—firstly, of the zone of *Ecogyra columba* as being of Upper Greensand age, and, secondly, of the existence of an unconformity between the above and the *Inoceramus Crispi*-zone.

The present state of our knowledge may be summarized in tabular form, as shown on p. 544.

In the first part of the present paper a detailed description will be given of the principal exposures of the Cretaceous in County Antrim, most of which have been personally inspected. Much obscurity has undoubtedly arisen, owing to the fact that previous writers have laid but little stress on the local variations which form a marked feature in connexion with these strata.

It appears to me that five divisions, in each of which the Cretaceous rocks exhibit peculiar characters, are clearly marked out, and these will be considered in turn. They are:—

1. A Southern Division, extending from Magheralin, 16 miles south of Belfast, to the north of Lisburn.

2. A Central Division, continuing the above from Colin Mountain, 5 miles south of Belfast, to a little north of that city.

3. An Eastern Division, including Islandmagee and all the exposures from Larne to Cushendall. Woodburn Glen, near Carrickfergus, occupies an intermediate position between this and the previous division.

4. North of Cushendall, and passing westward into Derry, is a great series of ancient rocks, from pre-Devonian to Trias, which

Formations.	Succession of Cretaceous Zones in England, etc.	Classification (Zonal) according to Tate.	Lithological Classification under Zones (Barrois).
MABTRICHTIEN.		Upper part of White Limestone.	
SENONIAN.	<i>Belemnitella mucronata</i> , <i>Belemnitella</i> [ <i>Actinocamax quadrata</i> ], <i>Belemnitella</i> [ <i>Actinocamax vera</i> or <i>Marsupites</i> ], <i>Micraster cor-anginum</i> , <i>Micraster cor-testudinarium</i> .	{ White Limestone = <i>Ammonites gollevillensis</i> , Spongiarian Zone, Zone of <i>Anachytes</i> [ <i>Echinocorys gibbus</i> = Chloritic Chalk, Absent.	White Limestone with flints. (Not recognized.) White Limestone with flints. } Chloritic Chalk.
TURONIAN.	<i>Holaster planus</i> , <i>Terebratulina gracilis</i> , <i>Inoceramus labiatus</i> .	Absent.	{ Chloritic Sands and Sandstones = <i>Exogyra columba</i> and <i>Inoceramus Crispi</i> of Tate. Absent.
CENOMANIAN.	<i>Ammonites</i> [ <i>Acanthoceras rotomagensis</i> ], <i>Ammonites</i> [ <i>Schlaubachia varians</i> ], <i>Stauronema Carteri</i> .	Chloritic Sands = <i>Exogyra columba</i> and <i>Inoceramus Crispi</i> -zones.	} Grey Marls and Yellow Sandstones.
UPPER GREENSAND.	<i>Pecten asper</i> , <i>Ammonites</i> [ <i>Schlaubachia inflatus</i> ].	Yellow Sandstones = Zone of <i>Ostrea carinata</i> , Glauconitic Sands = Zone of <i>Exogyra conica</i> .	Glauconitic Sands. Absent.

appears to have formed a prominent peninsula or island during the major portion of the Cretaceous period. The Chalk strata connected with this peninsular or insular region will be dealt with under the Peninsular Division.

5. Finally, a Northern Division will include the Cretaceous strata which are developed on the northern and north-eastern coast of Co. Antrim, extending from west of Portrush to Ballycastle.

### (1) THE SOUTHERN DIVISION.

#### From Magheralin to Kilcorrig.

The White Limestone is exposed in numerous quarries and may be well studied at Magheralin, at Soldierstown, near Moira, and at Kilcorrig, near Brookmount. It consists of a compact hard chalk, in which flattened flints are arranged in regular layers, generally separated by intervals of 4 to 5 feet. At Soldierstown, in the quarry situated farthest from the road, occurs a very fine example of the 'paramoudras' of Buckland. At this locality five of these barrel-shaped or pear-shaped potstones, about 18 inches in height and a foot in diameter, form a vertical series, the lowest rising from a bed of flint below, while the highest is cut off at the next succeeding flint-layer. They are pierced from end to end by a broad tubular canal, which has subsequently become filled with calcareous sediment. It was in this district that Buckland first met with these remarkable bodies, which Sollas regards as the Cretaceous representatives of the recent sponge *Poterion patera*, Hardwicke, and has consequently named them *P. cretaceum*.<sup>1</sup> The skeleton appears to have consisted of pin-headed spicules.

A section of the limestone from Magheralin shows it to consist of a calcareous paste, enclosing numerous examples of multilocular foraminifera, among which *Globigerina*, *Textularia*, *Bolivina*, a Marginuline form, and polyzoa may be recognized.

The fauna of the Chalk in this district varies in but slight degree, and is of a very general character, the principal species observed by me being, in order of importance:—

*Belemnitella mucronata*, Schloth.

*Rhynchonella plicatilis*, var. *octoplicata*, Sow.

*Terebratula carnea*, Sow.

*Echinocorys scutatus*, Leske.

*Ostrea verticularis*, Lam.

*Cidaris* (probably *C. sceptrifera*, Mant. } in the lower part of the  
*Inoceramus* (in fragments). } limestone especially.

Polyzoa; *Onychocella* sp.

The Flinty Flag of Kilcorrig, 15 feet from the base of the Chalk, which is described by Tate as a 'highly splintery limestone, irregularly crowded with flints, its upper surface covered with branching sponge-remains embedded in a glauconitic paste,'<sup>2</sup> is unfortunately no longer visible, and in consequence we were not

<sup>1</sup> Ann. & Mag. Nat. Hist. ser. 5, vol. vi. (1880) p. 441.

<sup>2</sup> Quart. Journ. Geol. Soc. vol. xxi. (1865) p. 26.

able to collect any of the members of the interesting fauna which he obtained from this locality. It may be useful to give a list of the species described by Tate, with the addition of *Ammonites* [*Pachydiscus*] *peramplus*, which has not been previously recorded. They are:—

CEPHALOPODA: *Ammonites* [*Pachydiscus*] *peramplus* (Mantell), *P. gollevillensis*, d'Orb., *Belemnitella mucronata*, Schloth.

GASTEROPODA: *Turritella unicarinata*, Woodw., *Cinulia catenata*, Tate.

PELECYPODA (Monomyaria): *Ostrea vesicularis*, Lam., *Pecten nitidus*, Mant.; (Dimyaria): *Pholadomya cordata*, Tate, and *Ph. Stewarti*, Tate.

BRACHIOPODA: *Terebratula carnea*, Sow., *Rhynchonella octoplicata*, Sow., and *Megerlia* [*Kingena*] *lima*, DeFr.

ECHINOIDEA: *Echinocorys vulgaris*, Breyn. = *E. ovatus*, Lam., type and var. *pyramidatus*, Portl., *Cardiaster ananchytis*, Leske, *Galerites abbreviatus*, Lam., *Cyphosoma corollare*, Park.

ACTINOZOA: *Parasmilia centralis*, Mant.

PORIFERA: *Guettardia stellata*, Mich.

Tate remarks: 'from beyond Colin Glen, by Kilcorrig, near Lisburn, to Moira, it [the White Limestone] is seen resting directly on the New Red Marls.'<sup>1</sup> This statement must be somewhat modified, the base of the Chalk being in reality a mulatto-stone, that is, a greyish or pinkish limestone, in which are embedded numerous very rounded grains of quartz, glauconitic casts of foraminifera, and green irregular masses. Often this rock becomes conglomeratic, owing to the presence of large pebbles of quartz and other detrital fragments. We have noticed this type at Magheralin and Kilcorrig, and it is recorded in the Geological Survey Memoir, Expl. Sheet 36, from near Moira.

Of the mulatto-stone from Magheralin 14·16 grammes were dissolved in 20% hydrochloric acid, yielding 2·72 grs. of residue (this excludes fine clay). The most numerous constituents of the insoluble portion are extremely rounded grains of transparent quartz, having an average diameter of ·5 mm., flakes of silvery muscovite, and green to yellow-green glauconitic casts of the internal chambers of foraminifera, the original septation being in many cases still clearly marked out.

In the quarry at Kilcorrig lay blocks of mulatto-stone, containing ramose bodies (often referred to under the vague terms *Spongia*, *Amorphospongia*, etc.) and many pebbles, some of large size, one a transparent specimen of quartz, being 2 inches in length and 1 in breadth. *Belemnitella mucronata* was the only fossil observed. Although the rock was not visible in place, we were told by the foreman that it formed the floor of the quarry. The Chalk appears to overlie directly the Keuper Marls, but a small rising covered by grass hides the junction of the two rocks, so that the conglomeratic limestone cannot be much more than a foot thick. A microscopic section shows the calcareous part to consist of a cal-

<sup>1</sup> Quart. Journ. Geol. Soc. vol. xxi. (1865) p. 25.

careous paste, in which organic remains are numerous. Small single chambers of foraminifera, .06 mm. in diameter, are the most common, though unions of two, three, or more such are very frequent. The only identifiable forms are several minute globulose *Textulariæ*, .2 mm. in length. Nautiloid, rod-like, spiral, spindle- and dumbbell-shaped sections are also abundant, the remaining organic constituents being unidentifiable calcareous rods (.75 mm. in length), sponge-meshes, and fragments built up of hexagonal columns closely set together. In addition to the above the Chalk contains angular grains of quartz, some of which enclose apatite, and irregular green patches of glauconite. A pebble of a glauconitic felspathic sandstone is also present, and round its borders the limestone has lost all trace of the organic contents, becoming a fine-grained paste, and at one point passing into crystalline calcite. Some flakes of pyrites are visible in the latter constituent.

Near Maghaberry, 2 miles east of Soldierstown, greensand is said to have been reached at the base of the quarry. It would appear from all the cases that have come under my notice in this district that this 'greensand' is in reality a 'mulatto-stone,' the true greensand, the 'Glauconitic Sands,' appearing to be entirely absent in these localities. At Balmer's Glen, close to the above village, beds rich in silicate of iron (probably glauconite) are said to have a thickness of 5 feet.<sup>1</sup> Similar beds are recorded from Mullaghearton, as occurring between the Chalk and red Triassic shales, and also south-east of Kilcorig, near Lisburn.

In this division the junction-beds between the basalt and the Chalk are finely exhibited in several localities. At Kilcorig a deposit of lignite and red flints underlies the basaltic mass; while at Soldierstown the entrance to the quarry previously mentioned is cut through a dyke of considerable breadth. The Chalk on each side has a bluish tint, while the flints are coloured various shades of pink or red. The basalt itself, for a space of 2 feet from its junction with the Chalk, is split into a number of thin layers running parallel to the sides of the dyke.

The Southern Division is characterized :—

1. By the frequency of paramoudras.
2. By the existence of a conglomeratic chalk at the base of the white limestone, containing very large pebbles, which point to the conclusion that the area from which they were derived could not have been far distant. The presence of *Belemnitella mucronata* in the rock leads one to infer that it was formed towards the close of the Upper Cretaceous period.

Note.—The officers of the Geological Survey have marked the Upper Greensand as occurring along the line of outcrop throughout the district. This arises from a misuse of the term Upper Greensand, which in most of the Memoirs has been used for mulatto-stone (even though the latter contained fossils of higher zones), as well as for the underlying Cretaceous Beds, if present.<sup>2</sup>

<sup>1</sup> Mem. Geol. Surv. Irel. Expl. Sheet 36, p. 32.

<sup>2</sup> *Ibid.* p. 10.

## (2) THE CENTRAL DIVISION.

## From White Mountain to Cave Hill.

The first indication of a change in the character of the strata underlying the White Chalk is a remark in the Geological Survey Memoir, Expl. Sheet 36, p. 29: 'North of the cross-roads, S.W. of Castle Robin, a reddish sandy rock may be seen, containing fragments of *Inocerami*: this is probably the upper portion of the Greensand;' and near Groganstown, still farther north, are '12 feet of greenish-grey mulatto-stone, containing small pebbles of quartz in such numbers that it might with propriety be termed a fine conglomerate.'

## Colin Mountain.

On the sides of Colin Mountain, a large limestone-quarry is being worked, to the south-west of which a small stream runs in a deep groove, cut in the Cretaceous rocks. Here the lowest Cretaceous beds, the Glauconitic Sands, are well exposed, a central band, 3 feet thick, full of *Exogyra conica*, var. *levigata*, Sow., being very conspicuous. *Pecten* [*Janira*] *quinquecostatus*, Sow., *P.* [*Amussium*] *orbicularis* (Mant.), and *Avicula*, near *lineata*, Röm., occur sparingly in the band itself, but a little above it are more numerous. A fragment of an ammonite, most probably *Hoplites catillus*, Sow., was also obtained. These beds pass into sands of a brownish-red colour above, and into unfossiliferous deep-green sands below. Many pebbles of small size are scattered throughout the series. The total thickness of these strata is at least 12 feet, so that this locality presents not only the most southerly, but also the best developed exposure of these rocks, which, as we shall see later, are of Upper Greensand age. They appear to correspond to the 'glaucous marls' of Expl. Sheet 36, p. 28. A bridge crossing the stream, and a waterfall, prevent a close examination of the Yellow Sandstone, which rests upon the strata just described.

Higher up the stream, above the bridge, there are loose greenish-yellow sands, which pass into a glauconitic sandstone, containing unidentifiable sponge-remains. In the limestone-quarry itself, some 50 feet of White Chalk is exposed, containing *Belemnitella mucronata*, Schloth., and *Terebratula carnea*, Sow., but otherwise presenting no features of interest. Mr. Bell has obtained *Terebratula obesa*, Sow., and *Ostrea vesicularis*, Lam., at this locality.

## Colin Glen.

The section in this glen, which is one of the most complete in this part of the country, has been especially referred to by Prof. Tate. Owing to repeated faulting, the Trias, Lias, and Cretaceous are traversed several times in ascending the stream, so that the accuracy of the succession can be carefully tested.

The red and green sandstones and marls of the Trias form the base of the series at this locality. Above these follow the Rhætic

beds, which here attain a considerable development, *Avicula contorta*, Portl., *Cardium rhæticum*, Merian, and *Pecten valoniensis*, Defr., being especially abundant in the shales. These *Avicula*-shales contain a bone-bed, which, from specimens in Mr. Swanston's collection, must be as clearly marked as those in the West of England. Although we did not find the main band, teeth (probably of *Saurichthys apicalis*, Ag.) and scales were present in considerable abundance. The Liassic strata, which have been described in detail by Tate,<sup>1</sup> were not particularly examined, *Ammonites* [*Arietites*] *Johnstoni*, Sow., alone having been obtained.

The Glauconitic Sands, forming the base of the Cretaceous, at once attract attention, and are at all times easily recognizable, by their deep-green, almost blue-green colour, due to the large proportion of glauconite-grains which they contain. The fossils in these strata are numerous and well-preserved, including *Exogyra conica*, var. *levigata*, Sow., *Pecten* [*Amussium*] *orbicularis* (Mant.), *Cucullæa carinata*, Sow., also teeth of fishes, namely, *Corax falcatus*, Ag., *Lamna appendiculata*, Ag., and *Ptychodus mammillaris*, Ag. Casts of *Trigonia* and *Thetis* (?) are not uncommon, but the pelecypoda are generally in a condition which renders them difficult of identification. Fragments of wood are also present, and large quartz-pebbles are not infrequent. The fossils are most abundant in a band containing phosphatic nodules. Tate gives the thickness as 8 feet 6 inches.

The glauconitic sand passes into a grey marl, the lower half of which is crowded with *Vermicularia concava*, Sow., and *V. quinquecarinata*, Röm., fragments of *Pecten* [*Janira*] also being noticed. The greensand close to the point of junction contains yellowish branching enclosures in great abundance, whose origin it is difficult to understand. In this upper layer a large *Pecten* [*Janira*] *quinquecostatus*, Sow., was found.

The marl, which in its upper part is of a dark blue-grey colour, is not much more than 2 feet thick, the buff-coloured Yellow Sandstones above, on the contrary, attaining a thickness of 30 feet, which, as Tate remarks, represents the greatest development of the arenaceous series in Ireland. This rock, which contains cherty masses, is markedly fossiliferous only along certain bands. The fauna includes *Ostrea* [*Alectryonia*] *carinata*, Lam., *Pecten* [*Janira*] *quadricostatus*, Lam. (of large size), *Vermicularia quinquecarinata*, Röm. (not uncommon), *Lima semisulcata*, d'Orb., *L. globosa*, Sow., *Panopea mandibula*, Sow., species of *Avicula*, *Pinna*, *Trigonia* (a very fine *Tr. scabricula*, Lyc., is probably from here), and *Galeolaria plexus* (Sow.). About 2 feet from the top a band rich in *Pecten* [*Janira*] *quinquecostatus* was met with.

The Yellow Sandstones pass above into a greensand containing a *Cucullæa* and small *Ostrea carinata*, Lam. The Chloritic Sandstones here consist of alternating hard, calcareous, glauconitic sandstones, and softer greensand rocks of the same nature, the latter being those that are richest in organic remains. A noticeable feature

<sup>1</sup> Quart. Journ. Geol. Soc. vol. xx. (1864) p. 103, & vol. xxiii. (1867) p. 297.

is the presence of numerous brown nodules, similar to those occurring in the Chloritic Marl.

Tate remarks that a lower band is charged with *Vermicularia concava*, Sow.<sup>1</sup> It is, however, a higher band that has attracted the most attention, being full of large specimens of *Exogyra columba*, Lam., accompanied by an *Ostrea* (near *biauriculata*), *Trigonia crenulata*, Lam., a *Tellina* or *Anatina* (probably the *Anatina Royana*, d'Orb., mentioned by Tate), *Oxyrhina Mantelli*, Ag., *Corax falcatus*, Ag., *Ptychodus mammillaris*, Ag., *Pt. decurrens*, Ag., and *Lamna sulcata*, Ag. *Pecten asper*, Lam., also occurs rarely here, and *Patellina* [*Orbitolina*] *concava*, Lam.,  $\frac{1}{2}$  inch in diameter, has been obtained in the glauconitic sandstone. Tate also records *Cucullæa fibrosa*, *Trigonia dædalea*, Park., *Pecten* [*Janira*] *aquicostatus*, Lam.?, *Ostrea semiplana*, Sow., and *Ammonites* [*Pachydiscus*] *leuesiensis*, Mant. I have been unable to obtain a single specimen of the above ammonite, and an *Ostrea semiplana* from Hannahstown, near Belfast, is from the Chloritic Chalk, a higher horizon. The highest of the softer beds contains many specimens of a crustacean, referred to *Callianassa*, which is accompanied by a *Natica* and polyzoa.

The junction between these glauconitic sands and the higher beds is very obscure, though in the upper part of the glen there is a glauconitic sandy limestone containing *Belemnitella* [*Actinocamax*] *vera* (Mil.). This is the rock described by Gault as 'hard green speckled chalk, coarsely conglomeratic at the base; large rounded pebbles of quartz and other rocks; the glauconitic grains are very large and thickly scattered throughout, giving the bed its well-known name of mulatto-stone. The fossils, except the sponges and brachiopods, are broken and worn, being probably derived from the waste of an older bed. Sponges are very numerous, but other fossils are rare.'<sup>2</sup> The fauna corresponds in essentials with that of the Chloritic Chalk in the Eastern Division, there being here a distinct case of unconformity. This rock, which is very rich in *Ventriculites*, and also contains *Cæloptychium*, *Echinocorys scutatus*, Leske, and fish-teeth, plays an important part in the district now under consideration.

The hard White Chalk, 2 feet thick, which overlies this bed, contains but few flints, and is immediately followed by white chalk with flints arranged in regular rows. These upper beds will probably repay further examination, so far as regards the detailed distribution of their fauna.

### Black Mountain and Crow's Glen.

On the slopes of Black Mountain (1272 feet) are a number of quarries, in which the upper strata of the series are better exposed than is the case at Colin Glen. A little to the north, a very complete section is obtained in a glen (Crow's Glen), which differs but slightly, either as regards thickness or character of succession,

<sup>1</sup> Quart. Journ. Geol. Soc. vol. xxi. (1865) p. 24.

<sup>2</sup> Proc. Belfast Nat. Field Club, n. s. vol. i. (1877) p. 256.

from that observed at the previous locality. In view of this fact, we may content ourselves here with noting the variations observed.

1. At the base is a yellowish-green sand, which yielded very delicate shells, resembling small *Exogyra*.

2. The Glauconitic Sands are of the usual deep-green colour, containing *Exogyra lavigata*, Sow., in abundance, *Pecten* [*Janira*] *quinquecostatus*, Sow., *P.* [*Amussium*] *orbicularis* (Mant.), a *Littorina*-like gasteropod, *Vermicularia quinquecarinata*, Röm., and an undetermined bivalve.

3. There is a passage upward into dark glauconitic marls, which at the base contain *Vermicularia quinquecarinata*, Röm.

4. The Yellow Sandstone, of typical character, is here at least 25 feet thick, and, although not very fossiliferous, yielded *Pecten æquicostatus*, Lam., *Rhynchonella convexa*, Sow., *Vermicularia quinquecarinata*, Röm., *V. concava*, Sow., and fish-scales.

5. The 'Chloritic' Sands and Sandstones are also well-developed, but whereas the fossils at Colin Glen were mainly in the softer sandstones, here they are present in the harder beds. These strata consist of three hard sandstone-bands separated by two layers of softer greensand. In the lowermost hard stratum, *Pecten æquicostatus*, Lam., and *Vermicularia concava*, Sow., are present, *Rhynchonella Schloenbachi*, Dav., being also recorded. The second hard band is full of *Exogyra columba*, Lam., to the apparent exclusion of other organisms, while the soft quartzose greensand above contains fish-remains (*Lamna appendiculata*, Ag., etc.). The hard glauconitic limestone at the top of the series is apparently unfossiliferous.

6. There is no evidence of Chloritic Chalk in the glen itself, but at the limestone-quarries blocks of this rock are lying about, the original exposure being unfortunately hidden now. Large specimens of *Belemnitella mucronata*, Schloth., and *Echinocorys scutatus*, Leske, are abundant, accompanied by ammonites (not more closely identifiable) measuring more than a foot in diameter, *Baculites anceps*, Lam., *Ventriculites*, and *Ceoloptychium*.

The White Chalk itself contains *Belemnitella mucronata*, Schloth., *Inoceramus*-fragments, *Lima Hoperi*, DeFr., *Nautilus Atlas*, Whiteaves, and *Baculites anceps* aff.

### Forth River.

This stream, issuing from the hills, has cut a deep channel through the basalts, and through the Cretaceous and Triassic rocks.

The lithological succession is not so clearly displayed as in previous sections, the White Chalk with *Belemnitella mucronata* resting directly on a hard glauconitic sandstone, which has given rise to a small waterfall. The base of the latter rock contained many specimens of a *Belemnitella*-like form, which Mr. Crick has identified as *Actinocamax Alfridi*, Janet,<sup>1</sup> a species of rare occurrence in England. *Spondylus spinosus*, Sow., is also present. The

<sup>1</sup> See Janet, Bull. Soc. géol. France, ser. 3, vol. xix. (1891) p. 720, etc.

junction between the glauconitic beds (which contain in places pebbles over  $\frac{1}{2}$  inch in diameter) and the Yellow Sandstone is of a peculiar nature: the glauconitic rock enclosing many fragments of the lower bed, while the latter in its upper part is crowded with blocks of calcareous glauconitic sandstone.

The Yellow Sandstone itself is of the usual character, and a *Cucullæa* (*C. ligeriensis*, d'Orb., according to Tate), *Vermicularia*, and thin-shelled pectens are the principal forms noticed.

The Glauconitic Sands were not observed here.

### Squires Hill.

Several large quarries have been opened up here, in the second of which (counting from the side nearest Cave Hill) the Chalk is some 50 feet thick, and contains regular layers of flint. Fossils are numerous at the base, including abundant *Belemnitella mucronata*, Schloth., *Echinocorys scutatus*, Leske, *Terebratula carnea*, Sow., tooth of *Lamna* sp., *Bourgueticrinus*-stems, plates and spines of *Cidaris*, *Inoceramus*-fragments, polyzoa, *Ventriculites* sp., *Coscinopora* sp., *Parasmilia centralis*, Mant., *Kingena lima*, Sow., and *Serpulæ*.

Beyond this large quarry is a small one behind a farmhouse, in which the lower beds of the series are well exposed, the rocks at this point dipping steeply westward, and being apparently much crushed owing to the movements to which they have been subjected.

At the base of the quarry, Glauconitic Sands of the usual deep-green colour are well displayed, containing numerous specimens of *Exogyra lævigata*, Sow., and *Pecten* [*Janira*] *quinquecostatus*, Sow. When the quarry was first opened, Mr. R. S. Bell obtained a number of fine casts of *Cucullæa ligeriensis*, and since then he has sent me another, resembling a *Ceromya*, from the same locality. Total thickness 4 feet 6 inches (this was determined for me by Mr. Bell). The uppermost layer of this greensand is spotted with darker patches, and is characterized by *Vermicularia quinquecarinata*, Röm.

In the Yellow Sandstone (18 feet thick), the only fossils observed were *Vermiculariæ* and a broken *Pecten*.

The soft greensand which succeeds it, 8 feet thick, yielded only a solitary shark's tooth, but the harder glauconitic sandy limestone above is full of *Belemnitella* [*Actinocamax*] *quadrata* (Blainv.), *Echinocorys scutatus*, Leske, and fragmentary sponges. One of the most remarkable features at Squires Hill is the nodular character at times assumed by the chalk containing *B. quadrata*. A section taken across the nodules, which are brown to black externally, shows them to consist of a glauconitic chalk, characteristic of many of the Irish mulatto-stones.

The southernmost quarry is remarkable for two thin vertical dykes which traverse the whole thickness of the Chalk. Mr. W. J. Atkinson, F.G.S., has called my attention to the fact that, in a microscopic section showing the junction of the basalt and the Chalk, though the latter is thoroughly altered to a finely granular compact

limestone, yet many specimens of foraminifera situated close to the line of junction appear practically unchanged.

Mr. Bell has sent me a number of specimens, from the Chloritic Chalk and base of the White Limestone at this quarry, which show that the nodular rock is crowded with *Belemnitella* [*Actinocamax*] *quadrata* and *Micraster cor-anguinum*, Forbes, *A. Alfridi* being also present. The Chalk immediately above this bed contains *Turritella unicarinata*, Woodw., fine pectens, *Pleurotomaria*, and a gasteropod of doubtful genus. *Nautili* and *Ammonites* appear to be fairly common, but the latter are not perfect enough to admit of closer identification.

### Cave Hill.

At the top of the tramway-line leading to the large quarry cut in the side of this hill, the Glauconitic Sands, of a deep green colour, overlies strata of Liassic age. The fossils are most abundant in a hard rusty-brown layer, and include *Ecogyra lævigata*, Sow., *Pecten* [*Janira*] *quinquecostatus*, Sow., *P.* [*Chlamys*] *Dutemplei*, d'Orb., or *P. Galliennæi*, d'Orb., *Belemnites ultimus*, d'Orb., and large bivalves in the form of casts, which have some external resemblance to *Thetis Sowerbyi*; *Vermicularia quinquecarinata*, Röm., and *P.* [*Amussium*] *orbicularis* (Mant.), also occur, but very rarely. Above the fossiliferous layer, the rock was of a deep brown colour, and barren of fossils.

The Yellow Sandstone is very nodular at this point, and contains large chert-fragments; in its upper part it is filled with blocks richer in glauconite, and is overlain by a true glauconitic sandstone.

The Chloritic Sandstone has yielded numerous fish-remains (notably *Corax falcatus*, Ag., *Ptychodus latissimus*, Ag., *Pt. mammillaris*, Ag.) and *Ostrea semiplana*, Sow.; while in the pink glauconitic chalk above, *Spondylus spinosus*, Sow., is most noticeable.

The White Chalk itself is very rich in organisms, especially at the base. These include *Belemnitella mucronata*, Schloth., *Echinocorys ovatus*, Lam., *Ventriculites*, *Rhynchonella plicatilis*, Sow., and *Rh. limbata*, Dav. In addition to these may be mentioned *Notidanus microdon*, Ag., *Anomæodus* sp., *Hamites*, *Nautilus Lavigilliertianus*, d'Orb., *N. Deslongchampsianus*, d'Orb., *Amm.* [*Pachydiscus*] *Oldhami* (Sh.)—*Pach. Portlocki* (Sh.) is recorded by the Geological Survey,—fine specimens of *Lima* (which apparently belong to a new species), *Pecten* sp., *Pleurotomaria perspectiva*, Mant., *Terebratulina striata*, Wahl., of large size, and differing from the typical *T. Defrancei*, Brongn., in being more depressed, *Galerites conicus* (Breyn.), a Trochosmilian coral, and *Cœloptychium belfastiense*, Tate.

The quarry at Whitewell is famous as being the locality where remains of *Mosasaurus gracilis*, Owen, have been discovered, and these have been mentioned by Mr. Swanston in a short paper.<sup>1</sup>

<sup>1</sup> Proc. Belfast Nat. Hist. & Phil. Soc. 1886, pp. 18-19.

The Central Division is characterized :—

Lithologically :

1. By the great thickness of those beds which are clearly of detrital or chemical origin, namely : the Glauconitic Sands, Yellow Sandstones, and Chloritic Sandstones.
2. By the marked unconformities existing between the detrital deposits and the calcareous beds of organic origin.
3. By the frequency of a nodular layer at the base of the limestone series.

Zonally :

4. By the prominence and richness in organic remains of the zone of *Exogyra columba*.
5. By the extreme reduction, if not entire absence, of the zone characterized by fragments of *Inoceramus* and *Spondylus spinosus* (see next division).
6. By the exceptional development of the zone of *Belemnitella (Actinocamax) quadrata*, especially at Squires Hill.

Palæontologically :

7. By the abundance and large size of the Dimyarian Pelecypoda, especially the genera *Trigonia* and *Cucullæa*, and forms like *Thetis*, in the Glauconitic Sands and Chloritic Sandstones ; and the large size attained by the Monomyarian Pelecypoda at the base of the White Chalk, and by *Ostrea carinata* in the Yellow Sandstone.
8. By the great development of gasteropoda and cephalopoda in the lower beds of the White Chalk.
9. By the abundance of fish-remains in the zone of *Exogyra columba*.

### (3) THE EASTERN DIVISION,

from Belfast to Larne (including Islandmagee).

The Geological Survey Memoir, Expl. Sheets 21, 28, & 29, states that White Chalk and Chloritic Sandstone have been met with east of Carnmoney Hill, but it is impossible from the description to understand the stratigraphical distribution of the fossils, which include *Belemnitella mucronata*, Schloth., *Spondylus spinosus*, Sow., *Inoceramus Crispi*?, and *Micraster cor-anguinum*, Forb. Between Carnmoney Hill and Woodburn Glen, a distance of 5 miles, there are no important exposures of the Cretaceous rocks, but at the latter locality two very complete sections of these strata are observable, formed by two streams which cut through the hill at this point. As these exposures present almost identical features, the one supplementing the other in details only, their description will be united.

These beds, which have been taken as types both by Tate and Barrois, have been also selected as the most suitable for examination

by analysis and microscopic study, and the observations resulting therefrom will be dealt with in the sequel.

The Glauconitic Sands, which here attain a thickness of nearly 8 feet, are very fossiliferous, especially in a nodular band at the centre of the zone, termed by Tate the bed of *Evogyra conica*. Some of these *Evogyrae* measure as much as 2 inches or more in diameter. In addition *Pecten* [*Amussium*] *orbicularis* (Mant.), as also species of *Arca*, *Inoceramus*, and *Avicula*, attest the great richness of the molluscan fauna at this period. The conical casts of biconcave vertebræ of fish have also been obtained. Moreover, Tate records *Belemnites ultimus*, *Pecten* [*Chlamys*] *Dutemplei*, *P. virgatus*, and *Terebratula squamosa*.

The greensands graduate into a dark sandy marl dotted with green glauconitic grains, the Glauconitic Marls, which stratum forms a connecting-link between the Grey Marls above and the Glauconitic Sands below.

The Grey Marls become very light in the upper part, where ramifying masses of a glauconitic sandy limestone are scattered through them, similar to the rock next to be described. The marls, so far as I have observed, are quite unfossiliferous; but, as they contain cherty nodules, they are in all probability merely a more clayey facies of the Yellow Sandstone, and are in fact quite as rich in detrital material as the Yellow Sandstone of Colin Glen.

In the chemical analysis, the marl and enclosed grit have been separately treated, and in Table II. [facing p. 584] are respectively numbered 4 and 4a. Tate gives the marls a thickness of  $2\frac{1}{4}$  feet, but my measurements assign  $1\frac{1}{2}$  feet to the glauconitic dark marls, and  $1\frac{1}{2}$  feet to the yellower marls above, or a total of 3 feet.

The Grey Marls are succeeded by a calcareous glauconitic sandstone similar in its nature to the one above-mentioned, and the peculiar inclusions already referred to bear out Tate's contention that there is an unconformity between this rock and the underlying strata. The series shows a gradual change upward, from this sandy type to a sandy glauconitic limestone at the summit, but about a foot from the base occurs a band, which, from the ease with which it is identified, has been used by previous authors as of considerable importance in their discussions.

Its characteristic feature is the presence of innumerable fragments of *Inoceramus* scattered through a calcareous matrix, rich in glauconite- and sand-grains. I have been unable to obtain any proof that the *Inoceramus* present is *I. Cripsii*, Goldf., non *Crispi*, as suggested by Tate and others, though in his paper there is a question-mark against the name. On the other hand, neither has any further evidence been forthcoming of their connexion with *I. Brongniarti*, Park., although, judging from their associated fossils, they may possibly be referable to that species. The only perfect specimen of *Inoceramus* that I have been able to examine from this horizon hails from Armoy, and is a genuine *I. Brongniarti*.

The principal fossils obtained by me at this locality were

*Spondylus spinosus*, Sow., *Pecten* [*Janira*] *quinquecostatus*, Sow., and *Terebratulina carnea*, Sow. A *Cidaris*-spine and *Ostrea semiplana* have also been obtained, the *Cidaris* noted here having always been classed with *C. subvesiculosa*, d'Orb. Of the greatest interest, perhaps, is the occurrence of *Echinocorys scutatus* var. *gibbus*, Lam., at this horizon, two characteristic specimens being obtained by me in the northern glen, and these were in close connexion with the fragmentary *Inocerami*, *Spondylus*, and *Janira*. Special stress must be laid upon the occurrence of this sea-urchin at this locality, because Tate has placed the *Inoceramus*-band in the Lower Chalk, or Cenomanian, and Barrois does not appear to have obtained it here. In addition *Rhynchonella robusta*, Tate, a well-marked variety of *Rh. limbata*, Dav., occurs at this horizon.

If some of the *Inoceramus*-shells be placed in dilute hydrochloric acid, the greater portion of the shell dissolves away, leaving an open hexagonal mesh of siliceous material behind. Mr. Chapman has obtained similar results in the Bargate Beds, and has also shown me a section in which chalcedony occurs between the prisms composing the *Inoceramus*-test. It would appear that silicification in this case is interprismatic, and not, as in so many familiar instances, the replacement of the calcareous prisms themselves by silica. These results throw light on the structures obtained by me in the *Inoceramus labiatus*-zone in the Isle of Wight,<sup>1</sup> which at the time were doubtfully referred to sponges, but are evidently identical with those just described.

Above the *Inoceramus*-band the character of the rock remains apparently unaltered for a thickness of about 2 feet, but in its upper part some large pelecypoda were observed, lying parallel to the bedding, and all on the same horizon. The hardness of the rock prevented their extraction in fragments sufficiently large for identification, but the appearance suggested a form of *Spondylus*.

The Chloritic Chalk, which follows next in succession, is a pinkish white limestone, about 4 feet thick, having brown nodules from 1 inch in diameter downward scattered through it, while the limestone itself is dotted with green grains of glauconite. This appears to be the equivalent of the Spongiarian zone of Tate, and is characterized by the presence of beautiful internal and external casts of many foraminifera and sponge-spicules. From the thicknesses given by Tate and Barrois it would appear that the upper part of this limestone was included by them in the White Limestone, but in the section in the southern glen, where the Chloritic Chalk was more especially studied, no direct contact with the latter rock (containing *Belemnitella mucronata*) was observed by me.

In the upper part of the glen the White Limestone with flints is well displayed, though much disturbed by the intrusion of numerous dykes of basalt. The chief fossils are *Belemnitella mucronata*, Schloth., and *Rhynchonella octoplicata*, Sow.

<sup>1</sup> 'Chemical and Micro-Mineralogical Researches on the Upper Cretaceous Zones of the South of England,' London, 1893, p. 48.

The Cretaceous exposures north of Woodburn Glen, in Islandmagee, are among the most interesting of the whole series, and as many of these have been but lightly touched upon by previous writers, it may be advisable to deal with them more fully here. Near Castle Dobbs, 3 miles north-east of Carrickfergus, the officers of the Geological Survey observed a chloritic sandstone, containing abundant specimens of *Terebratula carnea*, Sow., small *Exogyra columba*, Lam., *Inoceramus* sp., *Spondylus spinosus*, Sow., *Echinocorys scutatus*, Leske, and a *Galerites* hesitatingly referred to *G. subrotundus* (Breyn.). At Seamount, about 4 miles north-east of Carrickfergus, the chloritic sandstone has also been recorded by them, but with quite a distinct fauna: *Rhynchonella limbata*, Dav., *Serpula* [*Galeolaria*] *plexus* (Sow.), and *Lamna acuminata*, Ag., being the principal occurrences.

### Whitehead.

The Glauconitic Sands, which were well exposed during the construction of the tunnel between Carrickfergus and Whitehead, have been described by Tate. At the present time the lower strata are not clearly exhibited, though south of the tunnel Mr. Bell found a glauconitic sandstone crowded with *Rhynchonella Schlenbachi*, Dav., a fossil which appears to be especially characteristic of the lower part of the Chloritic Sandstone, or zone of *Exogyra columba*.

South of Whitehead is a large chalk-quarry, now unworked, in the upper part of which the somewhat flattened flints are in regular layers, these becoming more scattered and irregular towards the base of the section, the chalk at the same time being of a more bluish tint. In the lower part of the quarry, large ammonites were very abundant, and have been commonly referred to *A. lewesiensis*, Sharpe. As under this name several species possibly may be included, a revision of the specimens obtained at this locality would be advisable, but it is doubtful whether any remain in a sufficiently good state of preservation to admit of a more accurate determination.

On the sea-shore at Whitehead the base of the Chalk is exposed, here consisting of a compact white limestone containing *Belemnitella* [*Actinocamax*] *vera* (Mil.). A layer of tabular flints separates this from the Spongiarian zone, characterized by the abundance of the sponge-remains. The upper part of this band consists of a limestone full of green nodules, which in most cases show distinct sponge-structure. In the lower portion the sponges are closely crowded, and include *Ventriculites cribrosus*, Phil., *V. radiatus*, Mant., *Coscinopora infundibuliformis*, Goldf., *Etheridgia mirabilis*, Tate, probably *Plocoseyphia*, and possibly *Becksia*.

A glauconitic sandy limestone full of *Inoceramus*-fragments completes the section, the rocks lower than this being covered by seaweed, and only visible at low tide.

From Whitehead a path passes round Blackhead, a bold headland formed by the Lower Amygdaloidal Basalt. The amygdaloidal

cavities in this rock have been drawn out parallel to the direction of flow, and zeolites have been abundantly formed in the vesicles. A quarter of a mile to the north-east, a little south of Cloghfin Harbour, the Cretaceous rocks are well exposed on the shore, especially at low tides. The beds dip S.W. at an angle of about  $5^{\circ}$ , and every member of the series is clearly visible. The order of succession is as follows, commencing from the top:—

1. Compact limestone, crowded with green sponge-nodules 6 inches thick. This band forms the summit of a low platform, which gradually slopes south-westward, and is undoubtedly the same as that previously mentioned as occurring on the shore at White-head.

2. Limestone, much jointed, and readily breaking into flakes an inch or more thick, characterized, as in the previous case, by the great abundance of sponge-remains, these forming a particularly well-marked layer at the base. The species are the same as those mentioned above, *Ventriculites cribrosus*, Phil., and *Etheridgia mirabilis*, Tate, being especially characteristic. Total thickness =  $3\frac{1}{4}$  feet.

3. The Chloritic Chalk and Sands are well exposed in a low cliff running parallel to the strike of the beds, the summit of which is formed by the base of the Spongiarian zone above-mentioned. In the upper part, which is really a glauconitic limestone, *Echinocorys gibbus*, Lam., is abundant. Other fossils obtained by us at this level were *Parasmilia centralis*, Mant., *Bourquetierinus* (portions of stem), *Cidaris*-spines, probably *C. sceptrifera*, Mant., *Terebratulina carnea*, Sow., *Spondylus spinosus*, Sow., *Exogyra* near *plicata*, *Inoceramus*-fragments, and numerous sponges. Total thickness = 3 feet.

4. At this point a band of *Serpula filiformis* is easily recognizable. The lower part of the cliff is less fossiliferous, though three *Inoceramus*-bands are well-marked, the lowest, 2 feet 8 inches from the *Serpula*-layer, being composed of larger fragments. Numerous branching forms, apparently of polyzoan nature, are present at this level, and a little below it I obtained an example of *Galerites albogalerus*, var. *angulosus*, Desor.

5. The remaining 2 feet 6 inches consists of soft glauconitic sands, which, with the above exception, did not yield fossils. The base of these beds is hidden by pebbles and seaweed, but the thickness of the strata thus obscured must be at least 4 feet, calculated by pacing.

6. The Yellow Sandstones and Marls (cropping out in a step-like manner, the latter being more rapidly denuded) are here some 8 feet thick, and consist of alternating strata of compact calcareous sandstone and softer marls. In the latter iron-pyrites nodules are not uncommon, and in the sandstone-bands are many peculiar dark branching bodies, occasionally divided into several segments. High up in the series occur large specimens of *Pecten* [*Janira*] *quadricostatus*, Sow., while *Vermicularia concava*, Sow., and *V. quinquecarinata*, Röm., are very abundant. These species of *Vermicularia*

are also present in the Glauconitic Marls near the base, these being separated from the Glauconitic Sands by a band of compact yellow sandstone.

7. The Glauconitic Sands are well exposed at low tide, and are of the usual blue-green colour. Fossils are very abundant. *Exogyra conica*, var. *levigata*, Sow., *Pecten* [*Amussium*] *orbicularis* (Mant.), and *P.* [*Janira*] *quinquecostatus*, Sow., are large and numerous. *P.* [*Chlamys*] *asper*, Lam., and *P. Galliennii*, d'Orb., are by no means uncommon, and a special feature is the abundance of small brachiopoda, especially *Rhynchonella* near *Cuvieri*, Sow., *Terebratulæ* (*T. squamosa*, Mant., or stunted *T. biplicata*, Sow.), *Kingena lima*, Defr., and an unidentified species. Turbinate gasteropoda (? *Littorina*), *Aviculæ* of different species, teeth of fishes (apparently *Lamna appendiculata*, Ag.), and a belemnite which foreshadows the characters of *Belemnitella* [*Actinocamax*] *vera*, but is much longer and thinner, were also obtained. Thickness, over 4 feet.

The upper part has yellow spots sprinkled through the deep-green matrix, and yielded no fossils.

### Hillsport.

No continuous sections are to be observed north of the exposure just described, but blocks of the various types are plentifully scattered along the shore. The Spongiarian layer is particularly prominent, as weathering causes the sponge-fragments to stand out in branching masses on the surface of the rock. *Echinocorys scutatus* is also abundant, so too is *Camerospongia fungiformis*, Goldf., and casts of lamellibranchiata.

The character of the Chloritic Sands was well illustrated in a large mass which had slipped down the hillside. Instead of the fossils being irregularly scattered throughout the rock, clearly-marked bands are noticeable, the succession being:

	Depth below Sponge-layer.
	Ft. ins.
1. Sponge-layer.	
2. <i>Serpula filiformis</i> -band .....	0 6
(In addition to the <i>Serpulæ</i> , large <i>Inocerami</i> and <i>Spondylus spinosus</i> were present.)	
3. First <i>Inoceramus</i> -band.....	3 6
4. Second " " .....	5 0
5. <i>Ostrea semiplana</i> -band .....	5 6
(In this band are numerous branching bodies, one of which Dr. J. W. Gregory has recognized as a species of <i>Spiropora</i> .)	
6. <i>Rhynchonella</i> -band .....	8 6
(It contains abundant examples of <i>Rh. plicatilis</i> , Sow., <i>Rh. limbata</i> , Dav., and <i>Rh. robusta</i> , Tate. At the base specimens of <i>Catopygus columbarius</i> , Lam., are not infrequent.)	

Of other fossil forms, *Echinocorys scutatus* and *Terebratula carnea* are mainly restricted to the upper part, while spines of *Cidaris* are present throughout the whole series. *Inoceramus*-

fragments occupy the central portion, *Ostrea semiplana* and the branching bodies are only in their own band, and the *Rhynchonellæ* are mainly restricted to the lower 3 feet.

The Yellow Sandstone is comparatively rich in fossils, these including *Vermicularia quinquecarinata*, Röm., *Ditrupa difformis*, Lam., *Pecten* [*Janira*] *quadriricostatus*, Sow., *Rhynchonella conveca*, Sow., and *Lamna appendiculata*, Ag. This is the only locality where sea-urchins and corals have been recorded from this horizon, *Micrabacia coronula*, Goldf., being frequent, and *Discoidea subuculus*, Klein, not uncommon. We obtained a larger echinoderm here, but it was too imperfect to admit of identification.

The Glauconitic Marls are displayed beneath the sandstone, and Glauconitic Sands occur from time to time, containing a *Pecten asper* of large size.

### Barney's Point, near Mill Bay, west side of Islandmagee.

On the eastern side of Islandmagee, 2 miles north of Ballycarry, occurs a large quarry which must at one time have been extensively worked, but now appears to be deserted. A cutting has been carried through the Cretaceous rocks, presenting one of the finest sections of these visible in Co. Antrim. Commencing from the top, we observe:—

1. Chalk with regular layers of flints, passing below into chalk with scattered flints, which contains *Belemnitella mucronata*, Schloth., *Echinocorys scutatus*, Leske, *Cidaris*-spines, polyzoa, and *Porosphæra*.

2. A flaky chalk, 4 feet thick, probably represents the Spongiarian zone, which was not so clearly recognized palæontologically as at Whitehead.

3. The Chloritic Chalk and Sands merge one into another, forming a rock of distinctly green tint, 20 feet thick. Fossils are extremely abundant, and special bands are very clearly marked. The principal may be thus summarized:—

- (a) Near the upper part of the series is an *Echinocorys scutatus*-band, in which *Spondylus spinosus* and *Camerospongia fungiformis* are also abundant. The rock is a glauconitic limestone.
- (b) *Serpula filiformis*-band.
- (c) The distance from *b* to the upper *Inoceramus*-band is probably between 3 and 4½ feet; below is a second *Inoceramus*-layer, also containing *Ostrea semiplana* and numbers of small *Rhynchonellæ* (*Rh. limbata*, Schloth., and *Rh. robusta*, Tate). The third layer of *Inoceramus*-fragments is at the base of the series, 2 feet below the second band, and contains *Rhynchonella plicatilis*, Sow., *Catopygus columbarius*, Lam., *Cidaris*-spines, and probably *Pseudodiadema variolare*, Brongn., and *Micraster breviporus* Ag. (in casts only).
- (d) Yellow-green sands, 4 feet thick, containing *Vermiculariæ*, a small *Ostrea carinata*, Sow., a cast of *Exogyra columba*, Lam., and *Ostrea semiplana*, Sow.

This section is of especial importance, as showing that the zone of *Exogyra columba* is below that of *Inoceramus Crispi*?, and not

above it, as suggested by Tate. By combining the previous two sections together we are now enabled to range these beds by means of their fauna as follows :—

ZONE.	Sub-zone.
<i>Spondylus spinosus</i> or <i>Inoceramus</i> sp.	<div style="display: flex; align-items: center;"> <div style="font-size: 3em; margin-right: 10px;">{</div> <div> <p><i>Echinocorys gibbus.</i></p> <p><i>Serpula filiformis.</i></p> <p><i>Ostrea semiplana</i> = main Inoceramus-beds.</p> <p><i>Rhynchonella plicatilis.</i></p> <p><i>Catopygus columbarius.</i></p> </div> </div>
<i>Exogyra columba.</i>	.....

*Spondylus spinosus* is found throughout the series, except in *d*, while *Terebratula carnea* is restricted to the upper part. The Yellow Sandstone here attains a thickness of 20 feet, chert being developed in thick bands, at regular intervals throughout the whole rock; but the organic remains appear to be few, a possible *Ostrea carinata* and *Rhynchonella* of unrecognized species being alone noted in the highest chert-band. At the base some 4 feet of Glauconitic Sands are exposed, these containing small *Exogyra* and a *Pecten* of doubtful species. On the opposite side of Larne Lough, at Redhall, a mile north of Ballycarry, the officers of the Geological Survey record chloritic sandstone, and judging from the number of sponges mentioned, including *Achilleum fungiforme* and species of *Coscinopora*, *Siphonia*, and *Ventriculites*, it seems highly probable that at least the base of the Spongiarian zone is represented. Moreover, the presence of *Terebratula carnea* (common), *T. semiglobosa*, *Rhynchonella plicatilis*, *Exogyra columba* (small), *Inoceramus*-fragments, *Spondylus spinosus* (common), *Echinocorys scutatus*, *Micraster cor-anguinum*, *Lamna acuminata*, and *Ptychodus latissimus*, strengthens the view that the main body of the Chloritic Sand is here represented. It should be noted that *Galerites subrotundus* is also recorded from this locality.

### Magheramorne.

At this village, situated on the western coast of Larne Lough, opposite Barney's Point, is the large Magheramorne chalk-quarry. The limestone has been analysed by members of the Belfast Naturalists' Field Club, the result being as follows :—

Carbonate of lime.....	98·63%
Carbonate of magnesia .....	0·38%
Phosphate of lime .....	0·10%
Oxide of lime and alumina .....	0·08%
Silica and insoluble clay .....	0·45%
	99·64

For the present writer's analysis, see p. 578.

### Glynn.

The character of the rocks at this locality has been noted by Dr. C. Barrois, but no facts of importance arise from their study. The succession and thicknesses are :—

	Feet.
1. Chalk with flints .....	70
2. Chloritic Chalk.....	6
3. Chloritic Sands .....	4½
4. Calcareous yellow sandstone with branching masses .....	3
5. Glauconitic Sands .....	10
	93½

In the latter only *Exogyra levigata*, Sow., and *Pecten* [*Janira*] *quinquecostatus*, Sow., have been recorded.

### Larne.

A mile north of Larne, near Waterloo House, is a remarkable exposure of the Chloritic Sands, of a distinct red colour. It is of particular interest, as being one of Dr. Barrois's type-localities for the beds of Turonian age. The beds are in succession, beginning from above:—

- (a) White Chalk with irregular flints, containing *Belemnitella mucronata* and *Echinocorys scutatus*.
- (b) Chloritic Chalk, very nodular.
- (c) Red glauconitic siliceous limestone (part of Chloritic Sands?).

Barrois has recognized three bands in this rock, and I shall place the list of fossils collected by Messrs. Stewart, McLean, and myself side by side with his list, as ours differs in very material particulars.<sup>1</sup>

#### Barrois.

*Spondylus spinosus*, Sow.  
*Pecten* [*Janira*] *quinquecostatus*, Sow.  
*Terebratula hibernica*, Tate.  
*Rhynchonella Tolliezana*, Cornet-Briart (near *plicatilis*).

In lower part only:  
*Inoceramus*-fragments.  
*Rhynchonella robusta*, Tate.  
 — *Cuvieri*, Sow.  
*Terebratula semiglobosa*, Sow.  
*Cidaris subvesiculosa*, d'Orb.  
*Galerites subrotundus*, Breyn., sp.  
 Casts of bivalves.

#### Present Paper.

*Spondylus spinosus*, Sow.  
*Pecten* [*Janira*] *quinquecostatus*, Sow.  
*Inoceramus*-fragments.  
*Rhynchonella plicatilis*, Sow.  
 — *robusta*, Tate.  
*Terebratula carnea*, Sow.  
 — *semiglobosa*, Sow.  
*Cidaris*-spines.  
*Echinocorys scutatus*, var. *ovatus* (type), Lam.  
*Galerites albogalerus*, var. *angulosus*, Desor.  
*Ostrea semiplana*, Sow.  
 Teeth of fishes (probably *Corax*).  
*Camerospongia fungiformis*, Goldf.

The rock is sometimes distinctly oolitic. It will be seen, on examining the above lists, that mine differs from that of Barrois in giving the rock a higher zonal position than that assigned to it by him. For example, we failed to obtain the two distinctly Turonian forms, *Rhynchonella Cuvieri* and *Galerites subrotundus*, at the same time noting the presence of *Echinocorys scutatus* and *Galerites albogalerus*, the latter of a type much more characteristic of the Senonian.

<sup>1</sup> I gather that the part of this rock which we found most fossiliferous would correspond most nearly with D 6, 7, and 8 of Barrois, 'Recherches sur le Terrain Crétacé Supérieur de l'Angleterre et de l'Irlande,' Lille, 1876, p. 211.

This matter will be more fully dealt with when discussing the general stratigraphical relationship (p. 594).

Besides the *Inoceramus*-band which was accompanied by this rich fauna, two others occur, but these did not yield any other fossil forms. A yellow-green sandy layer separates the red glauconitic limestone from a flaky yellow sandstone appearing at the base.

The Sponge-layer bed was observed on the shore at Waterloo, above it being the layer with green sponge-nodules.

Inland, at Ballycraigie Bridge, near Killyglen, a pink chalk was seen, containing *Ventriculites*, *Rhynchonella* sp., *Spondylus* sp., *Ostrea vesicularis*, Lam., and *Belemnitella mucronata*, Schloth.

At the time of our visit, a cutting was being made in the road, the upper part of which was composed of yellow, the lower of bluish-green sands. The presence of *Vermiculariæ* in the upper part makes it probable that these beds represent the Yellow Sandstones, Glauconitic Marls, and possibly the Glauconitic Sandstones.

### Ballygalley Head.

A little to the south of this head, nearly 4 miles north of Larne, Barrois examined an interesting exposure. A band of rolled nodules separated the white chalk-with-flints from a slightly glauconitic limestone (1 foot thick), this again overlying 3 feet of hard glauconitic limestone, very rich in fossils. These include *Belemnitella* sp., *Serpula*, *Inoceramus* sp., *Ostrea canaliculata*, d'Orb., *O. semiplana*, Sow., *Spondylus spinosus*, Sow., *Terebratula semiglobosa*, Sow., *Rhynchonella plicatilis*, Sow., *Cidaris sceptrifera*, Mant., *Galerites conicus* (Breyn.), *Echinocorys gibbus*, Lam., *Parasmilia centralis*, Mant., and numerous sponges, notably *Camerospongia fungiformis*, Goldf., and *Etheridgia mirabilis*, Tate, a fauna which in many respects resembles that of the red rock at Waterloo, and is very similar to that of the glauconitic limestone below the main sponge-bed at Blackhead.

Beneath the limestone is a very sandy glauconitic rock, a bed consisting of fragments of *Inocerami*, associated with pebbles, while the base of these Chloritic Sands consists of a soft sandstone, containing large grains of quartz and glauconite, the only fossil observed being *Spondylus spinosus*.

The Yellow Sandstone is possibly represented by a soft sandstone containing cherty nodules.

The White Chalk between Ballygalley Head and Glenarm possesses a very simple fauna, *Belemnitella mucronata*, Schloth., *Rhynchonella octoplicata*, Sow., *Rh. limbata*, Schloth., *Echinocorys scutatus*, Leske, and *Magas pumilus*, Sow., recurring with monotonous regularity. Only at one locality, 2 miles south of Glenarm, were the lower beds visible. There the succession is, beginning at the top:—

1. Chalk with regular layers of flint.
2. Chalk, with irregularly-scattered flints, having a nodular character at the base.
3. Glauconitic Chalk, 2 feet below becoming
4. Quartzose glauconitic limestone with pebbles  $\frac{3}{8}$  inch or more in diameter.

This band contained *Inoceramus*-fragments in large quantity, as also *Spondylus spinosus*, Sow., *Terebratula carnea*, Sow., and *Cidarid*-spines; *Ostrea semiplana*, Sow., occurred a little higher up. Vegetation obscures the beds below, but these can be seen to consist of greenish-yellow sands, from which no fossils were obtained.

Between Glenarm and Carnlough the ground is very much broken, landslips having taken place on a considerable scale. The conditions recall those observed in Islandmagee, the bed with green sponge-nodules, of the Spongiarian zone, being visible in one quarry, while the sponge-floor with *Ventriculites* and *Coscinopora* is also probably present.

Isolated blocks of glauconitic sandstone were also found by us, containing pebbles  $\frac{1}{2}$  inch in diameter, abundant *Inoceramus*-fragments, *Terebratula carnea*, Sow., and a *Rhynchonella* (possibly *plicatilis*). This district is also characterized by the abundance of *Spondylus spinosus*, Sow., and *Ostrea vesicularis*, Lam. Gasteropoda, such as *Pleurotomaria* and *Turbo*, fishes (*Corax maximus*, *Lamna acuminata*, Ag., *L. appendiculata*, Ag., and *Ptychodus mammillaris*, Ag.), and several species of *Lima* have also been recorded by the Survey.

North of Garron Point, the officers of the Geological Survey record two exposures of glauconitic conglomerate, the one near Milltown, the other near Retreat Castle, 2 miles south-west of Cushendall. This rock (which is referred to the Upper Greensand in the Geological Survey Memoir, Expl. Sheet 14) is described as a bed about 12 inches thick, composed of pebbles of vein-quartz and Lias nodules, in a glauconitic ('chloritic') sand. *Terebratula carnea*, Sow., *Inoceramus* sp., *Pecten* [*Janira*] *quinquecostatus*, Sow., and *Lamna appendiculata*, Ag., are the principal fossils. It will thus be seen that it is probably identical with the rock examined by us at Carnlough.

The Eastern Division is characterized:—

#### Zonally:

1. By the reduction in thickness, or total absence, of the zone of *Exogyra columba*.
2. By the great development of the glauconitic sandy limestone containing fragments of *Inocerami* and *Spondylus spinosus*, the zone of *Inoceramus Crispi* of Tate.
3. By the presence in the above zone of definite fossil-bands.

#### Palæontologically:

4. By the abundance, in the Glauconitic Sands, of *Pecten* [*Chlamys*] *asper*, *P. Galliennei*, and small brachiopoda.
5. By the frequent occurrence of sea-urchins in the Yellow Sandstone and at the base of the Chloritic Sands.
6. By the existence of a Hexactinellid sponge-floor at the base of the White Limestone.

This division includes Tate's most typical sections, and it is here that Barrois obtained the evidence which led him to recognize the

existence of Turonian strata in Ireland. It is in view of these facts that I have dealt at some length with the description of this district.

#### (4) THE PENINSULAR OR INSULAR DIVISION.

(Between Cushendall and Ballycastle, and Western Cretaceous exposures of Co. Derry.)

North of Cushendall the coast consists mainly of rocks far older than the Cretaceous, though on the hill-slopes patches of Chalk are from time to time visible under the cappings of basalt. In one locality only, namely, at Murlough Bay, near Ruebane Point, 6 miles east of Ballycastle, the junction of the Chalk with the underlying beds is clearly displayed. (See Pl. XLIV.) Here the red Triassic sandstone is separated from the White Limestone by a well-marked conglomerate, a foot thick, consisting of pebbles of quartzite, 1 inch in diameter, vein-quartz, mica-schist fragments (these sometimes also included in the Chalk above), red sandstone, and Lias nodules, the whole being enclosed in a glauconitic limestone. Fossils are sparsely distributed, *Rhynchonella octoplicata*, Sow., being the most conspicuous species present.

As the white limestone here rests so closely on beds of sandstone, it seemed advisable to take samples of the chalk from different levels above the Pebble-conglomerate, with a view to determining whether denudation of the land had ceased suddenly, or whether there had been a gradual diminution in the quantity of detrital material. Consequently, specimens were selected from the Pebble-conglomerate, and from the immediately overlying Chalk, the remaining three samples of chalk being obtained at intervals of 6 feet above. The results are described in the Chemical Section, pp. 579-584 & Table II.

The best sections in this division are, however, to the west in Co. Derry, and are as follows:—

#### Magherafelt, Moneymore, and Tamlaght.

Prof. Judd has placed in my hands a collection made by him at Moneymore, which clearly shows the presence of an important Cretaceous beach at this locality. The quartzite and quartz-schist pebbles here attain considerable dimensions, one being over 3 inches long, 2 broad, and  $\frac{3}{4}$  thick. Associated with these are a number of organic remains, including abundant specimens of *Galerites abbreviatus*, Goldf. (very small and low, and showing but little trace of the original structure), gasteropoda (*Trochus* or *Turbo*, *Acteon*, *Emarginulina*), pelecypoda (*Venus* sp., *Pecten* [*Janira*] *quinquecostatus*, Sow., *Inoceramus*-fragments), also a much-rolled *Actinocamax*, in outline resembling *A. Alfridi*, and other forms which do not permit of absolute identification. (For Cretaceous beaches, see p. 601.)

Formerly there appears to have also been an important exposure at Tamlaght, near Coagh, Portlock recording it thus:—'The lower portion of the chalk is here a very curious pebbly or conglomeratic bed, with much green matter, but still containing many fossils of the lower chalk or grey marl, such as *Ammonites lewesiensis*, *Nautilus elegans*, var., *N. radiatus*, d'Orb.,<sup>1</sup> *Baculites Faujasii*, *Hamites* sp., *Inoceramus Cripsii*, *Cardium decussatum*, etc. Its total thickness is about 30 feet, and it rests on the variegated shales or marls of the New Red Sandstone.'<sup>2</sup> In addition, he mentions *Ventriculites radiatus*, Mant., and *Holaster planus* (Mant.), (small specimens .6 inch long). *Echinocorys ovatus*, Lam., *Catopygus columbarius* aff., and *Belemnitella mucronata*, Schloth., have also been recorded.

Respecting *Ammonites lewesiensis*, Sowerby remarked, 'These specimens lead me to suspect that *A. lewesiensis* is only a compressed variety of *A. peramplus*.' Those obtained at Tamlaght very closely resemble Mantell's original examples. This species is said to be abundant in the lower or glauconitic portion of the western chalk, and seems to mark a distinct bed along its escarpment. The rock itself consists of a pink chalk, with a few glauconitic grains scattered through it.

### Slieve Gallion.

In this district the Chalk beds overlie the Keuper marls, being about 30 feet thick near Coagh. The Geological Survey Memoir, Expl. Sheet 26, p. 28, states that, in a stream south of the large quarry N.W. of Spring Hill, the lower part of the Chalk is a compact white limestone speckled with minute grains of quartz, and containing water-worn pebbles of quartz, quartzite, and quartz-porphry. The arenaceous portion is confined to a depth of about 6 inches, but scattered pebbles occur for some distance higher up, embedded in the ordinary compact chalk, into which the former seems gradually to pass. In the adjacent quarry the chalk-rock is found to reach a thickness of about 30 feet above the Triassic strata.

At Slieve Gallion Carn (3 miles from the main summit of Slieve Gallion) the Chalk is seen to rest directly on Carboniferous sandstone. The lower part is a faint pink limestone dotted with a few glauconitic grains, but containing numerous pebbles and fragments of quartz. The officers of the Geological Survey regard this bed as a connecting-link between the Chalk and Upper Greensand, classing it with the former on account of the abundance of Chalk fossils which it contains. So far as can be judged, this deposit must be very similar in its fossil contents to that at Moneymore.

### Benbradagh, Dungiven, and Keady Hill.

The White Chalk of these localities is particularly interesting, on account of the character and abundance of the fauna that it contains.

<sup>1</sup> One labelled thus in the Jermyn Street Museum appears to me to be *N. Deslongchampsianus*.

<sup>2</sup> 'Report Geol. Londonderry, etc.,' Dublin, 1843, pp. 115-116.

The cephalopoda, gasteropoda, and small sea-urchins are especially noticeable, while many species of polyzoa and foraminifera have been obtained by Mr. Joseph Wright, from the interior of flints. From Benbradagh we are able to record a large *Pecten*, *Arca* sp., *Trochus* sp., *Baculites anceps*, Lam., *Hamites* sp., and *Anisoceras* sp.; from Dungiven, *Dianchora*, casts of corals (possibly Trochosmilian), *Ammonites* [*Pachydiscus*] *Griffithii*, Sharpe, *A.* [*P.*] *Oldhami*, Sh., and *Belemnitella mucronata*, Schloth.; and from Keady, *Galerites vulgaris* and *Calliostoma*. Dungiven is, moreover, rich in sea-urchins (*Echinocorys scutatus*, Leske, and *Galerites abbreviatus*, Goldf.), *Pleurotomaria*, and pelecypoda, including *Spondylus spinosus*, Sow., *Ostrea vesicularis*, Lam., and *Pecten* [*Janira*] *quinquecostatus*, Sow., besides numerous dimyaria, which have been referred by the officers of the Geological Survey to *Nucula*, *Thetis*, etc. Among brachiopoda may be mentioned *Rhynchonella limbata*, Schloth., *Rh. plicatilis*, Sow. (ordinary and *octoplicata* varieties), *Terebratula carnea*, Sow., and *T. semiglobosa*, Sow.

The base of the Chalk near Boyd's Mountain is said to be a compact sandstone mottled with glauconitic particles.<sup>1</sup>

The main characteristics of the Peninsular Division are:—

1. The great development of pebble-conglomerates at the base of the Chalk, which here rests directly on the older rocks. These conditions are already suggested in the northern portion of the Eastern Division.
2. The presence of well-marked Cretaceous beaches, having a rich fauna of gasteropoda and small sea-urchins.
3. The abundance of organisms in the lower strata of the White Limestone, resembling in character those found in a similar position in the Central Division.

#### (5) THE NORTHERN DIVISION.

(The Northern Coast of Co. Antrim and Rathlin I.)

##### Tircreven Burn.

An examination of this section made by Mr. Stewart and myself, in the burn north of Ben Evenagh, proved very disappointing. The Cretaceous rocks were displayed in the valley a little below the junction of the two streams, the strata dipping at a high angle (about 15°) up stream, or eastward. They consist in the upper part of a nodular pink chalk dotted with glauconitic grains, passing below into a more glauconitic limestone, containing *Spondylus spinosus*, Sow., *Belemnitella* sp., worn *Inocerami*, and fragments of *Echinocorys* and sponges, a fauna recalling in its character that of the Spongiarian zone. Portlock also appears to have found evidence

<sup>1</sup> Mem. Geol. Surv. Irel. Expl. Sheet 12, p. 1

of the presence of the Glauconitic Sands with *Exogyra lævigata* and *Janira quinquecostata*, but these do not as yet appear to have been obtained in place.

### Downhill to White Park Bay.

Along the northern and north-eastern coasts of Antrim, from Downhill, three stations east of Portrush, to White Park Bay, the White Chalk is well displayed, the Lias underlying it unconformably both at Portrush and White Park Bay. It is in this region a very compact white limestone, with flint-layers at intervals of about 4 feet. The fossils appear to be of the usual character.<sup>1</sup> At one spot on the east side of White Park Bay Barrois was able to make out the following succession:—

	Feet.
1. White compact limestone with flints ( <i>Belemnitella mucronata</i> and <i>Echinocorys scutatus</i> ) .....	} 100
2. The same with <i>Belemnitella</i> [ <i>Actinocamax</i> ] <i>quadrata</i> .....	
3. White limestone with three bands of flints (large <i>Inoceramus</i> -fragments and <i>Echinocorys gibbus</i> ) .....	7
4. White limestone with flints, with <i>Belemnitella</i> [ <i>Actinocamax</i> ] <i>vera</i> , <i>Micraster</i> sp., <i>Marsupites ornatus</i> , <i>Bourgueticrinus ellipticus</i> , etc. ....	5

Below this point the strata present no special features of interest.

My attention has also been called by Mr. W. W. Watts to the pinkish marly conglomerate near Ballycastle quay; but, although examined by several members of the Geologists' Association, it has not up to the present yielded any conclusive results. The officers of the Geological Survey appear to have found *Terebratulina gracilis* in some abundance, but I have hitherto obtained the species in Ireland only in specimens of the Spongiarian zone from Hillsport (Islandmagee), sent me by Miss Thompson.

The most noticeable points in the Northern Division are:—

1. The great thickness attained by the White Limestone, and the presence in it of *Marsupites*.
2. The reappearance of several elements characteristic of the Eastern Division, such as the Spongiarian layer and the *Inoceramus*-beds.
3. The presence of Glauconitic Sands with *Exogyra lævigata*.

### II. CHEMICAL AND MICRO-MINERALOGICAL SECTIONS.

The second portion of this paper is devoted to a chemical and microscopical examination of a series of typical rocks, selected from the principal lithological or zonal divisions of the Irish Cretaceous, the methods adopted being similar to those employed by me in

<sup>1</sup> For lists see Barrois, 'Recherches sur le Terrain Crétacé Supérieur de l'Angleterre et de l'Irlande,' Lille, 1876, p. 206, and Geol. Surv. Irel. Mem. Expl. Sheets 7 & 8, pp. 45, 46.

I.—COMPARATIVE

Classification of Barrois.	sular Division.	Northern Division.	England.
.....	.....	.....	White Chalk of Trimmingham.
<i>Belemnitella mucronata</i> = White Limestone with flints.	te Limestone ints. Cephalo- a, etc., very mon at base.	White Limestone with flints 100 feet + thick, with <i>Echinocorys ovatus</i> at base.	White Limestone, with large flints above.



I.—COMPARATIVE TABLE OF ZONAL AND DIVISIONAL CLASSIFICATION (CRETACEOUS STRATA OF COUNTY ANTRIM).

Division.	Zone.	Zonal Classification of Tate.	Classification of Barrois.	Classification of Gault. Central Division.	Classification of present Paper.	Southern Division.	Central Division.	Eastern Division.	Peninsular Division.	Northern Division.	England.
SENONIAN OR UPPER CHALK.	Maestrichtien.	Upper part of White Limestone.	.....	.....	.....	.....	.....	.....	.....	.....	White Chalk of Trimmingham.
	<i>Belemnitella mucronata.</i>	White Limestone = zone of <i>Ammonites gollevillensis</i> . Spongiarian Zone.	<i>Belemnitella mucronata</i> = White Limestone with flints.	Zone of <i>Belemnitella</i> = White Chalk.	Zone of <i>Belemnitella mucronata</i> = White Limestone with flints.	White Limestone with regular layers of flint, 40 feet.  Mulatto	White Limestone with regular layers of flint 40-50 feet thick; rich fauna at base. In some places the Mulatto Stone occurs at the base of this zone.	White Limestone with regular bands of flint.  Large ammonites at base.	White Limestone with flints. Cephalopoda, etc., very common at base.	White Limestone with flints 100 feet + thick, with <i>Echinocorys ovatus</i> at base.	White Limestone, with large flints above.
	<i>Belemnitella [Actinocamax] quadrata.</i>	<i>Echinocorys gibbus</i> = Chloritic Chalk.	Not recognized.	Not specially recognized. Tabular flint at base.	Nodular Chalk, zone of <i>Belemnitella [Actinocamax] quadrata.</i>	Stone. Triassic Marls below.	Nodular Chalk with <i>Belemnitella [Actinocamax] quadrata.</i>	Not recognized as distinct zone.	Conglomeratic beds with gasteropoda.	<i>Belemnitella [Actinocamax] quadrata</i> at base.	Chalk with flints.
	<i>Belemnitella [Actinocamax] vera</i> or <i>Marsupites.</i>	Absent.	White Limestone with flints.	<i>Marsupites</i> = Chloritic Chalk.	Spongiarian zone.		Spongiarian zone with <i>Belemnitella [Actinocamax] vera.</i>	Spongiarian zone with <i>Belemnitella [Actinocamax] vera.</i>	Triassic, Carboniferous, and older rocks.	Flintless White Limestone, with <i>Belemnitella [Actinocamax] vera,</i> <i>Marsupites,</i> and <i>Micrasters.</i>	Chalk often without flints.
	<i>Micraster cor-anguinum.</i>	Do.		Zone of <i>Micrasters.</i>	Zone of <i>Echinocorys gibbus</i>		Not represented.	Glauconitic sandy limestone with <i>Echinocorys gibbus</i> and <i>Camerospongia.</i>			Chalk with zoned flints.
	<i>Micraster cor-testudinarium.</i>	Do.	Chloritic Chalk.		and <i>Inoceramus</i> -zone, with <i>Micraster breviporus</i> and <i>Rhynchonella</i> -band at base.		Not represented. <i>Inoceramus</i> -zone absent.	<i>Terebratula carnea</i> and <i>Serpula filiformis</i> ; <i>Inoceramus</i> -bands numerous; <i>Spondylus spinosus</i> throughout; <i>Ostrea semiplana</i> ; <i>Rhynchonella</i> -band.		Glauconitic Limestone, with <i>Inoceramus</i> -fragments.	Chalk with large bands of flints; <i>Micraster cor-testudinarium</i> abundant. Nodular rock with
	Chalk Rock.										
TURONIAN OR MIDDLE CHALK.	<i>Holaster planus.</i>	Do.	Zone of <i>Inoceramus Crispi.</i>	Lowest part of previous zone may belong here.		Not represented.	<i>Micraster breviporus.</i>			Not known.	<i>Micraster breviporus,</i> or <i>Holaster planus,</i> and chalk with same.
	<i>Terebratulina gracilis.</i>	Do.	Unconformity. Zone of <i>Ostrea columba.</i>	Part of the <i>Exogyra columba</i> -zone may belong here.		<i>Callianassa</i> -beds and yellow greensands	Part of the yellow-green sands with		Do.	Soft white chalk, or with marly bands, and with <i>Terebratulina gracilis.</i>	
	<i>Inoceramus labiatus</i> or <i>Rhynchonella Cuvieri.</i>	Do.				with fish-teeth, and the <i>Exogyra-columba</i> band may belong here.	<i>Ostrea semiplana</i> may belong to the Turonian.		Do.	Increasingly nodular chalk with <i>Inoceramus labiatus.</i>	
	Melbourn Rock.								Do.	Marls and limestones with <i>Belemnites plenus.</i>	
CENOMANIAN OR LOWER CHALK.	<i>Belemnites [Actinocamax] plenus.</i>										
	<i>Ammonites [Acanthoceras] rotomagensis.</i>	Chloritic Sands and Sandstones.	Yellow Sandstones	Zone of <i>Holaster-subglobosus.</i>	<i>Exogyra columba</i> -zone (major part or whole).		Major portion of <i>Exogyra columba</i> -zone should be referred here. <i>Trigonia,</i> <i>Ostrea carinata,</i> and <i>Orbitolina</i> at the base.	Yellow-green sands with <i>Exogyra columba</i> and <i>Catopygus columbarius,</i> and Glauconitic calcareous sandstone, with <i>Rhynchonella Schlenbachi.</i>		Do.	Grey Chalk with large ammonites, <i>Nautili,</i> and <i>Terebratule.</i>
	<i>Ammonites [Schlenbachia] varians.</i>		and <i>Inoceramus</i>				Scattered brown nodules.			Do.	Chalk Marl with <i>Ammonites varians</i> and <i>Rhynchonella Martini.</i>
UPPER GREENSAND.	Chloritic Marl.	<i>Crispi</i> -zone.			Nodules possibly.					Do.	Bed with brown nodules.
	<i>Pecten asper.</i>	Yellow Sandstones = zone of <i>Ostrea carinata.</i>	Glauconitic Sands.	Zone of <i>Pecten asper.</i>	Yellow Sandstones = zone of <i>Ostrea carinata</i> and zone of <i>Exogyra conica</i> in part,	Yellow Sandstone with large <i>Ostrea carinata,</i> <i>Panopea mandibula,</i> etc.	Yellow Sandstone with <i>Pecten quadrucostatus,</i> <i>Discoidea subucula,</i> and <i>Micrabacia coronula.</i>			Do.	In the west, yellow sands with cherts.
	<i>Ammonites inflatus.</i>	Glauconitic Sands = zone of <i>Exogyra conica.</i>	Note.—Barrois adopts Tate's zonal names.		and Glauconitic Sands = zone of <i>Exogyra conica.</i>	Glauconitic Sands. Abundant <i>Exogyra conica,</i> var. <i>laevigata,</i> <i>Pecten orbicularis.</i> Large Dimyarian mollusca.	Glauconitic Sands, with <i>Exogyra conica,</i> var. <i>laevigata,</i> <i>Pecten orbicularis.</i> <i>P. quinquocostatus.</i> many stunted brachiopoda, and numerous species of subgenus <i>Chlamys.</i>		Glauconitic Sands, with <i>Exogyra conica,</i> var. <i>laevigata.</i>	In the west, micaceous greensand with <i>Exogyra conica,</i> etc.	



studying the Cretaceous zones of the Isle of Wight and Folkestone.<sup>1</sup>

Many of the samples were obtained at Woodburn Glen, a locality which has been especially referred to by both Tate and Barrois; while from Murlough Bay a series of specimens were selected for the reasons mentioned on p. 565. I may recall that in Table II. the 'main residue' consists of the fine clayey or siliceous materials, the 'heavy residue' being the organic and mineral contents which remain after the clay has been removed by repeated washing and decantation.

### Glauconitic Sands. (Zone of *Exogyra conica*.)

#### Woodburn Glen. (No. 7 in Table II.)

The specimens obtained were of a deep-green colour, and consisted mainly of glauconite and quartz-grains loosely cemented by calcareous material. The samples were taken from the upper part of the bed, consequently above the well-known fossil-band.

The original weight, after drying, = 77.59 grammes. After solution in 20% hydrochloric acid there remained 58.66 grammes. Heavy residue = 75.6%.

Total composition:—

Carbonate of lime .....	24.4%
Heavy residue .....	75.6%
	100

The heavy residue was further subdivided into four divisions by sifting, namely:—

A (coarse). Weight = .45 gramme. Mainly composed of quartz-grains, the largest of which was a subangular fragment 3.5 mm. long and 1.5 mm. broad. The great majority of these are water-worn, and the larger ones are coloured green, pink, or yellow. Although many of the grains show evidence of the presence of crystal-faces, yet the angles are much worn down, and the smaller ones, averaging 1 mm. in diameter, are beautifully rounded and water-clear. A few small cleavage-fragments of red orthoclase are also present, the largest being about 1 mm. square.

B (medium). The greater proportion of this material consists of glauconite-grains of a deep blue-green colour. Most of these are undoubtedly the internal casts of foraminifera, the numerous lobes into which they are divided indicating the multi-chambered character of the genera which contained them. The average size of the better-defined examples is between .5 and 1 mm. As a rule it is quite impossible to determine the forms generically, but these may be differentiated into four types:—

1. Rotaline types, which include all grains having the chamber-casts rolled in a nautiloid manner, but with the earlier chambers only visible on one side. These are very numerous.

<sup>1</sup> See 'Chemical and Micro-Mineralogical Researches on the Upper Cretaceous Zones of the South of England,' London, 1893, pp. 11 & 12.

2. Haplophragmioid or Cristellarian types, in which the casts commence as spirally-convoluted chambers, the later chambers becoming rectilinear, or in some cases slightly curved inward, giving rise to crosier-like forms.

3. Globigerinoid types, the chambers being very globular in form, and in general not presenting the symmetrical arrangement displayed in the previous varieties.

4. Tritaxian types, which are much more indefinite and triangular in section, one of the edges being generally replaced by a narrow flat plane.

5. Together with the above, there are a number of oval forms having a depression running parallel to the major axis, which can be explained only as being the internal casts of ostracod valves, though any attempt at closer identification is impossible.

6. One beautiful cast of an undoubted *Cristellaria* was observed, every chamber being clearly outlined, the general form being that of *Cr. gibba*. It will be noticed that Textularian and Milioline types are unrepresented, nor have any sponge-casts been observed.

The glauconitic material from this locality has been chemically examined by Mr. A. P. Hoskins,<sup>1</sup> and the general results are of some interest. The point on which he lays most stress is the relative poverty in silica of the Woodburn specimens, the ascertained amount (40% SiO<sub>2</sub>) being 10% less than the lowest percentage obtained by Sipöcz in analyses of *Challenger* samples. The ferric oxide is also 4% less than the mean, while the percentage of potash is nearly double that found in the modern glauconite.

C. The lighter residue mainly consists of small quartz-grains .25 mm. in diameter.

D. The heavy-residue minerals, separated by means of cadmium borotungstate (sp. gr. 2.9), are as follows:—

Rutile. This mineral occurs both as crystals and grains. The crystals have a maximum length of .18 mm., breadth .07 mm., the faces of the prism and pyramid being well developed. Their pleochroism is deep yellow to straw-yellow, and they possess a prominent black border, due to their high refractive index. The enclosures are numerous, and have in most cases irregular outlines. In one crystal the central portion polarized in a deep orange-red, the outer part being bright golden yellow. Orange-yellow grains of rutile are numerous, as also very rounded examples of zircon. These are easily noticed on account of their high refractive index and high order polarization-colours. A few well-marked crystals are present, the largest having a length of .17 mm., with the prismatic faces well developed and the pyramidal faces much reduced.

Muscovite is not uncommon, in thin silvery flakes, which, owing to their extreme tenuity, do not display the high colours familiar in the same mineral when examined under crossed nicols in rock-sections. In nearly all cases they are seen to be of hexagonal outline, being viewed at right angles to the basal plane.

Biotite is also present in brown scales, which practically display

<sup>1</sup> Proc. Belfast Nat. Field Club, 1894-95, pp. 1-2.

no pleochroism, but, like the muscovite, are easily recognized by their glitter, especially when the residue is being washed in water.

Tourmaline is very rare, and when it occurs is in the prismatic forms with which we shall have to deal more fully in the higher zones.

The principal points of note in the above zone are :—

1. The abundance and large size of the glauconite-grains.
2. Their derivation in all cases as casts of the internal chambers of foraminifera, etc.
3. The extreme rounding of the grains of quartz.
4. The presence of muscovite and biotite, rutile, and zircon (the latter more usually rounded), and the rarity of tourmaline.

### Glauconitic Marls.

#### Woodburn Glen. (No. 6 in Table II.)

The rock is a blue-grey marl, dotted with glauconitic grains.

The original weight, after drying, = 80·63 grammes. After solution in 20% hydrochloric acid, there remained 29·18 grammes of residue = 36·19%. Total composition:—

Carbonate of lime, etc. ....	63·91 %
Sandy clay .....	= 18·30 grs. = 22·70 %
Heavy residue .....	= 10·88 „ = 13·39 %

100

The main residue consisted essentially of a dark blue siliceous clay, containing minute flakes of mica and spheres of iron pyrites.

The heavy residue chiefly contained grains of glauconite, many of which show clear traces of their origin as organic casts. Most of these are Globigerinoid or Rotaline in form, one-, three-, or five-chambered aggregates being frequently noticed. The remainder is, mainly composed of quartz-grains, the larger ones perfectly rounded and colourless, or else subangular and even highly angular; while the finer residue consists almost entirely of quartzose angular particles and flakes of silvery muscovite.

By means of heavy liquid the following minerals were obtained :—

**Tourmaline.** Crystals of this mineral are abundant, the hexagonal prism and rhombohedral terminations being well developed. The length varies from ·048 to ·161 mm., and the breadth from ·029 to ·068 mm. The colour is usually yellow-brown to purple-brown, minute dark enclosures also being very abundant. The absorption is, as usual, very strong, with  $O > E$ , and in the smaller examples the polarization-colours are high, of delicate pink and blue tints. A few fragments are also present.

Rutile occurs in red and deep yellow-brown rods (maximum length ·165 mm., breadth ·03 mm.) and light yellow irregular fragments. One of the crystals is beautifully zoned and twinned, giving rise to the familiar knee-shaped combination. In one of the larger yellow masses numerous enclosures of ellipsoid, rod-like, and irregular character are visible.

Zircon is present in very rounded grains, many of which are distinctly zoned. Maximum length .056 mm., breadth .026 mm.

Iron Pyrites is abundant in rods, rounded aggregates, and thin films, and limonite is also not uncommon.

As previously mentioned, flakes of silvery muscovite and brown biotite are numerous, in addition to green micaceous films of chlorite.

Garnet. A very transparent mineral, having perfect crystalline form (rhombic dodecahedron) and quite isotropic, agrees in its characters with the crystals which have been definitely determined in the next zone.

Kyanite. A rectangular block with feebly-developed pinacoidal cleavages at 90°, polarizing in low grey tints and having an extinction angle of 30°, is evidently an example of this mineral.

As in the previous cases, opaque white and dull brown adamantine grains are numerous, but their true nature has not been determined.

A second experiment carried out on 42.45 grammes of material yielded:

Carbonate of lime.....	70.32%
Residue .....	29.68%

100

While the marl was dissolving a delicate foraminifer was obtained, which Mr. Chapman has identified as *Flabellina cordata*, Reuss, a representative of the *Nodosariniæ* most commonly present in the Cenomanian. Further washing of the marl for foraminifera yielded no further results.

Compared with the previous zone, the Glauconitic Marls show:—

1. A diminution in the size and quantity of the glauconitic grains.

2. An increase in the calcareous constituents.

3. An increase in the amount and variety of the contained detrital minerals, accompanied by a diminution in their size.

4. An abundance of tourmaline, particularly in the crystal form.

Especially characteristic of these marls is:—

5. The abundance and variety in form of iron pyrites.

While we may further note:—

6. The presence of kyanite and garnet.

### Grey Marls or Yellow Sandstone.

#### Woodburn Glen. (No. 4 *a* in Table II.)

The weight of material employed in the analysis was 83.74 grammes. After solution in acid the insoluble residue yielded:—

Clay.....	36.88 grs. or	$\left\{ \begin{array}{l} \text{CaCO}_3 \dots\dots\dots 45.22\% \\ \text{Clay} \dots\dots\dots 44.04\% \end{array} \right.$
Heavy residue ...	8.99 „ =	
	45.87	99.99

The main residue consists chiefly of finely-divided clay and minute quartz-grains.

The heavy residue was divided by sifting into four parts:—

A. Exceeding 1 mm. in diameter = .33 gramme; this is composed almost entirely of water-clear rounded grains of quartz. But some which are green-tinted, due to thin films of chlorite, are more angular in character.

B. .345 gramme is formed of quartz- and glauconite-grains in about equal proportions, these having an average diameter of .5 mm. The quartz is, in the main, rounded and transparent. A few silicified *Inoceramus*-prisms are also present, together with red and black fragments whose nature has not been determined. The glauconitic grains show distinct evidence of alteration to a lighter yellow-green product, only the darker green forms retaining their organic outline.

C. The finest portion of the residue (8.18 grammes) consists of minute angular grains of quartz, some of them almost rod-like in character, flakes of mica, well-crystallized blocks of iron pyrites, and green glauconite-grains.

D. The heaviest residue, obtained by the use of heavy liquids, though not abundant, was interesting. The minerals, in order of note, are as follows:—

Iron Pyrites or Marcasite. It is practically impossible to distinguish between these two forms of iron sulphide, though the silvery white aggregations more probably contain a larger proportion of the latter, and the brass-yellow cubic crystals may be safely referred to the former.

Tourmaline. Crystals of this mineral are fairly abundant, the rhombohedral faces being well-marked at one extremity, while the other end is irregularly outlined or flat, having apparently suffered fracture.

Zircon. Fragments of this mineral are numerous, but distinct crystals are few and these also rarely show zoning.

Rutile occurs in orange-yellow irregularly-shaped grains, no crystals being noted.

Anatase. This is, so far as I am aware, the first record of this mineral in the Cretaceous of these islands. The crystal is of a blue colour, changing to pale golden yellow. The pyramidal form is clearly shown at one extremity, but the other end has been cleaved parallel to the basal plane. The lustre is adamantine, and the length = .046 mm.

Chlorite is present in thin micaceous films.

This zone differs from the preceding by:—

1. The greater abundance of detrital materials.
2. The reduction in amount of glauconite.
3. The presence of anatase.

Yellow Sandstone. (Zone of *Ostrea carinata*.)

Hillsport, Islandmagee. (No. 5 a in Table II.)

The specimens obtained were of a light yellow colour, and apparently consisted of quartz-grains with a slight admixture of glauconite.

The original weight after drying = 41.39 grammes. After solution in 20% hydrochloric acid there remained 24.6 grammes = 59.4%, or total percentage composition :—

Carbonate of lime .....	40.6%
Residue .....	59.4%
	100

The residue consists mainly of sand-grains, very minute glauconitic casts, fragments of opal showing traces of organic structure, and abundant thin flakes of muscovite exhibiting iridescent tints. In addition the following minerals were observed: rutile, no definite crystals, but red and orange-yellow fragments; zircon, both in well-terminated crystals and rounded grains, .085 mm. in diameter; tourmaline, generally showing perfect prismatic outline and good rhombohedral terminations; biotite in thin brown cleavage-flakes.

A green mineral showing strong cleavage parallel to the vertical axes with occasional cross cleavages at 90°, having straight extinction, fair polarization-colours, and no apparent pleochroism, most resembles enstatite in its appearance and characters.

A dull black mineral occurring in rounded botryoidal fragments is also present, often displaying a bluish tint. When tested in borax and sodium-carbonate beads in the reducing flame, no evidence of manganese or iron was obtained. At present, therefore, its true nature must remain uncertain, although both limonite and psilomelane have suggested themselves.

Yellowish brittle masses are also present, of less hardness than glass, but not as yet further recognized.

#### Yellow Sandstone.

##### Colin Glen. (No. 5 in Table II.)

Forty grammes of the rock yielded 25.3 grammes of residue = 63.25%, that is :—

Carbonate of lime .....	36.75%
Residue .....	63.25%
	100

The residue consists mainly of small quartz-grains less than .25 mm. in diameter, thin flakes of muscovite, tourmaline in beautifully-preserved crystals (showing hexagonal prisms terminated by rhombohedral faces), rutile in deep red, more or less rounded grains, and rounded examples of zircon.

The rock differs from that previously described in not containing any glauconitic casts, and both the Yellow Sandstones are lacking in iron pyrites, therein differing from the Grey Marls of Woodburn.

#### Enclosure in Grey Marls.

##### Woodburn Glen. (No. 4 in Table II.)

Of the enclosed calcareous sandstone 79.97 grammes was dissolved in 20% hydrochloric acid, yielding 49.84 grammes of residue, almost the whole of which can be classed as heavy.

Total percentage composition :—

Carbonate of lime .....	37·68 %
Clay, etc. ....	1·86 %
Heavy residue .....	60·46 %
	100

The largest fragment is a block of quartz, coloured green by thin chloritic films, 4 mm. in length and 3·5 mm. in breadth. There are also yellow grains of the same mineral (2 mm. in greatest diameter), most of the water-clear type having an average size of 1·5 mm. While the majority are extremely rounded, it should be noted that those having a green tint are in almost all cases distinctly sub-angular. Glauconite is also present, showing traces of organic structure. A few cleavage-flakes of red orthoclase also occur. The greater part of the residue consists, therefore, of beautifully rounded quartz- and glauconite-grains.

In a heavy liquid having a specific gravity of over 3·34, a large crop of minerals was obtained, including —

1. Rounded transparent dark-bordered zircons.
2. Deep red and light yellow grains of rutile.
3. Beautifully perfect crystals (rhombic dodecahedra) of garnet of a pink to red colour, remaining entirely isotropic under crossed nicols.
4. Crystallized iron pyrites.
5. Kyanite is also present in some quantity, having the same characters as the mineral described under the Glauconitic Marls (p. 572).

In the lighter residue occur large crystals of tourmaline and green flakes of chlorite.

It will thus be seen that these enclosed fragments are particularly distinguished by the abundance of their detrital residue, the minerals noticed being quartz, orthoclase, zircon, rutile, tourmaline, garnet, kyanite, iron pyrites, glauconite, and chlorite. In the presence of garnet and kyanite this grit resembles the Glauconitic Marls rather than the Yellow Marls in which it is enclosed.

*Inoceramus*-band. (Zone of *Inoceramus Crispi*, Tate.)  
Woodburn Glen. (No. 3 in Table II.)

After solution 81·42 grammes yielded 27·34 grammes of insoluble material, 25·97 of which may be called heavy residue.

¶¶ Total composition :—

Carbonate of lime .....	66·42 %
Clay .....	= 1·37 grs. = 1·68 %
Heavy residue .....	= 25·97 „ = 31·90 %
	100

The residue, above 1 mm. in diameter, consists in the main of angular and rounded fragments of quartz- and glauconite-grains. These occasionally show their origin as organic casts, and have a

deep green colour, but in most cases are altering to a light green variety.

The quartz-grains are usually translucent, the largest being 4.5 mm. long and 3 mm. broad, and are at the same time coloured green by films of chlorite. The water-clear examples are far more rounded than those which are coloured, but some still retain angular outlines. There are also loose aggregates of quartz and glauconite, probably formed *in situ*. We may thus divide the coarser detrital materials into three parts:—

- (a) Quartz derived from schists, etc., usually coloured and subangular.
- (b) Quartz-grains which are water-clear, transparent, generally highly rounded, and probably derived from clastic rocks.
- (c) Loose friable aggregates of quartz and glauconite, presumably formed in place.

In this zone first appear delicate meshes of Hexactinellid sponges replaced in glauconite, though unfortunately most of them break up very readily. One of these, which was somewhat better preserved than others, has been examined by Dr. G. J. Hinde, who informs me that from so small a piece it is impossible to state the genus to which it belonged, though it may not improbably be a mesh of *Plocoscyphia*.

The finer residue is composed of glauconite and angular grains of quartz, together with many thin flakes of silvery white mica. The glauconite is frequently in the form of green rods, these being portions of the spicular meshes previously mentioned.

A number of heavy minerals were obtained by the use of borotungstate of cadmium (sp. gr. 2.93), these including:—

Zircon, frequently well preserved, showing combinations of the prism and pyramid of opposite orders. One was identical in form with Dana's type 5 with elongated axis.<sup>1</sup> Beautifully rounded grains are also numerous.

Rutile in deep crimson and orange-yellow fragments.

Tourmaline, both in black columnar (schorl) and grey-brown crystals.

Garnet of a distinct pink colour, in perfectly formed rhombic dodecahedra.

Kyanite, showing two cleavages at 90°, low polarization-colours, and extinction at about 30°.

Pyrites is present as small spheres of brassy-metallic lustre, also in combinations of cubic crystals, while rod-like silvery white aggregates must probably be referred to marcasite. A *Textularia globulosa* was observed completely replaced in pyrites.

Limonite is very abundant in dull-red amorphous masses.

Muscovite is common in the lighter washings.

For interprismatic silicification of *Inoceramus*, see p. 556.

This zone markedly differs from the preceding in:

1. The great increase in the calcareous constituents.
2. The presence of glauconitic sponge-meshes.

<sup>1</sup> 'System of Mineralogy,' 6th ed. (1892) p. 483.

Chloritic Chalk (Spongiarian Zone).  
Woodburn Glen. (No. 2 in Table II.)

After solution 80.66 grammes yielded 4.88 grammes of insoluble material, 3.96 of which may be classed as heavy residue.

Total composition :—

Carbonate of lime .....	93.95 %
Clay, etc. ....	= .92 gr. = 1.14 %
Heavy residue.....	= 3.96 grs. = 4.91 %
	100

The residue exceeding .5 mm. in diameter consisted of angular colourless flakes of quartz, and a great abundance of glauconitic grains, most of which are changing to a yellowish or reddish alteration-product, having a limonitic aspect. A special feature is the perfect preservation of many of the casts, the nature of the foraminifera being easily determinable, while spicular meshes are also conspicuous. A few delicate white siliceous tests of foraminifera are also present.

Mr. Chapman has been able to identify the following species from these well-preserved glauconitic casts, and the remarks attached are his :—

<i>Textularia globulosa</i> , Ehr. ....	Internal casts, frequent.
<i>T. anceps</i> , Reuss .....	One example of an internal cast.
<i>Verneuilina triquetra</i> (Münst.) ...	An external cast.
<i>Tritaxia tricarinata</i> , Reuss .....	Internal casts.
<i>Bulimina Orbigny</i> , Reuss .....	An external cast.
<i>B. elegans</i> , d'Orb. ....	" " "
<i>B. Murchisoniana</i> , d'Orb. ....	" " "
<i>B. obtusa</i> , d'Orb. ....	" " "
<i>B. variabilis</i> , d'Orb. ....	" " "
<i>Globigerina bulloides</i> , d'Orb.....	" " "
<i>G. æquilateralis</i> , Brady .....	" " "
? <i>Discorbina rosacea</i> (d'Orb.) .....	An internal cast.
<i>Anomalina ammonoides</i> (Reuss) ...	External casts.
? <i>A. grosserugosa</i> (Gümbel) .....	External and internal casts.
<i>Truncatulina Ungeriana</i> (d'Orb.)..	Internal casts.

For further notes on these casts, see p. 581.

In the finer residue, angular transparent quartz, glauconitic spicular meshes, fragments of silicified foraminifera, and hexagonal flakes of muscovite are numerous. The glauconite-grains and quartz are often coated with a layer of red-brown limonite. In general the former do not show much trace of their organic origin, except in the case of the green rods (casts of spicular axial canals presumably), which are relatively most abundant in the finest portion of the residue.

Heavy minerals are less marked than in previous cases, though zircon, in colourless grains; rutile, in large yellow grains (no deep red varieties being noted); tourmaline, fairly abundant and in good crystals; garnet, in small pink rhombic dodecahedra and larger flat fragments; felspar, undergoing kaolinization; and chlorite, in blue-green flakes, have been noticed.

The principal points of interest in this zone are:—

1. The predominance of calcareous constituents.
2. The angularity of the quartz-grains.
3. The abundance and good preservation of glauconitic casts of foraminifera and sponge-meshes.
4. The diminution in the quantity and size of the heavy minerals, with the exception of tourmaline.

White Limestone. (Zone of *Belemnitella mucronata*.)

Woodburn Glen. (No. 1 b in Table II.)

Of this white chalk 82·4 grammes was dissolved in 20 % hydrochloric acid, yielding ·505 gramme of clay, and ·015 gramme of heavy residue.

Total percentage composition:—

Carbonate of lime .....	99·379 %
Clay, etc. ....	·613 %
Heavy residue .....	·0182 %
	100

The heavy residue consists of a few small angular quartz-grains, two or three flakes of muscovite, and limonite.

Same Zone, Divis Hill. (No. 1 in Table II.)

After solution as above 81·42 grammes yielded ·547 gramme of clayey material, and ·0042 gramme of heavy residue, the latter consisting almost entirely of limonite, with one or two quartz-grains (probably wind-blown).

Total percentage composition:—

Carbonate of lime .....	99·323 %
Clay, etc. ....	·672 %
Heavy residue .....	·005 %
	100

Same Zone, Magheramorne. (No. 1 a in Table II.)

On analysis 80·6 grammes yielded ·394 gramme of insoluble clay, silica, etc., and ·0327 gramme of heavy residue, giving

Carbonate of lime .....	99·47 %
Fine residue .....	·488 %
Heavy residue .....	·041 %
	100

The main residue consists of a thin, flaky brown clay, while the heavy residue is in greater quantity than is usual with chalks from the *Belemnitella mucronata*-zone. This excess is due, in some degree, to the presence of large silicified fragments of organisms; but the alteration has proceeded too far for us to be able to identify the

original nature of the test thus altered. Apart from these fragments, the detrital minerals are more numerous than in the other cases analysed, quartz-grains being abundant. These are mostly very angular, and are either colourless or coloured yellow by ferruginous coatings. In addition to these, zircon-crystals and tourmaline have been noted, though these are very rare. Glauconite-grains are also present, and show clearly that they have originated as the internal casts of foraminifera.

Speaking generally, the *Belemnitella mucronata*-zone is distinguished by the absence of detrital minerals.

The reasons guiding the selection of the following specimens obtained at Murlough Bay have been stated on p. 565.

#### Pebble-Conglomerate. (No. 12 in Table II.)

The specimens obtained consisted of a pink limestone, spotted with glauconitic grains, and enclosing rounded and subangular pebbles of quartzite and vein-quartz. The analysis is that of the chalk itself, the pebbles having been previously removed.

The original weight after drying = 53·67 grammes. After solution in 20% hydrochloric acid, there remained: Clay, etc. = 2·22 grammes; heavy residue = 38·56 grammes.

Total percentage composition :—

Carbonate of lime .....	28·16%
Clay, etc. ....	4·14%
Heavy residue .....	67·70%
	100

The main residue calls for little comment, consisting only of fine clayey material, enclosing minute grains of quartz and glauconite.

The heavy residue has been further subdivided, by means of sifting, into four parts :—

A (material that does not pass through a sieve with 30 meshes to the inch). Mainly composed of pebbles of quartzite, some altogether colourless, others coloured green owing to the presence of a thin chloritic coating, yellow-green masses of glauconite showing no traces of organic structure, red orthoclase-felspar, felspathic micaceous sandstone, finely micaceous golden-yellow sand-rock, and among the smaller examples colourless subangular grains of quartz.

B (not traversing a sieve of 60 meshes to the inch). In this residue the glauconite has more definite outlines, but its organic origin is very much obscured. Colourless and brown grains of quartz, both rounded and angular, are abundant. In many cases the glauconite-grains are distinctly tubular, having apparently been the internal casts of sponge-spicules. The light yellow-green glauconite-grains are clearly the first stages in the alteration of the deep-green varieties, most of which are undoubted internal casts of organisms. The latter are often coated with a lighter layer, or, if a dark-green grain be broken, it is often seen to have a distinct whitish to yellow border, penetrating to some depth. A few mica-flakes and silicified tests of foraminifera are also present.

C (not traversing a sieve of 120 meshes to the inch). Colourless quartz-grains make up the greater part of this residue, the remainder consisting almost entirely of dark-green and yellow-green glauconite, the former showing the characteristic rounded outlines.

D. The finest material is composed of very fine grains of quartz and glauconite, the former highly angular, and either colourless or pale yellow. Mica-flakes are numerous. By means of heavy liquid (cadmium borotungstate of sp. gr. 2·84), a large crop of heavy minerals was obtained, including rutile, zircon, tourmaline, garnet, and chlorite:—

1. Rutile.—In general this mineral shows no evidence of crystalline form, and is of an orange-yellow to a deep-red colour. While twinning is not marked in most cases, I have obtained one of the peculiar interlaced groups, consisting of a number of intergrown twinned needles, to which De Saussure applied the name of *sagenite*.

2. Zircon occurs in definite crystals of prismatic habit, the pyramidal terminations being, to some extent, rounded. Colourless grains are also not infrequent, the high refractive index and polarization-colours rendering them easy of identification.

3. Garnet.—This mineral is present in the form of pink-coloured fragments and perfectly formed crystals: the latter, owing to the unequal development of the faces of the rhombic dodecahedron, often appear to have a prismatic habit. Cleavage being wanting, the fracture-surfaces are usually irregular, and both fragments and crystals are, generally speaking, isotropic. It is very common in the residue.

4. Tourmaline.—A few crystals are present, showing the rhombohedral terminations and characteristically strong absorption.

5. Chlorite occurs in green flakes, when perfect showing hexagonal outlines, but not usually displaying strong pleochroism.

The most noticeable feature of this conglomerate is therefore the abundance and variety of the detrital materials.

### White Limestone immediately above the Conglomerate.

(No. 11 in Table II.)

This consisted of a white chalk in which a few pebbles of quartz were embedded.

The original weight after drying = 79·23 grammes. After solution there remained 3·35 grammes of residue = 4·24%, or

Main residue (clay, etc.) ...	= 1·82 gr.	= 2·29%
Heavy residue .....	= 1·538 „	= 1·94%
Carbonate of lime .....		95·77%

100

The heavy residue was further subdivided into:—

(a) Silicified *Inoceramus*-tests = 1·140 gramme. These consist of snow-white rectangular blocks, which show when fractured columnar

arrangements, like the pillars in an ancient temple. Chalcedonification has proceeded on an extensive scale, so that each pillar now consists of colloid silica, which has assumed a beaded form, due to the formation of minute stalactitic outgrowths of chalcedony. From the results obtained at Woodburn, we are led to the conclusion that this is but a further stage in the interprismatic silicification of the shells of *Inoceramus*.

(b) One mm. in diameter and above = .28 gramme. This includes a pebble of quartz with chlorite in the interspaces, 5 mm. in diameter. Most of the quartz-pebbles, which are numerous, are subangular, only the smaller grains being truly round. Glauconitic masses are numerous, but generally display no organic structure. In one case, however, it is clear that the whole consists of a delicate sponge-mesh of spicular casts still bound together, and further enclosed in a matrix of glauconitic material. Fragments of biotite, by their arrangement evidently relics of biotite-mica-schists, also occur.

(c) Residue over .5 mm. in diameter = .347 gramme. This consists almost exclusively of colourless, angular, subangular, and rounded quartz-grains, dark-green and yellow-green glauconitic casts (in general having no recognizable form, though one distinct spicular rod was observed), and fragments of silicified *Inoceramus*-prisms.

(d) Residue over .25 mm. in diameter. Practically the same as c, except that the quartz-grains are far more angular.

(e) Minute residue, about .22 gramme. The organic casts are more prominent than in the previous cases, the dark-green casts of the sponge-spicules often showing expanded knobs. Beautiful yellow casts of foraminifera, mostly in individual rounded cells, but sometimes exhibiting the whole structure in detail, are also preserved. Mr. Chapman, having examined these together with those of the Chloritic Chalk of Woodburn, has kindly supplied me with the following report:—

‘The glauconite-grains from the Chalk of the above localities are characterized by a quasi-translucent appearance, which is in distinct contrast to that of the glauconitic grains from some other sedimentary deposits, such as the *Nummulina*-zone of the Barton Series in the Isle of Wight, or the glauconitic clay of the Gault of Copt Point, near Folkestone.

‘Two kinds of casts are here present:—

‘Firstly, those which have been moulded within the chambers of the foraminifera. They reproduce most delicately all the minute spaces within the shell, even to the stolon-passages. The colour of these internal casts is usually found ranging from a dull yellow to an apple-green.

‘Secondly, there are grains in which the external form of the foraminiferal test is reproduced, and these usually have a less definitely finished surface, although many are exactly comparable in form with the original test. In point of fact, the casts selected exhibit so admirably all the superficial characters of the original shells that there can be no hesitation in assigning to the majority of the specimens their generic, and even specific, names.

‘ Besides the glauconite-casts of the foraminifera mentioned in the list below, there also occurred in the residues searched an example of a *Haplophragmium*, of small size, but probably *H. latidorsatum*, Bornemann, having the original arenaceous test:—

<i>Textularia agglutinans</i> , d'Orb. ...	An internal cast.
<i>T. globulosa</i> , Ehr. ....	Internal casts.
<i>Verneuilina spinulosa</i> , Reuss .....	„ cast.
<i>V. triquetra</i> (Münst.) .....	„ „
<i>Globigerina cretacea</i> , d'Orb. ....	„ casts.
<i>Anomalina ammonoides</i> (Reuss) ...	„ „
<i>Truncatalina Ungeriana</i> (d'Orb.)..	„ cast.'

It will be seen from the above report that, unlike the Chloritic Chalk of Woodburn, this limestone contains no external casts. The heaviest minerals were separated by means of cadmium borotungstate, and included deep-red fragments of rutile (not common), numerous colourless crystals (showing pyramid and prism), and rounded grains of zircon, grey-brown crystals and yellow-brown rounded examples of tourmaline, green flakes of chlorite, and amorphous red blocks of limonite. And here it may be well to mention that in many cases topaz is probably present. This mineral, owing to its comparatively low refractive index, may be easily mistaken for quartz, unless it be in well-marked cleavage-fragments. These do not, however, appear to be abundant. One crystal of garnet is also present. The average length of the prismatic minerals is .08 to .1 mm.

The principal differences between this and the previous residue are:—

1. The sudden reduction in the amount of detrital minerals present.
  2. The increasing angularity of the quartz-grains.
  3. The abundance of glauconitic internal casts of foraminifera.
- Compared with the casts obtained from Woodburn, we have
4. The apparent absence of external casts.

### Chalk, 6 feet above the Conglomerate. (No. 10 in Table II.)

After solution in acid, 72.86 grammes of chalk yielded 2.250 grammes of residue = 3.088 %, or a percentage composition of:—

Carbonate of lime, etc. ....	96.91 %
Clay, etc. .... = 1.51 gr. =	2.07 %
Heavy residue .... = .74 „ =	1.02 %
	100

In the coarse heavy residue none of the grains exceed 1 mm. in diameter; these consist mainly of rounded and rectangular fragments of quartz, and irregular glauconitic aggregates. The

finer residue is interesting from the abundance of glauconitic casts of sponge-spicules. Some of these are merely tapering rods, others are expanded at one extremity, forming a flat or subdivided head, separated from the main body by a constriction, and some are also spindle-shaped. Most of these are of a deep-green colour, therein contrasting with the yellow casts of the foraminifera. Of these, rounded individual chambers are most numerous, but unions of such are not uncommon, though the latter are not so well preserved as in the previous examples. Portions of a Textularian cast, showing the alternating character of the chambers, and *Globigerina* have been observed. Fragments of delicate silicified tests are also present.

No heavy minerals were obtained by the use of heavy liquids.

The most noticeable features in this limestone are :—

1. Quartz-fragments less than 1 mm. in diameter.
2. The increasing abundance of sponge-spicule casts.
3. The absence of heavy minerals.

### Chalk, 12 feet above the Conglomerate.

(No. 9 in Table II.)

After solution in acid, 80·92 grammes of chalk yielded 1·675 gramme of residue=2·07 %. The analysis therefore gives

Carbonate of lime .....	97·93 %
Clay, etc. .... = 1·522 gr. =	1·88 %
Heavy residue ..... = ·153 „ =	1·89 %

100

The residue above ·5 mm. in diameter consisted almost entirely of the siliceous meshes formed in the interspaces between the prisms of *Inoceramus*-shells. Viewed from the side, the delicate columns are beautifully shown in the larger specimens, while in most the replacing silica forms thin chalcedonic films, dividing up the test into irregular networks. The chalcedony appears snow-white on the upper and outer surfaces. An *Ammodiscus incertus* and other organic bodies are present, replaced in snow-white chalcedony. A few rounded and subangular grains of quartz were also observed, and some solid white masses of doubtful origin, breaking with an even fracture.

The finer residue consists mainly of films derived from *Inocerami* as described above, numerous rounded yellow spheres, the casts of individual foraminiferal chambers, in some cases united and then displaying the original form of the organisms. *Globigerina* is the most common genus, Textularian types not having been observed. In addition, rods, the internal casts of sponge-spicules, are numerous, but much smaller than those observed in previous cases. Deep-green glauconitic grains, though noticed, were rare. The detrital material is composed of small colourless angular grains of quartz,

shining flakes of muscovite, one fragment of black tourmaline (schorl), and a wine-yellow rutile, exhibiting knee-shaped twinning.

Compared with previous experiments, we notice here:—

1. The abundant evidence of silicification.
2. The reduction in size of the sponge-spicules.

### Chalk, 18 feet above the Conglomerate.

(No. 8 in Table II.)

After solution in acid, 80·84 grammes yielded ·922 gramme of residue = 1·14 %.

The analysis is therefore as follows:—

Carbonate of lime .....	98·86 %
Clay, etc. .... = ·840 gr. =	1·039 %
Heavy residue ..... = ·082 „ =	1·101 %
	100

Of the latter ·0225 gramme exceeding ·5 mm. in diameter consists almost exclusively of the thin siliceous fibrous films previously described, one or two quartz-grains, numerous rods and masses of limonite, extremely porous, and seen to be made up of minute rounded grains. Some of these, when broken open, are seen to possess a distinct labyrinthic structure, and in a few instances fine fibres project across the hollow cavities. Silicified foraminifera (one a much altered *Ammodiscus*), and ostracoda such as *Paracypris*, are sparsely distributed.

In the finer residue the limonitic rods are very abundant, together with minute glauconitic rods, the internal casts of sponge-spicules, and numerous rounded spheres or complete casts of foraminifera (especially of Rotaline and Globigerinoid types), in which each individual chamber is still bound together by a stoloniferous connexion.

The characteristic features of this residue are:—

1. The abundance of limonitic rods.
2. The great rarity of quartz and other detrital minerals.

This series gives a very complete account of the successive changes in the history of the Peninsular Division. The conglomerate appears to represent a period of maximum denudation; but, subsequent to its formation, the evidence points to a gradual and continuous deepening. This is marked by:—

- (a) The gradual diminution in the size of the quartz-grains.
- (b) The reduction in the number and size of the heavy minerals.
- (c) The steady increase in the percentage of calcareous constituents.
- (d) The reduction in the size of the spicular casts.
- (e) The diminution in the size of the foraminiferal casts.
- (f) The increase in limonitic materials, in this respect agreeing with the deeper-water chalks of the South-east of England.

## IN THE IRISH UPPER CRETACEOUS STRATA.

Per cent. of Heavy Residue.	Per cent. of Total Residue.	Per cent. Soluble in acid.	Locality.
·0051	·677	99·32	Divis Hill, near Belfast.
·0406	·529	99·47	Magheramorne.
·0182	·631	99·47	Woodburn Glen, near Carrickfergus.
4·91	6·05	93·95	Do. do.
31·9	33·58	66·42	Do. do.
60·46	62·32	37·68	Do. do.
10·73	54·78	45·22	Do. do.
63·25	63·25	36·75	Colin Glen, near Belfast.
59·4	59·4	40·6	Hillsport, Islandmagee.
13·39 .....	36·19 29·68	63·91 70·32	Woodburn Glen.
75·6	75·6	24·4	Do.
·1014	1·140	98·86	Murlough Bay, near Ballycastle.
·1892	2·07	97·93	Do. do.
1·016	3·088	96·91	Do. do.
1·940	4·238	95·76	Do. do.
67·71	71·846	28·15	Do. do.



II.—TABLE SHOWING THE RELATIVE AMOUNTS OF RESIDUE IN THE IRISH UPPER CRETACEOUS STRATA.

Number.	Zone or Division.	Original Weight.	Weight of Main Residue.	Weight of Heavy Residue.	Total Weight of Residue.	Per cent. of Main Residue.	Per cent. of Heavy Residue.	Per cent. of Total Residue.	Per cent. Soluble in acid.	Locality.
1.	<i>Belemnitella mucronata.</i>	81.42	.547	.0042	.5512	.672	.0051	.677	99.32	Divis Hill, near Belfast.
1 a.	Do.	80.6	.3938	.0327	.4265	.489	.0406	.529	99.47	Magheramorene.
1 b.	Do.	82.4	.505	.015	.520	.613	.0182	.631	99.47	Woodburn Glen, near Carrickfergus.
2.	Pink Chalk with nodules.	80.66	.92	3.96	4.88	1.14	4.91	6.05	93.95	Do. do.
3.	<i>Inoceramus</i> -band.	81.42	1.37	25.97	27.34	1.68	31.9	33.58	66.42	Do. do.
4.	Grey Marl. Enclosed Grit.	79.97	1.49	48.35	49.84	1.86	60.46	62.32	37.68	Do. do.
4 a.	Grey Marl. Marly portion.	83.74	36.88	8.99	45.87	44.04	10.73	54.78	45.22	Do. do.
5.	Yellow Sandstone.	40	Not separated.	40	40	.....	63.25	63.25	36.75	Colin Glen, near Belfast.
5 a.	Do.	41.39	Not separated.	41.39	41.39	.....	59.4	59.4	40.6	Hillsport, Islandmagee.
6.	Glaucinitic Marl.	80.63 42.45	18.30 .....	10.80 .....	29.18 12.60	22.70 .....	13.39 .....	36.19 29.68	63.91 70.32	Woodburn Glen.
7.	Glaucinitic Sands.	77.59	.....	58.66	58.66	.....	75.6	75.6	24.4	Do.
8.	Chalk 18 feet above Pebble Conglomerate.	80.84	.840	.082	.922	1.039	.1014	1.140	98.86	Murlough Bay, near Ballycastle.
9.	Chalk 12 feet above Pebble Conglomerate.	80.92	1.522	.153	1.675	1.881	.1892	2.07	97.93	Do. do.
10.	Chalk 6 feet above Pebble Conglomerate.	72.86	1.51	.740	2.250	2.072	1.016	3.088	96.91	Do. do.
11.	Chalk just above Pebble Conglomerate.	79.23	1.82	1.538	3.358	2.292	1.940	4.238	95.76	Do. do.
12.	Pebble Conglomerate.	53.67	2.22	36.34	38.56	4.137	67.71	71.846	28.15	Do. do.



ENCLOSURE IN UPPER PART OF YELLOW SANDSTONE.	INOCERA BAND	BROUGH BAY CHALK.		
		CHALK 6 FEET ABOVE.	CHALK 12 FEET ABOVE.	CHALK 18 FEET ABOVE.
Large grains numerous and rounded.	Larger grains variable, rounded and subangular.	Small angular grains.	Very rare.	
.....	Chalcedonic replacement films.	Chalcedonic films.	Chalcedonic films abundant.	
Orthoclase rare.	.....	.....	.....	
.....	Muscovite abundant.	Muscovite-flakes.	.....	
.....	.....	.....	.....	
.....	Black and brown crystals numerous.	One fragment.	.....	
Rounded grains numerous.	Good crystals frequent.	.....	.....	
Deep-red and yellow grains numerous.	Deep-red yellow fragments.	One twin of rutile.	.....	
.....	.....	.....	.....	
Perfect crystals common.	Perfect crystals common.	.....	.....	
Frequent.	.....	.....	.....	
Green films common.	.....	.....	.....	
Fairly abundant.	Often as of Hexagonal meshes.	Regular cages and of sponge- spicules.	Casts of sponge- spicules and foraminifera.	
.....	Very abundant.	.....	Sponge- and foraminiferal casts.	
Well crystallized.	Cubic crystals and aggregates.	.....	Limonitic rods abundant.	







### III. CONCLUSIONS AS TO THE SEQUENCE AND CORRELATION OF THE IRISH CRETACEOUS STRATA.

We are now in a position to trace the probable sequence of events in Ireland, comparing it with the established standards of the English Cretaceous zones, and in doing so it will be well to commence with the lowest division, the Glauconitic Sands.

#### Glauconitic Sands (Zone of *Exogyra conica*).

These beds, easily recognized by their deep-green colour, are mainly restricted to the Eastern and Central Divisions, extending from Larne to Colin Mountain, a little south of Colin Glen, a range of over 25 miles, though Portlock's record of their occurrence in Tirereven Burn shows them to have been also present in the Northern Division. In their southernmost exposure at Colin Mountain they attain their maximum thickness of 16 feet, in all other localities where they have been examined varying from 5 to 8 feet thick. These strata are remarkable for the uniformity of their lithological character, being largely composed of glauconitic (with an admixture of arenaceous) grains, and containing an abundant fauna, especially in a central band. *Exogyra levigata*, Sow., is ubiquitous, being generally accompanied by *Pecten* [*Amussium*] *orbicularis* (Mant.), and *P.* [*Janira*] *quinquecostatus*, Sow.

In addition to the three species just enumerated, which are common to both divisions, the following list shows the principal fossils obtained in the greensands and their divisional distribution:—

CLASS.	CENTRAL DIVISION.	EASTERN DIVISION.
REPTILIA .....	Vertebrae of <i>Plesiosaurus</i> .	
PISCES .....	<i>Corax falcatus</i> , Ag., <i>Lamna appendiculata</i> (Ag.).	<i>Lamna appendiculata</i> (Ag.).
CEPHALOPODA ...	<i>Ammonites</i> [ <i>Hoplites</i> ] <i>catillus</i> , Sow. (probably). <i>Belemnites ultimus</i> , d'Orb.	<i>Ammonites</i> [ <i>Schloenbachia</i> ] <i>varians</i> , Sow., sp. (Tate). Belemnite foreshadowing <i>Belemnitella</i> [ <i>Actinocamax</i> ] <i>vera</i> (Mil.).
GASTEROPODA ...	? <i>Littorina</i> (numerous).	? <i>Littorina</i> .
PELECYPODA:		
Dimyaria .....	<i>Trigonia</i> , sp. (mainly Colin Glen). <i>Arca</i> [ <i>Cucullæa</i> ] <i>carinata</i> , Sow. Large casts of <i>Cucullæa ligeriensis</i> (d'Orb.) at Squires Hill. Casts of <i>Thetis Sowerbyi</i> (?), Röm. (large at Cave Hill). <i>Avicula</i> , sp.	<i>Avicula</i> , near <i>A. lineata</i> , Römer.
Monomyaria ...	As above.	As above, and <i>Pecten</i> [ <i>Chlamys</i> ] <i>Gallieniei</i> , P. [ <i>Chl.</i> ] <i>asper</i> , Lam.
BRACHIOPODA ...	.....	<i>Rhynchonella</i> near <i>Rh. Cuvieri</i> , Sow. <i>Terebratula squamosa</i> , Mant., or <i>T. bicipitata</i> , Sow. <i>Kingena lima</i> , DeFr.

In the foregoing list the most prominent species observed by the present writer are mentioned, except where a name is attached, indicating the authority for the occurrence.

Besides these the following species have been recognized:—

*Exogyra conica*, var. *undata*, Sow. ; large casts of *Cucullæa ligeriensis* (d'Orb.), from Squires Hill (agreeing with casts obtained at Vimoutiers); and *Cyprina*, of unrecognized species, from Squires Hill.

Mr. Jukes-Browne has examined a series of fossils from this horizon, and the following notes are culled from his remarks and suggestions:—‘Of the *Avicula* there are three different species, one of which resembles *Avicula lineata*, Römer; but, though there is a resemblance, the figure shows a ridge on the anterior side which is absent in the Irish specimen.

‘Of the pectens the fragment of the large coarse species is *P. asper*; the ribs become more separated with age. Another (probably that referred to by Tate as *P. Dutemplei*) is nearer *P. Galliennei*, d'Orb., and agrees with those from Warminster identified by me as *Galliennei*. The smaller ones have no oblique striation and are nearer to *P. hispidus*, Goldf. There is also a small *Pecten* allied to *P. divaricatus*, Reuss.

‘The *Rhynchonella* seems to be *Rh. Cuvieri*. It might be *Rh. Weistii* of Davidson's Supplement, but appears to agree better with *Rh. Cuvieri*. (This appears to be the species referred to by Tate as *Rh. nuciformis*.) Some triangular single valves also occur, which may be young individuals, of the triangular race of *Rh. Mantelliana* as it occurs in Dorset.

‘The small *Terebratulæ* are not determinable; there is one which may be *T. squamosa*, but also it may be a young *biplicata*. Some have the shape of *Kingena lima* and are probably that shell.’

Respecting the age of these beds, Tate says:—‘The zone of *Exogyra conica* represents the basement-beds of the Etage Céno-manien of the French geologists, and is approximately equivalent to the Greensand of Blackdown.’<sup>1</sup> Barrois remarks: ‘The glauconitic zone with *Ostrea conica*, *Pecten asper*, *Belemnites ultimus*, and *Ammonites varians*, corresponds almost certainly with the Cenomanian zone of *Pecten asper*, the Warminster Beds of England, and the *Holaster nodulosus*-zone of M. Hébert. It strikingly recalls, both in its fauna and petrographical characters, the zone of the same name in the North-east of France.’<sup>2</sup> The fauna above mentioned bears the closest resemblance to that of the Upper Greensand in the West of England, almost every species present in Ireland having also been recorded from the latter district. But though the general relationships of the Glauconitic Sands are thus easily determinable, the consideration of their position in the classification of the Upper Cretaceous rocks involves a discussion of nomenclature. Barrois,<sup>3</sup> following Hébert, placed the Upper Greensand at the base of the Cenomanian, regarding it as markedly separate from the underlying Gault. A further study of these

<sup>1</sup> Quart. Journ. Geol. Soc. vol. xxi. (1865) p. 33.

<sup>2</sup> ‘Recherches sur le Terrain Crétacé Supérieur de l'Angleterre et de l'Irlande,’ Lille, 1876, p. 213.

<sup>3</sup> *Ibid.* p. 7.

two formations in the western counties of England has convinced the majority of English students of Cretaceous geology that such a separation is not justified by the evidence, which tends to prove that they are different lithological conditions of the same division, the greensands being more conspicuous in the western counties, near the ancient coast-line, while the clays of the Gault predominate to the east.

The results of these researches have also convinced these observers that a true Cenomanian base-line, the Chloritic Marl, exists at the summit of the greensands, characterized by a marked change in the fauna and lithological conditions, and by the presence of fossils derived from the underlying strata. The views thus briefly summarized have been clearly set forth by Messrs. Jukes-Browne & Hill,<sup>1</sup> who have also argued that the same statements are applicable to the Cretaceous strata in the North of France. Believing that these results have placed the classification on a secure basis, I am of opinion that the Glauconitic Sands can no longer be retained as Cenomanian, but must be placed in the combined Upper Greensand-and-Gault division, for which sooner or later a convenient reference-name will be required.

In attempting to correlate more precisely the English and Irish greensands, the somewhat different character of the fauna in the Central and Eastern Divisions must be kept constantly in mind, and the non-recognition of these factors appears to be the cause of the differences between the classifications published by Tate and Barrois. For comparison, the subdivisions of the Upper Greensand adopted are as follows:—

	<i>Devon and Wiltshire.</i>	Zones.
UPPER GREENSAND	{ Warminster Beds..... { Devizes Beds..... { Blackdown Beds (in part) ...	{ <i>Pecten asper.</i> { <i>Ammonites</i> [ <i>Schloenbachia inflatus.</i>

Though the retention of *Pecten asper* as the title of a zone is open to objection, no species is sufficiently characteristic of this horizon to take its place satisfactorily.

The main features in the Glauconitic Sands which should be emphasized are:—

1. *Exogyra lævigata*, *Pecten* [*Janira*] *quinquecostatus*, and *P. [Amussium] orbicularis* are ubiquitous.
2. The Central Division is characterized by the great abundance and large size of the dimyarian pelecypoda.
3. The Islandmagee area is, on the contrary, marked by an absence of such pelecypoda, and by the abundance of the subgenus *Chlamys* and small brachiopoda.

Speaking generally, the lithological character of the strata, together with the presence and large size of *Exogyra lævigata* and *Pecten orbicularis*, find their nearest parallel in Bed 3 of Meyer,<sup>2</sup> and Bed 7 of Downes,<sup>3</sup> that is, high representatives of the Blackdown Series, or at the very base of the Upper Greensand; but the

<sup>1</sup> Quart. Journ. Geol. Soc. vol. lii. (1896) pp. 99-178; see especially pp. 170-177.

<sup>2</sup> *Ibid.* vol. xxx. (1874) p. 373.

<sup>3</sup> *Ibid.* vol. xxxviii. (1882) p. 75, & vol. xli. (1885) p. 27.

majority of the mollusca present are most abundant in the *Ammonites inflatus*-beds of the West of England—for example, *Hoplites catillus*, Sow., *Cucullæa carinata*, Sow., and the large dimyarian bivalves. In the Central Division no member of a fauna characteristically later than this zone (the zone of *Ammonites inflatus* of Barrois) has been met with, but the brachiopoda and pectens obtained in Islandmagee suggest the probability that Warminster (*Pecten asper*-zone) conditions had already commenced in the deeper waters of the Eastern Division.

In connexion with this latter supposition we have not ourselves noted *Ammonites* [*Schloenbachia*] *varians*, recorded by Tate from the latter district, but the pectens (subgenus *Chlamys*) obtained were *P. asper*, Lam., *P. Galliennei*, d'Orb., and *P. hispidus*, Goldf. *Chlamys* is therefore abundant, and these species are more common in the Warminster than in the Devizes beds; it must also be admitted that the *Rhynchonella* and *Terebratulæ* accompanying them usually occur in beds younger than the *Ammonites inflatus*-zone. We conclude then that the Glauconitic Sands commenced during the earlier period of the *Ammonites inflatus*-zone, and, owing to their nearer proximity to a coast-line than the Devon Greensands, they retain a strong admixture of the earlier Blackdown fauna, though, in the deeper-water exposures, containing forms which, as depression proceeded in England, became dominant in the upper zone of the English greensand.

Murray and Renard<sup>1</sup> have given an account of the general mode of formation of glauconite, pointing out that it is along high and bold coasts, where no rivers enter the sea, and where accumulation is apparently less rapid, that glauconite appears in its most typical form and greatest abundance. These deposits are also formed near continental masses of land about the lower limits of wave-, tidal, and current-action: that is, in the neighbourhood of Murray's mud-line, in the zone of maximum chemical activity.

The Irish rock is richer in glauconite than the typical examples dredged by the *Challenger* Expedition, the nearest approach to it being the dark greensand obtained by the U.S.S. *Tuscarora*. That the deposit was formed near land seems certain from the great numbers of the pelecypoda, their existence in colonies, and their large size; the probability of a high coast-line is testified by the abundance of glauconite, and comparatively small percentage of detrital minerals. The chemical action is evidenced by the frequency of casts, especially among the dimyaria of the Central Division. As these deposits do not continue to the north much beyond Larne, and to the south disappear at Colin Mountain, it would seem that the formation was laid down in an indentation of the coast, the Central Division being nearest to the shore-line. A fauna similar to that of the highest Blackdown Beds here found a suitable home, and, so long as the conditions continued favourable, flourished in a high degree, thus becoming contemporaneous with species characteristic of higher zones in England.

<sup>1</sup> *Challenger Reports*, 'Deep-Sea Deposits,' p. 382.

These organisms, however, seemingly disappeared before the lithological conditions had undergone complete change, and in the Glauconitic Marls above a new fauna poor in species takes their place. *Vermicularia* (*V. quinquecarinata*, Röm., and *V. concava*, Sow.) are abundant, and large pectens are occasionally present, but these are not sufficient to determine the exact stratigraphical position of the marls. The evidence afforded by the chemical examinations tends to show that a depression was taking place, and the continental slopes were being denuded, heavy minerals being more abundant, and the calcareous element very pronounced. The depression continuing, fine sands replace the clays, and the great series of the Calcareous or Yellow Sandstones is deposited.

### Yellow Sandstones (Zone of *Ostrea carinata*).

These beds have practically the same extension as the Glauconitic Sands, but have not hitherto been recorded from the Northern Division. They attain their maximum thickness of 30 feet in Colin Glen, varying in the other localities examined from 4 to 20 feet in thickness. These strata are very uniform in lithological character, being mainly composed of extremely minute arenaceous grains, though in the Eastern Division a clayey admixture is noticeable, and glauconite is present in minute particles. Organic contents are, as a rule, rare, but they are more abundant in the Eastern Division, the corals and sea-urchins recorded from this horizon having been collected chiefly in the Islandmagee localities. The distribution and nature of the species present are as follows:—

CLASS.	CENTRAL DIVISION.	EASTERN DIVISION.
CEPHALOPODA .....	.....	<i>Ammonites</i> [ <i>Acanthoceras</i> ] <i>rotomagensis</i> (in museum), Defr., sp.
PELECYPODA :		
Dimyaria .....	<i>Trigonia scabricula</i> , Lyc. <i>Avicula</i> sp., <i>Pinna</i> sp. <i>Panopæa mandibula</i> , Sow. <i>Cucullæa ligeriensis</i> , d'Orb., sp. (Tate), in upper part.	<i>Arca</i> sp., <i>Mytilus</i> sp. <i>Avicula</i> , sp.
Monomyaria .....	<i>Pecten</i> [ <i>Janira</i> ] <i>quadricos-</i> <i>tatus</i> (Sow.), lower part. <i>Pecten</i> [ <i>J.</i> ] <i>quinquecostatus</i> , Sow., & <i>J. æquicostata</i> , Lam. (in upper part). <i>Ostrea</i> [ <i>Alectryonia</i> ] <i>car-</i> <i>inata</i> , Lam. (large). <i>Lima semisulcata</i> , d'Orb., & <i>L. globata</i> , Sow. (abundant).	<i>Janira quadricostata</i> (Sow.). <i>Ostrea canaliculata</i> , Sow. <i>Plicatula inflata</i> , Sow.
BRACHIOPODA .....	<i>Rhynchonella dimidiata</i> , var. <i>convexa</i> , Sow.	<i>Rhynchonella dimidiata</i> , var. <i>convexa</i> , Sow.
VERMES .....	<i>Vermicularia quinquecar-</i> <i>inata</i> , Röm., & <i>V. concava</i> , Sow.	<i>Ditrupea difformis</i> , Lam. <i>Vermicularia quinquecar-</i> <i>inata</i> , Röm., & <i>V. concava</i> , Sow.
ECHINODERMATA ...	.....	<i>Discoidea subucula</i> , Klein.
ACTINOZOA .....	.....	<i>Micrabacia coronula</i> , Goldf.

In the Central Division these Yellow Sandstones pass insensibly into the Chloritic Sandstones. Tate remarks:—‘The zone of *Ostrea carinata* represents most certainly a portion of the Upper Greensand of England and the Lower Cenomanian of Normandy,’ a view which, apart from the question of nomenclature previously raised, agrees with our own. Barrois submitted ‘that the sandstones with cherts containing *Ostrea carinata*, *Micrabacia coronula*, resting on the zone of *Pecten asper*, and containing a Cenomanian fauna without admixture, are naturally to be placed on a level with the *Holaster subglobosus*-zone in England.’ The lithological character of the Yellow Sandstones appears to resemble very closely that of the sands with chert, as developed, for instance, at Warminster. The large *Pecten* [*Janira*] *quadricostatus* agrees in all respects with those occurring in the Warminster Beds, in which *Lima semisulcata*, *Janira quinquecostata*, *Vermicularia concava*, and *Discoidea subucula* have also been obtained.<sup>1</sup> *Ostrea carinata* has also been recorded from the chert-beds at Durdle Cove, Purbeck, by Barrois.<sup>2</sup> Sandstones with chert-beds of similar nature form Bed 5 of Mejer,<sup>3</sup> of which *Janira quadricostata* is a typical fossil. Indeed the succession at Colin Glen shows an interesting parallelism when compared with Mejer’s Beds:—

The lowest Yellow Sandstone with cherts and <i>J. quadricostata</i> is similar to .....	} Bed 5
The middle Yellow Sandstone with large <i>Ostrea</i> is similar to .....	
The base of the Chloritic Sands with <i>Orbitolina concava</i> and <i>Rhynchonella Schlenbachi</i> is similar to .....	} Bed 8
The <i>Exogyra columba</i> - and <i>Callianassa</i> -beds with polyzoa are similar to .....	
	} Bed 11

At Colin Glen the Yellow Sandstone corresponds nearly in its fauna with Beds 5–7 of Mejer: that is, the upper portion of the Devizes beds, or zone of *Ammonites inflatus*. In his Bed 10 occur together some of the most characteristic of the fossils mentioned above, including *Ostrea* [*Alectryonia*] *carinata*, *Pecten* [*Janira*] *quinquecostatus*, Sow., *Rhynchonella dimidiata*, var. *convexa*, Sow., *Lima semisulcata*, d’Orb., and *Discoidea subucula*, Klein. It therefore appears probable that the Yellow Sandstones correspond as a whole with Beds 5–10 of Mejer, and are mainly parallel with the Warminster greensands, or *Pecten asper*-zone. We have not been able to substantiate the presence of *Holaster subglobosus*, Leske, but *Ammonites* [*Acanthoceras*] *rotomagensis* (Defr.) appears to have been found in this formation from Sallagh, a specimen of it being present from this horizon in the Belfast Museum. There is therefore a possibility that the Cenomanian fauna was already foreshadowed in the Eastern Division.

We conclude that the Yellow Sandstones are mainly of Warminster or *Pecten asper*-age, but that they still possess, in the shallower-water Central Division, an admixture of the fauna of the

<sup>1</sup> A. J. Jukes-Browne, Geol. Mag. 1896, p. 261.

<sup>2</sup> ‘Recherches sur le Terrain Crétacé Supérieur, etc.’ p. 92.

<sup>3</sup> Quart. Journ. Geol. Soc. vol. xxx. (1874) p. 373.

lower *A. inflatus*-zone, while in the easternmost localities the true Cenomanian conditions are foreshadowed, the corals and sea-urchins also occurring only in the latter.

### Chloritic Sands and Sandstones.

These beds present a difficult problem, the differences between the Central and Eastern Divisions being extremely marked. (Woodburn Glen, in its characters and relations, must now be included in the Eastern Division; in the previous cases it occupied an intermediate position between the two types.)

Tate remarks:—‘The Chloritic Sands and Sandstones have, on the whole, a fauna possessing an Upper Greensand facies, many species, however, pointing to higher zones. It is very probable that the Chloritic Sands of Woodburn (the zone of *Inoceramus Crispi*?) may be inferior to the Chloritic Sandstones of Colin Glen, the zone of *Exogyra columba*. These zones, however, never come into contact.’

Barrois concludes that, as all the fossils obtained in these beds were Turonian, these strata must be considered as belonging to that stage, and refers them to the zones of *Terebratulina gracilis* and *Holaster planus*.

The zone of *Exogyra columba* is characteristic of the Central, the *Inoceramus*-zone of the Eastern district, and the former will be first dealt with.

### Central Division. (Zone of *Exogyra columba*.)

These sands and sandstones, often of a greenish-yellow colour, are well developed in this Division, attaining a thickness of nearly 20 feet at Colin Glen. In the Eastern Division, however, they are of rare occurrence, being represented by yellow-green sands 4 feet thick at Barney’s Point, in Islandmagee, where the two zones mentioned by Tate are in contact, and it is seen that the *Exogyra columba* is the lower of the two.

Gault has added a considerable number of species, which have not come under our notice.<sup>1</sup>

As I have already remarked, *Orbitolina concava* and *Rhynchonella Schläenbachi* characterize Bed 9 of Meyer (which he still includes in the Upper Greensand), and the latter does not extend beyond his Bed 12. *Ostrea carinata*, Lam., *Pecten asper*, Lam., *Cucullea ligeriensis* (d’Orb.), *Trigonia crenulata*, Lam., *Oxyrhina Mantelli*, Ag., *Ptychodus decurrens*, Ag., and *Callianassa* are limited in the same manner in Devon, and most of these are found only in Beds 10 and 11. Barrois also observed the *Orbitolina*- and *Rhynchonella Schläenbachi*-beds in Devon, overlain by a fauna in part similar to the above, accompanied by *Ammonites* [*Acanthoceras*] *Mantelli* (Sow.) and *A. Coupei* (Brongn.), and regarded them as of Warminster age.<sup>2</sup> It is therefore evident that the *Exogyra columba*-zone has a strong Lower Cenomanian

<sup>1</sup> Proc. Belfast Nat. Field-Club, n. s. vol. i. (1877), p. 258.

<sup>2</sup> ‘Recherches sur le Terrain Crétacé Supérieur, etc.’ p. 70.

CLASS.	CENTRAL DIVISION.	EASTERN DIVISION.
PISCES .....	<i>Oxyrhina Mantelli</i> , Ag., <i>Ptychodus latissimus</i> , Ag., <i>Pt. decurrens</i> , Ag., <i>Pt. mam-</i> <i>millaris</i> , Ag., <i>Corax fal-</i> <i>catus</i> , Ag., <i>Lamna sulcata</i> , Ag., <i>Lamna appendicu-</i> <i>lata</i> (Ag.).	
CEPHALOPODA .....	<i>Ammonites</i> [ <i>Pachydiscus</i> ] <i>lewesiensis</i> , Mant. (Tate).	
GASTEROPODA .....	<i>Natica</i> sp., and others un- described.	
PELECYPODA:		
Dimyaria .....	<i>Trigonia crenulata</i> , Lam., <i>Tr. Dædalea</i> , Park., <i>Car-</i> <i>dium gibbosum</i> , Tate, <i>Ana-</i> <i>tina Royana</i> (d'Orb.).	
Monomyaria .....	<i>Exogyra columba</i> , Lam. (large), <i>Ostrea</i> [ <i>Alectryo-</i> <i>nia</i> ] <i>carinata</i> , Lam., <i>O.</i> <i>canaliculata</i> , Sow., <i>O.</i> <i>semitana</i> , Sow., <i>Pecten</i> [ <i>Chlamys</i> ] <i>asper</i> , Lam., <i>P.</i> [ <i>Janira</i> ] <i>quincocostatus</i> , Sow., <i>P.</i> [ <i>Janira</i> ] <i>æqui-</i> <i>costatus</i> , Lam.	<i>Exogyra columba</i> , Lam., <i>Ostrea semiplana</i> , Sow., <i>O. carinata</i> , Lam., <i>Pecten</i> [ <i>Janira</i> ] <i>quincocostatus</i> , Sow.
BRACHIOPODA .....	<i>Waldheimia hibernica</i> , Tate.	<i>Rhynchonella Schloënbachi</i> , Dav.
VERMES .....	<i>Vermicularia concava</i> , Sow.	<i>Vermicularia concava</i> , Sow.
CRUSTACEA .....	<i>Callianassa</i> sp.	
ECHINODERMATA .	.....	<i>Catopygus columbarius</i> , d'Orb.
FORAMINIFERA ...	<i>Patellina</i> [ <i>Orbitolina</i> ] <i>con-</i> <i>cava</i> , Lam.	

aspect. It is true that *Ostrea semiplana*, a common Turonian fossil in England, has been recorded by both Tate and Barrois, and I have obtained it at the very summit of the zone in Islandmagee, but it is impossible at present to say whether the association at this point is not due to the mixing of the two zones at the unconfusable junction.

The fishes above mentioned are also of common occurrence in the Turonian strata, but they equally occur in the Cenomanian, *Ptychodus decurrens* being especially frequent in the latter.

The view here set forth receives further support when the conditions prevalent in France during Cenomanian time are specially considered. Thus in the province of Maine is a thick series of sands, the Sables du Maine, which enclose among other fossils *Orbitolina concava*, Lam., *Trigonia crenulata*, Lam., *Tr. Dædalea*, Park., *Ammonites* [*Acanthoceras*] *rotomagensis* (Defr.), *A. Mantelli*, Sow., and *Catopygus columbarius*, Lam.

In the Perche district, the Sables du Perche, which contain *Ammonites* [*Acanthoceras*] *navicularis* (Sow.), *Ostrea carinata*, Lam., *Exogyra columba*, Lam., *Rhynchonella compressa*, Lam., and *Trigonia*

*crenulata*, Lam., belong to a higher zone than the beds previously described, but are included in the Cenomanian series.

Guillier<sup>1</sup> has given a long list of the Cenomanian fossils in that department, but unfortunately the poverty of the Irish fauna renders comparison difficult. Nevertheless *Orbitolina concava* occurs at the base of the French Cenomanian, increasing in abundance in the upper strata, till near Le Mans a calcareous yellowish grit containing abundant glauconitic grains and numerous quartz-fragments is met with, yielding among other fossils *Trigonia crenulata*, and in lower beds *Ammonites* [*Schloenbachia*] *varians*, *A.* [*Acanthoceras*] *Mantelli*, and small individuals of *Ostrea columba*.<sup>2</sup>

In the Sarthe *Exogyra columba gigas* and *Callianassa Archiaci* also occur in the Turonian.

In the Rhone Basin, as shown by M. Kilian, in the Montagne de Lure,<sup>3</sup> calcareous grits with *Exogyra columba*, *Ammonites* [*Acanthoceras*] *rotomagensis*, and *Trigonia crenulata* overlie a glauconitic grit filled with *Orbitolina concava*.

Near Marseilles, at Escragnolles, grits with *Exogyra columba* rest on grits and limestones containing a Rouen fauna, these again overlying clays and limestones with *Ammonites* [*Acanthoceras*] *Mantelli* and *Orbitolina concava*.

In the Gard also, glauconitic marls with *Pecten asper*, *Trigonia crenulata*, and *Orbitolina concava* begin the Cenomanian Series, being separated from a band with *Exogyra columba* by a fluvio-marine formation. *Orbitolina concava* is also at the base of the Cenomanian in Spain.

Finally, it may be mentioned that in the Orange district the Maine beds reappear as a green sandstone or grit with *Exogyra columba*; but in this instance a bed with large *Exogyra columba*, followed by a marly bluish limestone with *Callianassa*, actually overlies a limestone containing Turonian ammonites.

With the above two exceptions, the whole weight of the evidence is in favour of the view that the Chloritic Sandstones mainly represent the Cenomanian beds of Western England, at the same time sharing the shore-line characters of the same strata in the West and South of France. It is interesting to note that brown casts of bivalves, probably *Inoceramus*, occur in the sandstones at Colin Glen, in this respect recalling the characteristic feature of the Chloritic Marl at the base of the Cenomanian.

The lithological characters seem to point to depression and subsequent elevation, the lowest or *Pecten aequicostatus*-beds being sandstone, with very small glauconitic grains; the *Exogyra columba*-layer above is green uncompact sand with soft calcareous sandstone, the sandstone with but few glauconitic grains subsequently reappearing in the *Callianassa* sub-zone, containing these crustacea in abundance.

There is little doubt that Gault is right in noting a strong uncon-

<sup>1</sup> 'Géologie de la Sarthe,' pp. 244-260.

<sup>2</sup> *Ibid.* p. 226.

<sup>3</sup> 'Montagne de Lure,' p. 293.

formity at the summit of the *Callianassa*-bed, this being immediately overlain by the conglomeratic mulatto-stone of the zone of *Belemnitella* [*Actinocamax*] *vera*. The break is still more marked in other portions of the Central Division, where the same zone overlies the Yellow Sandstones with clear unconformable junction. The Chloritic Sands of the Eastern Division mainly consist of arenaceous glauconitic limestones (containing *Inoceramus*-fragments and *Spondylus spinosus*), which extend farther northward than the beds previously described, thus presenting a distinct case of overlap. *Spondylus spinosus* occurs in the Chloritic Sands as far south as Cave Hill, and as far north as Glenarm. These beds are also present in the Northern Division, as at Tircreven Burn.

### Eastern Division. (Zone of *Inoceramus Crispi*?)

While easily distinguishable from the greenish-yellow sand of the *Exogyra columba*-zone, the *Inoceramus*-zone passes insensibly above into that of *Echinocorys gibbus*.

Principal fossils:—PISCES: *Scapanorhynchus rhapsiodon*, Ag., *Ptychodus latissimus*, Ag., *Anomæodus* sp.

GASTEROPODA: *Pleurotomaria perspectiva*, Mant.

PELECYPODA MONOMYARIA: *Inoceramus* sp. (fragments abundant), *Ostrea semiplana*, Sow., *Pecten* [*Janira*] *quinquecostatus*, Sow., *Spondylus spinosus*, Sow.

BRACHIOPODA: *Rhynchonella plicatilis*, Sow., *Rh. limbata*, Schloth., *Rh. robusta*, Tate.

VERMES: *Serpula filiformis*, Sow.

POLYZOA: *Spiropora* sp.

ECHINODERMATA: *Micraster breviporus*, Ag., *Catopygus columbarius*, Lam. (both at the base). *Cidaris clavigera*, König, also probably belongs here. Spines of *Cidaris* sp. abundant.

At Woodburn, Larne, and Whitehead, we have in addition found the following associated with, or below, the beds of *Inoceramus*-fragments:—*Echinocorys vulgaris*, Breyn., var. *ovatus* (Larne), and *E. gibbus*, Lam. (Woodburn), *Galerites albojalerus*, var. *angulosus*, Desor (Larne and Whitehead), *Terebratula carnea*, Sow. (flattened type), *T. semiglobosa*, Sow., and *Camerospongia fungiformis*, Goldf. (Larne). In general, however, these last-mentioned species are restricted to the highest portion of the glauconitic sandy limestones, beds which Tate would probably class with the Chloritic Chalk.

As already stated, the lowest 4 feet of glauconitic sand with *Vermicularia*, *Ostrea carinata*, and *Exogyra columba*, must be regarded as Upper Greensand or Cenomanian, the occurrence of *Rhynchonella Schloenbachi* in quantity at Whitehead also showing the existence of the zone of *Exogyra columba* in this division. There is no apparent lithological break between these sands and the overlying *Rhynchonella*-band, but every evidence of the existence of palæontological unconformity.

Having recently visited the Chalk Rock of Hertfordshire, etc.,

I have been much struck with the resemblance which some of the Irish fossils have to the English species from that horizon. For example, the Irish specimens of *Micraster breviporus* agree almost absolutely in size with those obtained from the base of the *Micraster cor-testudinarium*-zone in Surrey and at Eastbourne, or from the Chalk Rock at Baldock, near Hitchin, while the *Rhynchonella plicatilis* and *Rh. limbata* are very similar in both cases. Also, as Barrois has urged, *Spondylus spinosus*, *Ostrea semiplana*, and *Inoceramus* sp. are particularly abundant in the upper part of the Turonian. The fauna, taken as a whole, may be termed that of the reversing layer, or the point where the secondary elevation leading to the formation of the Chalk Rock attained its maximum; and indeed, if anything, these sandy limestones have been formed on the depression side of it.

Nor have I been able to confirm Barrois's discovery of *Galerites subrotundus* and *Rhynchonella Cuvieri*. These must be uncommon, and would consequently not affect the general Chalk Rock character of the organisms present.

Looking at the question from a historical point of view, it would appear that the Eastern Division of Ireland had now joined in the great second movement of depression which appears to have begun in England after the formation of the Chalk Rock, the shallower waters of the Antrim Sea preserving the fauna of the transition-period longer than was the case in England. If this view be adopted, these beds will have to be considered as Lowest Senonian, but still presenting a strong Turonian aspect.

#### Chloritic Chalk. (Zone of *Echinocorys gibbus*.)

The principal fossils are:—

MOLLUSCA: *Spondylus spinosus*, Sow.

ECHINODERMATA: *Echinocorys gibbus*, Lam., *Cidaris sceptrifera*, Mant. (probably).

VERMES: *Serpula filiformis*, Sow.

CRINOIDEA: *Bourgueticrinus* sp.

BRACHIOPODA: *Terebratula carnea*, Sow.

ACTINOZOA: *Parasmilia centralis*, Mant.

PORIFERA: *Camerospongia fungiformis*, Goldf., *Ventriculites* sp.

This zone differs from the last, with which it is intimately connected, only in the increase of the calcareous constituents and the thoroughly deep-sea character of the fauna, the large mollusca having almost entirely disappeared. It apparently represents, with the sands previously described, the whole of the Lower Senonian, minus the *Belemnitella* [*Actinocamax*] *vera*-zone. The main feature is the abundance of *Echinocorys scutatus*, *Terebratula carnea*, and *Camerospongia fungiformis*, all of which fossils connect it with the zone above, but as *B.* [*Actinocamax*] *vera* has not yet been obtained in these beds, they must at present be excluded from that zone.

CLASS.	CENTRAL DIVISION.	EASTERN DIVISION.	PENINSULAR DIVISION.	NORTHERN DIVISION.
CEPHALOPODA.....	<i>Belemnitella</i> [ <i>Actinocamax vera</i> ] (Mil.), B. [A.] <i>quadrata</i> (Blainv.), B. [A.] Alfridi, Janet.	<i>Belemnitella</i> [ <i>Actinocamax vera</i> ] (Mil.), B. [A.] <i>quadrata</i> (Blainv.).	<i>Belemnitella</i> [ <i>Actinocamax</i> ] Alfridi, Janet.	<i>Belemnitella</i> [ <i>Actinocamax vera</i> ] (Mil.), B. [A.] <i>quadrata</i> (Blainv.).
GASTEROPODA.....	<i>Trochus</i> sp. (G.)	.....	<i>Emarginulina</i> sp., <i>Calliostoma</i> sp., <i>Actæon</i> sp.	
PELECYPODA:				
Dimyaria .....	.....	.....	<i>Venus</i> sp.	
Monomyaria.....	<i>Spondylus</i> sp. (G.)	<i>Pecten</i> [ <i>Janira</i> ] <i>quinquecostatus</i> , Sow.	<i>Pecten</i> [ <i>Janira</i> ] <i>quinquecostatus</i> , Sow.	<i>Ostrea laciniata</i> , Goldf., <i>O. lateralis</i> , Nilss.
BRACHIOPODA .....	<i>Terebratula carnea</i> , Sow. (G.)	<i>Terebratulina gracilis</i> , Schloth.	.....	<i>Terebratula striata</i> , Wahl.
ECHINOZOA.....	<i>Micraster cor-anguinum</i> , Forbes.	.....	<i>Galeries abbreviatus</i> , Goldf.	<i>Micraster</i> sp., <i>Cidaris hirudo</i> , Sorrig., <i>C. subvesticulosa</i> , d'Orb.
PELMATOZOA .....	<i>Echinocorys scutatus</i> , Leske.	.....	.....	<i>Marsupites ornatus</i> , Mil., <i>Bourgueticrinus ellipticus</i> , Mil.
POBIFERA .....	<i>Etheridgia mirabilis</i> , Tate, <i>Camerospongia fungiformis</i> , Goldf., <i>Ventriculites decurrens</i> , Smith, <i>V. radiatus</i> , Mant., <i>V. alternans</i> (Röm.).	<i>Ventriculites cribrosus</i> , Phil., <i>V. radiatus</i> , Mant., <i>Etheridgia mirabilis</i> , Tate, <i>Coscinopora infundibuliformis</i> , Goldf., <i>Plocoscyphia</i> sp., <i>Cephalates</i> sp.		

Zone of *Belemnitella* [*Actinocamax*] *vera* and  
*B. [A.] quadrata*.

It is very evident that it was during the period of these two zones that the greater part of Antrim became submerged beneath sea-level, with the production of mulatto-stone or conglomeratic chalk in the Central Division, of Spongiarian beds in the Eastern and part of the Central districts, and of beach-deposits in the Peninsular area, while true White Chalk was already being formed in the Northern Division. We have seen that *Belemnitella* [*Actinocamax*] *vera* occurs in the conglomerate at Colin Glen, in the Spongiarian zone of Islandmagee, and in the white limestone of the Northern Division; *B. [A.] quadrata* (Blainv.) and *B. [A.] Alfridi*, Janet, in the glauconitic rock of Forth River; *B. [A.] quadrata* and *Micraster cor-anguinum* in the nodular glauconitic chalk of Squires Hill; and *B. [A.] Alfridi* together with gasteropoda in the beach-deposits of the Peninsular area. These zones have been at present classed together, because hitherto the two zone-fossils have been seldom obtained in the same locality; but when thus found, the rule usual elsewhere is followed, *B. [A.] vera* being found in beds lower than those containing *B. [A.] quadrata*.

The principal fossils are tabulated on p. 596. The fossils for the Northern Division are enumerated on Barrois's authority; those marked with a G have been recorded by Gault from the Central Division.

Tate, in his table, places the Spongiarian zone and that of *Ananchytes gibbus* at the *Belemnitella* [*Actinocamax*] *quadrata*-level, but the above fauna shows that these are, in part at least, of *B. [A.] vera*-age. Barrois<sup>1</sup> also arrived at the conclusion that, whereas the sponge-beds in Germany are mainly at the summit of the *B. [A.] quadrata*-zone (zone of *Becksia Sœkelandi*, of Schlüter), those in Ireland occur at the base of this zone, and the two are consequently not comparable. Also, comparing the sponges obtained in the Spongiarian zone with those from the well-known horizon at Danes' Dyke near Bridlington, there is no sponge common to the two localities. Taking all the evidence together, there seems little doubt that the pebble-beds, mulatto-stones, and Spongiarian beds were formed mainly during the period of these two zones, the latter being most certainly of *B. [A.] vera*-age.

White Limestone. (Zone of *Belemnitella mucronata*.)

To this zone belongs the white hardened limestone overlying the strata previously described, which forms so conspicuous a feature in all the Antrim divisions. In the Southern, Central (Black Mountain), and Peninsular areas, *Belemnitella mucronata* occurs in a pebble-containing mulatto-stone.

Fossils.—General: *Belemnitella mucronata*, Schloth., *Ammonites*

<sup>1</sup> 'Recherches sur le Terrain Crétacé, etc.,' p. 210

*gollevillensis*, d'Orb., *Turritella unicarinata*, Tate, *Trochus* sp., *Ostrea vesicularis*, Lam., *Terebratula carnea*, Sow., *Rhynchonella plicatilis*, var. *octoplicata*, Sow., *Pecten cretosus*, Defr., *Magas pumilus*, Sow., *Parasmilia centralis*, Mant., *Porosphæra globularis* (v. Hag.).

Occurring mainly in the lower portions of the limestone:—*Mosa-saurus gracilis*, Owen, *Terebratulina Defrancei*, Brongn., *T. abrupta*, Tate, *Echinocorys scutatus*, Leske, *Megerlia* [*Kingena*] *lima*, Defr. (P), *Calliostoma* sp. (P), *Catopygus columbarius*, var., Lam. (P), *Galerites vulgaris*, Breyn.?, *Holaster planus*, Mant., Trochosmilian coral (P), *Noidanus microdon*, Ag., *Pleurotomaria perspectiva*, Mant., *Ammonites* [*Pachydiscus*] *Griffithsii* (Sharpe), and *P. Oldhami* (Sharpe), *P. peramplus*, Mant., *Nautilus Deslongchampsianus*, d'Orb., *N. Largilliertianus*, d'Orb., *N. Atlas*, Whiteaves, *Baculites*, near *anceps*, Lam., *Hamites* sp., *Anisoceras* sp., *Ventriculites* sp., *Cæloptychium* sp., and the Kilcorig fauna (see p. 546).

Tate concludes that 'the White Limestone certainly represents the Upper Chalk of Norwich and the Craie de Meudon, and some of its fossils point even to a higher parallel—that of the Maestricht Chalk.' Barrois also considers that these beds are on the level of the Norwich Chalk, but sees no evidence of the existence of Danian beds in this region.

It is clear that during this period the submergence of Antrim must have been very complete, the whole of the divisions having the White Chalk of this zone covering the older deposits, its preservation being due to the great overlying mass of basalt. The upper part is very unfossiliferous, the varied fauna above described being mainly developed at the base, though a small group of forms occurs throughout the series. The basal zone is a glauconitic chalk in most of the Southern and parts of the Central and Peninsular districts; in the others it is a pure white chalk, the chemical results showing it in some cases to be as pure as that of some of the English Upper Chalk-zones.

The following are the main stratigraphical conclusions:—

1. The Glauconitic Sands, or zone of *Exogyra conica*, corresponding in the main to the Devizes beds (zone of *Ammonites inflatus*) and part of the Warminster Beds (zone of *Pecten asper*) in England.

2. The Yellow Sandstones, or zone of *Ostrea carinata*, are of Warminster age, that is, the *Pecten asper*-zone of Barrois.

The above together correspond to the English Upper Greensand.

3. The Chloritic Sands and Sandstones (Central Division), or zone of *Exogyra columba*, are true shore-representatives of the Cenomanian (Lower Chalk) in Ireland.

4. The Chloritic Sands (Eastern Division) = zone of *Inoceramus Crispi*? of Tate, are equivalent to the highest Turonian (Middle Chalk) or lowest Senonian beds in England, being intimately associated with the changes which resulted in the formation of the Chalk Rock in England.

5. The Chloritic Chalk = zone of *Echinocorys gibbus* and

GASTEROPODA.	CEA.	HYDROZOA AND ACTINOZOA.	PORIFERA.	FORAMINIFERA.
<i>Turbo, Trochus,</i> <i>Turritella,</i> <i>Pleurotomaria</i> at the base.	oda.	<i>Porosphæra,</i> <i>Parasmilia</i> <i>centralis.</i>	Spicules abundant in flints.	Abundant in flints, silicified. No Porcellanea.
<i>Turbo, Trochus,</i> <i>Actæon, Emarginula.</i>	.....	.....	<i>Ventriculites,</i> <i>Coscinopora,</i> <i>Cæloptychium,</i> Hexactinellid band.	Not examined.
.....	.....	.....	Glauconic casts of	External and internal glauconic casts well-preserved.
.....	.....	<i>Parasmilia</i> <i>centralis.</i>	spicules abundant.	
.....	.....	.....	Glauconic casts of Hexactinellid spicules present.	Glauconic casts common, not specific- ally recognized.
<i>Natica</i> and <i>Aporrhais.</i>	a-band.	.....	.....	Glauconic casts common, not specifically recognized.
.....	.....	<i>Micrabacia</i> <i>coronula.</i>	.....	Rare. <i>Flabellina cordata.</i>
<i>Littorina.</i>	ic casts oda.	.....	.....	Large glauconic casts abundant.







*Camerospongia fungiformis*, represents the *Micraster cor-anguinum* and part of the *Marsupites* or *Belemnitella* [*Actinocamax*] *verazones*.

6. The Spongiarian Bed must be classed with the zone of *Belemnitella* [*Actinocamax*] *vera*. The mulatto-stones mainly belong to the zone of *B.* [*A.*] *quadrata*, but also in part to the preceding and succeeding zones.

7. The White Limestone is a member of the zone of *Belemnitella mucronata*, there being little evidence in favour of the existence of still higher strata.

The first four of the above divisions were classed by Tate as the Hibernian Greensands, under the impression that all these beds were Cenomanian. We have seen, however, as Barrois had already pointed out, that the *Inoceramus*-zone cannot be thus regarded. The first three might very conveniently be retained under the old name; but if a short designation be needed for the Chloritic Sands of the Eastern Division, the term 'Antrim Beds' suggests itself to me, which would include all the strata characterized by *Spondylus spinosus* and *Inoceramus*-fragments, having the Spongiarian band at the summit. The type-section for these beds is the quarry of Barney's Point, in Islandmagee.

#### IV. GENERAL CONSIDERATIONS.

Having dealt with the various lithological and zonal divisions in detail, it will now be advisable to consider the general questions which arise out of our previous study.

1. We have observed that there are certain organic remains in the Glauconitic Sands and Yellow Sandstones of the Eastern Division, which suggest higher zonal conditions than those indicated by the species with which they are associated, and it is mainly these which have guided Barrois in his classification of the lower Irish beds. They play, it is true, a purely subordinate part in the fauna, but their presence demands consideration, and various possibilities may be suggested.

(a) The Eastern Division I regard as having been in deeper water than the Central, firstly, because the detrital deposits are generally thinner here than in the Central Division; secondly, because brachiopoda, corals, sea-urchins, and chlamyd bivalves are present in its lower strata; thirdly, because large dimyarian bivalves, such as the *Trigonia*, *Arca*, *Thetis*, etc., so abundant in the Central, are very rare in the Eastern fauna. Again, there seems to be a growing belief that the organic changes in the English Upper Greensand are such as would result from gradual depression. It may be then that this is a case where a deeper is co-existent with a shallower-water fauna, and not successional, as in England.

(b) Another possible view is that an older fauna continued living longer near the Irish shore than in England, where a deeper-water one had already established itself, and had partly invaded the Irish area. This seems to me less tenable than the first view, because all

the palæontological evidence points to the conclusion that during the deposition of the Upper Greensand the English and Irish Cretaceous seas formed part of the same geographical province.

2. A second difficulty arises in regard to the Chloritic Sands and their divisions, the zones of *Exogyra columba* and *Inoceramus Crispi*. Why should the beds containing the former be developed on so extensive a scale south of Belfast, yet scarcely be known north of that city; and for what reason does the precise opposite hold good for the strata containing *Inoceramus*-fragments and *Spondylus spinosus*?

The following suggestion appears to offer the best solution of the enigma. The detrital deposits will be, speaking in general terms, thicker nearer a continental shore-line than they would be farther out at sea. Reasons have already been given for believing that the Central Division was closer to land than the Eastern, and we have seen that at Colin Glen the beds (largely composed of land-derived materials) below the mulatto-stone are 60 feet thick. In the Eastern area the corresponding beds do not, at their maximum, exceed 30 feet. If elevation took place, the strata nearest the land would first commence to be denuded, but, should the geocratic tendency not be prolonged, being of considerable thickness, a portion of the older beds would still remain unaffected by denudation. On the other hand, the thinner strata formed in deeper water would be less liable to denudation, and on depression recommencing, organic calcareous deposits would commence to form earlier here than in the littoral regions.

Our explanation, then, is this:—The strata of Upper Greensand, Cenomanian, and Turonian age in Colin Glen, etc., were laid down nearer shore, and were in consequence thicker than the corresponding beds in the Eastern Division. When elevation ensued, the Central Division was first affected by denudation, and any Turonian or Upper Cenomanian strata that had been formed were removed. On the other hand, in the Eastern Division, the hydrocratic movements of the beginning of the Upper Chalk period resulted in the formation of a series of strata of organic origin, which are practically unrepresented farther south-west. As a consequence, the unconformity in the Central Division is at the summit, in the Eastern near the base, of the Chloritic Sands: the greensands included under this name being, in the two areas, of different age, and, when carefully examined, of different characters.

3. In 'The Genesis of the Chalk'<sup>1</sup> the present writer has maintained that the zones of the English Chalk have been produced during the course of three great phases of movement, the first of submergence, lasting from the Upper Greensand to *Terebratulina gracilis*-times (Middle Chalk); the second, of partial elevation, the most visible result of which is the Chalk Rock; and thirdly, after the formation of this prominent lithological feature, a further period of submergence, far exceeding in magnitude the earlier

<sup>1</sup> Proc. Geol. Assoc. vol. xiii. (1894) pp. 211-246.

occurrence of the same nature. The three movements appear to have left very marked effects in Ireland, these being intensified owing to the immediate proximity of land. The changes during Upper Greensand and Cenomanian times run parallel with those taking place in Western England; but an elevation which, from the Irish evidence, must have taken place later than the beginning of the Cenomanian seems to have been the cause of the unconformities which have been noted, especially in the Central Division.

The advance of the second submergence is marked by both overlap and unconformity, the character of the incoming fauna being, as already observed, of highest Turonian or lowest Senonian age, and thus indicating that the oscillations were closely parallel, or connected, with those occurring in the English areas. The first signs of the new conditions are observed in the east of the Eastern Division, where there is merely a slight trace of lithological unconformity, but a considerable faunal break. The lower beds of the *Inoceramus*-zone are limited to the centre of this division, but the higher ones overlap the older strata both to the south and north, invading the Central area on the one hand, and extending to Carnlough on the other. Approaching the Southern and Peninsular regions, the unconformity occurs at the base of higher and higher zones, until in isolated exposures in these districts the *Belemnitella mucronata*-zone itself rests with an unconformable junction upon strata of Triassic, Carboniferous, or even earlier age, so that at the close of the Upper Chalk period every part of the Antrim area must have been submerged.

4. One of the most interesting occurrences in this connexion is the presence of definite beaches of Upper Chalk age, characterized by the large size of the mica-schist and other fragments which compose them, and at the same time containing a rich and distinctive fauna. These beaches, which have evidently been formed during the period of maximum depression, are inhabited by two sets of organisms, some, such as the gasteropoda and dimyarian bivalves, being shallow-water inhabitants, others of deep-sea origin, but stunted in growth because they lived under abnormal conditions of depth, etc., the types being the small *Galerites* which are among the commonest genera present. It is possible, indeed, to trace every gradation from these undoubted beaches to the pebble-conglomeratic limestones and mulatto-stones of the same period, these again passing, by gradual diminution of the detrital constituents, into the glauconitic and sponge-containing limestones of the deep-water divisions.

5. The geological evidence in favour of the existence of marine currents must be, as a general rule, only indirect, but at times a combination of circumstances unites to witness to their action. For instance, in the *Exogyra columba*-zone especially, a number of facts testify to the existence of a current of some magnitude; thus, a new fauna, not previously represented in Ireland, replaces the other species, individual forms by their abundance characterizing bands of no great thickness and limited horizontal extension (as,

for example, the *Exogyra columba*-, *Waldheimia hibernica*-, and *Callianassa*-bands), while a noticeable feature is the frequent occurrence of the teeth of fishes (Lamnidæ and Myliobatidæ) in the softer sands of the same zone.

I have already discussed the relation of a rich fish-fauna to currents as follows:—‘The current will evidently carry along with it large amounts of material derived from the littoral area, and far more suitable to a piscine palate than the usual minute pelagic fauna of an oceanic region. The result would be that comparatively shallow-water Teleostean fishes, such as *Beryx*, would have their range greatly extended, . . . whilst the rich increase in food-material would tend to bring together large numbers of predatory fishes, especially sharks, such as *Lamna*, etc. In this way, perhaps, the discovery of such a rich fauna may be explained.’<sup>1</sup> The same statements appear to apply to the case under consideration, and in addition it should be noted that the associated mollusca are distinctly littoral.

In the *Inoceramus*-zone the new fauna also appears in bands, but here the incoming species have a deeper-water aspect, and the beds containing them yield but few fish-remains.

Just as in the Central Division, it is below the unconformable junction that current-action is most suggested, so also above it there is strong evidence pointing in the same direction. Ground-currents must have been especially active during the period of the *Belemnitella* [*Actinocamax*] *vera* and *B.* [*A.*] *quadrata*-zones, judging from the extraordinary admixture of the older and younger beds at their junction, the nodular or conglomeratic character of the strata immediately overlying the unconformity, and the large size of the detrital materials.

The following appear to have been the principal currents:—(1) One resulting from the changes which ushered in the Cenomanian period, extending the range of a southern fauna northward, and accompanied in its course by a number of predatory fishes. (2) One commencing at the beginning of the Senonian, setting in from the oceanic areas towards land, and introducing the deep-sea fauna, unaccompanied by a prominent fish-fauna. (3) An indefinite current-system, resulting from the submergence of the prominent land-masses, and coincident in time with the *Belemnitella* [*Actinocamax*] *vera*- or *Marsupites*-zone. This gives rise to marked lithological disturbances and unconformities, and may have been synchronous with the deposition of the phosphatic chalks and nodular bands common in many Cretaceous districts at this horizon.

6. Reference may now be made to the relation of spongiarian bands to the subjacent and superjacent strata. It appears to me that such bands in many cases immediately overlie or are directly connected with beds displaying evidence of the commencement of depression, or partial elevation of deep-water beds accompanied by current-action. For example, outside Ireland, in the South-east of

<sup>1</sup> ‘The Genesis of the Chalk,’ Proc. Geol. Assoc. vol. xiii. (1894) p. 233.

England, mention may be made of the *Plocoseyphia maeandrina*-layer, lying immediately above the Chloritic Marl with its rolled phosphatic nodules. With this exception, throughout the whole of the Cenomanian and Turonian periods, no such colonial assemblage is again met with, until, at the very summit of the strata of the latter age, the Chalk Rock displays evidence of partial elevation. Analyses of the lower strata generally show no trace of glauconitic casts of sponge-spicules, yet the Chalk Rock and *Holaster planus*-beds of Devon, Eastbourne, and the Midlands, have without exception yielded these as the most important members of the residue. It is very interesting to find that precisely the same fact holds good for the *Inoceramus*-zone in Ireland, which I have regarded as partly synchronous with the Chalk Rock of England. In Antrim the abundance of these glauconitic casts of spicules is noticeable so long as the limestones contain small fragments of quartz and other detrital materials, but the sponges attain their maximum development (forming definite bands) at the point where the detrital minerals become rare, and pure white limestone is commencing to be formed. In other words, the most favourable locality for the formation of a sponge-bed appears to be that one where currents are carrying only the very finest particles in suspension, the sediment forming on the ocean-floor being almost purely calcareous. But although definitely recognizable sponge-beds cease at this level (the base of the White Chalk), the continued presence of these organisms in the chalk is evidenced by the abundance of flints.

If any one be yet inclined to dispute the connexion between flints and sponges, I would call special attention to a memoir by Prof. Sollas,<sup>1</sup> which had not come under my notice when discussing these questions in previous papers. He remarks (*op. cit.* p. 438):—‘The Trimmingham flints afford evidence straight to the point; for not only are sponge-spicules intimately associated with them and in great numbers, but these spicules afford us clear proof of the previous existence of a great mass of other spicules of which they are themselves but a miserable remnant.’ Considering the aggregation of flints in layers, he concludes that drifting has not occurred to any great extent, if present being only sufficient to help in mixing the different sponge-spicules together (for, as Sollas, Hinde, Wright, and others have shown, spicules of many genera have been preserved intermingled in flints), but not to sort them out into any distinct layer. His belief is, and personally I am inclined to adopt the conclusion, that the area where the spicules are now found was once a sponge-bed; with death and dissolution of the organisms the spicules were set free from different adjacent sponges, and, falling into the same deposit, naturally mixed together, movements of the surrounding sea-water helping to render the mixture more complete. Thus a chalky ooze would be produced, crammed with sponge-spicules of all sorts and sizes. Such sponges as possessed skeletons compact enough to maintain their general form after death would become filled with this ooze, and, undergoing silicification, would furnish us

<sup>1</sup> Ann. & Mag. Nat. Hist. ser. 5, vol. vi. (1880) pp. 384-395, 437-461.

with instances of fossil sponges presenting a well-preserved form externally and a curious mixture of spicules within.

Considering the question of silicification as a whole, we are now able to trace out some interesting facts with regard to the character of the preservation of sponge-spicules and other organisms as illustrated by the Irish strata :—

(a) In the Yellow Sandstones where detrital quartz is plentiful, but fossils capable of silicification are not numerous, the sponge-spicules which were present have been partly or completely dissolved, giving rise to definite chert-beds or cherty nodules.

(b) In the *Inoceramus*-zone and upward, the abundant glauconitic casts of spicules prove the former presence of a sponge-fauna which in other respects has left no trace of its former existence. The silica, thus passed into solution, has been redeposited in the interior, or as the replacement, of shells of *Inoceramus* and brachiopoda.

(c) Where large mineral fragments are no longer carried by the currents, solution appears to have been at its minimum and glauconitic replacement absent, the result being the preservation of the sponges and the formation of a definite sponge-bed.

(d) In the pure limestones the solution of the spicules is again considerable or complete, and organisms capable of silicification are either small or rare, so that a great excess of colloid silica is formed, which is subsequently redeposited as flint.

In addition to the formation of flint, silicification has proceeded to an extraordinary extent in the chalk, as is seen from the statement of Mr. J. Wright,<sup>1</sup> after examining the powder in the interior of a number of flints :—‘ Among the many specimens collected from these various places, I have recognized, besides corals and polyzoa, 17 species of ostracoda, 106 species and well-marked varieties of foraminifera, and 27 forms of sponge-spiculæ; many of these attain fine proportions, being much larger than those usually obtained from the washings of English Chalk. The microzoa, on being placed in hydrochloric acid, were found to be either not at all or but slightly affected by it, showing that their original composition has, to a great extent, been replaced by silica.’

The same statement holds good for the spicules described by Dr. G. J. Hinde from the Upper Chalk of Horstead, and Prof. Sollas has also discussed and emphasized the same point in the paper mentioned above, laying stress on the fact that when siliceous solutions are present they replace the molecule of carbonate of lime as a whole. In consequence of this latter property, not only internal casts, but absolute replacements of the original tests are met with.

Glauconite appears to behave in a precisely similar manner, the internal casts being frequently of a very perfect character. Prof. Sollas has suggested that these may be the result of the combination of silica, set free from decaying sponges, with alumina, iron, and alkalies, to the entire exclusion of lime. At present I am unable to obtain any evidence of the existence of sponges during the formation of an extremely rich deposit of glauconitic grains, as, for example,

<sup>1</sup> ‘Irish Cret. Microzoa,’ Proc. Belfast Nat. Field Club, ser. 2, vol. i. p. 74.

the Glauconitic Sands. It might be argued that this is due to the fact that the sponges yielding the necessary silica had entirely disappeared, but this reply is unsatisfactory, in that it is based entirely on negative evidence. The points on which I would lay stress are:— (a) That glauconite is an extremely variable mineral, casts of light yellow to dark green colour being indiscriminately ranged under this name. (β) There does appear to be a definite relation between glauconitic formation and depression, the glauconitic grains diminishing in size and quantity as the calcareous element increases; but we are still very much in the dark as to the precise relation of glauconite to the detrital materials on the one hand, and the organic tests enclosing or replaced by it on the other.

7. The reappearance of species in higher zones after having seemingly disappeared has been frequently noted by students of Cretaceous geology. Thus Mr. Jukes-Browne, speaking of the Chalk Rock of England, remarks that some of the species in it are indistinguishable from those of the Chalk Marl nearly 400 feet below,<sup>1</sup> and Mr. H. Woods, dealing with the mollusca of the Chalk Rock, says:—‘As a whole, the fauna presents a much greater resemblance to that of the Lower Cenomanian than to any which occur in the divisions of the Senonian and Turonian above and below it; and whereas the latter are of a deep-water type, that found in the Chalk Rock is certainly of a comparatively shallow-water character.’<sup>2</sup> In Ireland the fauna, which has thus been repeated at these widely differing horizons, is carried a stage higher, *Ammonites* (*Pachydiscus*, including *P. peramplus*, a common Middle Chalk species), *Hamites*, *Anisoceras*, *Baculites*, *Nautilus*, and examples of *Holaster planus*, together with forms of *Turbo*, *Trochus*, *Emarginulina*, etc., having been found in some abundance at the base of the *Belemnitella mucronata*-zone. The general aspect is undoubtedly similar in many respects to that of the Chalk Rock, and this fauna must have continued to exist throughout the Upper Cretaceous age in portions of the Chalk sea, being enabled from time to time to extend its range as the result of movements of elevation or depression and current-action.

8. The general distribution of the *Rhynchonella* and *Terebratulæ* is also not uninteresting, as the former seem, in the Irish strata at any rate, to have been capable of existing under conditions and circumstances which are not so favourable to the growth and development of the latter. Thus, while in the Glauconitic Sands both families are found together, in the beds formed largely of detrital materials, such as the Yellow Sandstones and lower beds of the Chloritic Sands, species of *Rhynchonella* are alone met with, the *Terebratulæ* being rare or absent, and only as depression advances becoming predominant. The *Rhynchonellæ* appear also to have been capable of existing in the conglomeratic beds of the Peninsular Division, where, so far as I am aware, *Terebratulæ* have never yet

<sup>1</sup> ‘Building of the British Isles,’ 1888, p. 177.

<sup>2</sup> Quart. Journ. Geol. Soc. vol. lii. (1896) p. 69.

been met with ; it is only in the quietly-deposited White Chalk that the two families are again found to co-exist.

This also appears to hold good to some extent for the English Chalk, the *Rhynchonellæ* being most marked in the marly or nodular strata (*Rh. Martini* in the Chalk Marl, and *Rh. Cuvieri* in the *Inoceramus labiatus*-beds), while *Terebratulæ* are more conspicuous in the calcareous deposits (*T. semiglobosa* in the Grey Chalk, and *T. carnea* in the White Chalk of the Senonian and Turonian). The uppermost beds of the Upper Chalk agree with the corresponding Irish Cretaceous strata in having the two occurring together.

#### DISCUSSION.

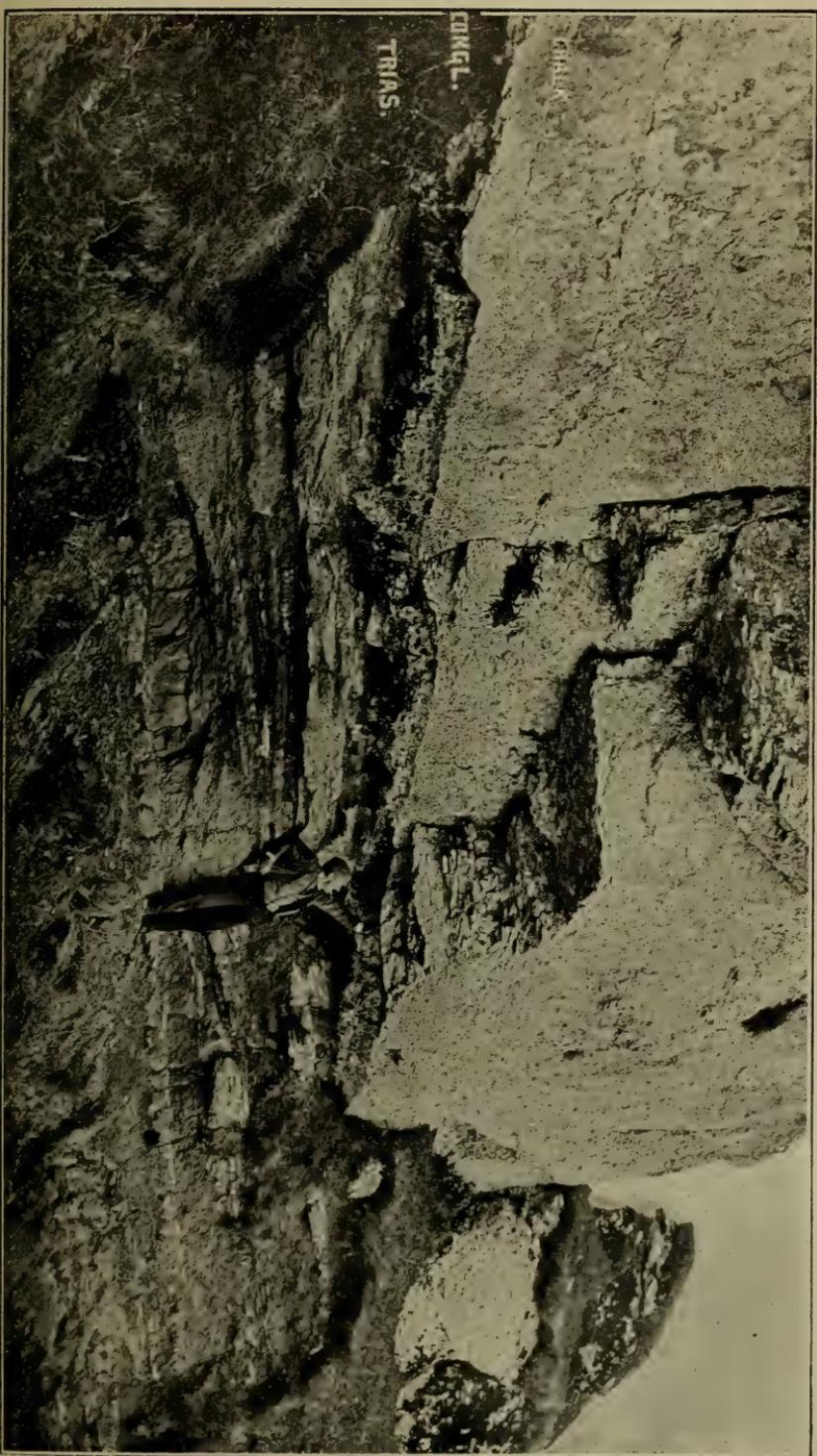
Prof. JUDD congratulated the Author on having been able, while dealing with a multiplicity of details, to bring out clearly their bearing on some very important generalizations. He thought that when the Author's valuable studies concerning the insoluble residues of the Cretaceous rocks were completed, geologists would have in their possession a body of facts of great interest and suggestiveness.

Prof. G. A. J. COLE remarked that the custom among Irish geologists has been to speak of the glauconitic and conglomeratic beds of the Cretaceous as the 'Hibernian Greensand,' without necessarily correlating these beds with the Upper Greensand of England ; and probably even the term 'Upper Greensand' on the Geological Survey maps may be regarded as mainly a lithological convenience. Irish workers would heartily welcome the correlation of the zones now put before them ; and the speaker was glad to see that no great break was insisted on in the Turonian Series. Geographical considerations as to the shore-line of the Cretaceous sea are complicated by the very considerable earth-movements that both accompanied and followed Eocene times. The base of the Templepatrick section would be of interest for comparison with the evidence given by the coast north-east and south-east of it, as bearing on any possible division between a northern and a southern area.

Mr. W. WHITAKER and Prof. H. G. SEELEY also spoke.

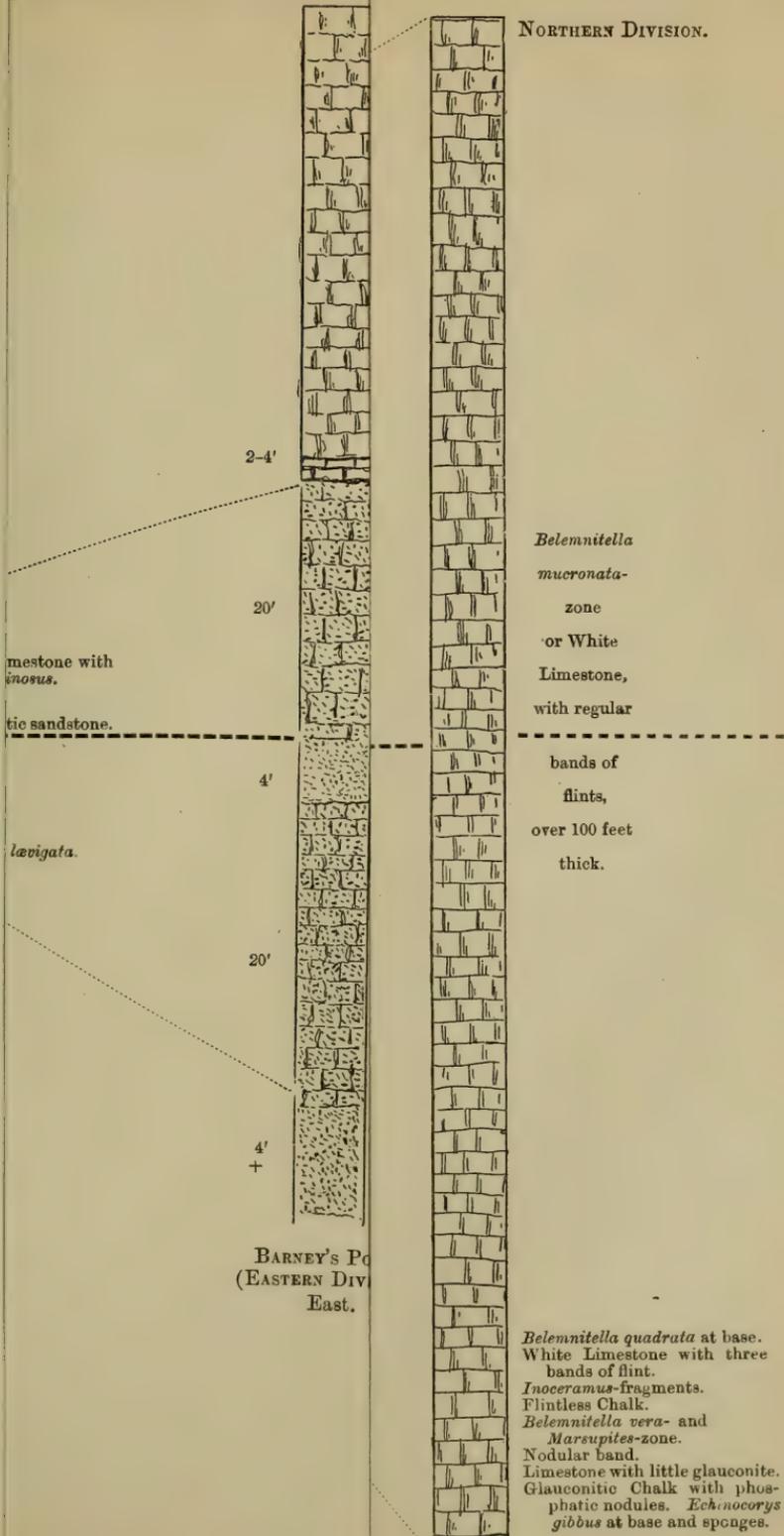
The AUTHOR, in answer to Prof. Cole, said that he had not examined the large quarry at Templepatrick, but its position suggests an intermediate character in its relations, as it is situated between the typical Eastern and Peninsular districts. In answer to Mr. Whitaker, he observed that the average thickness of the Chalk is about 50 feet south of Belfast, up to 80 feet north of Glenarm, and 100 to 200 feet near Portrush and Rathlin Island. In answer to Prof. Seeley, he pointed out that the Gault and Upper Greensand have not been absolutely separated in the paper, while the nodular beds resembling those of the *Inoceramus-labiatus* zone are found immediately above the unconformities, and belong to the three *Belemnitella*-zones (*B. vera*, *B. quadrata*, and *B. mucronata*), according to their position.

UPPER CRETACEOUS PEBBLE-CONGLOMERATE AT THE BASE OF THE CHALK, OVERLYING MARLS AND SANDSTONES OF TRIASSIC AGE, MURLOUGH BAY, NEAR BALLYCASTLE, CO. ANTRIM.





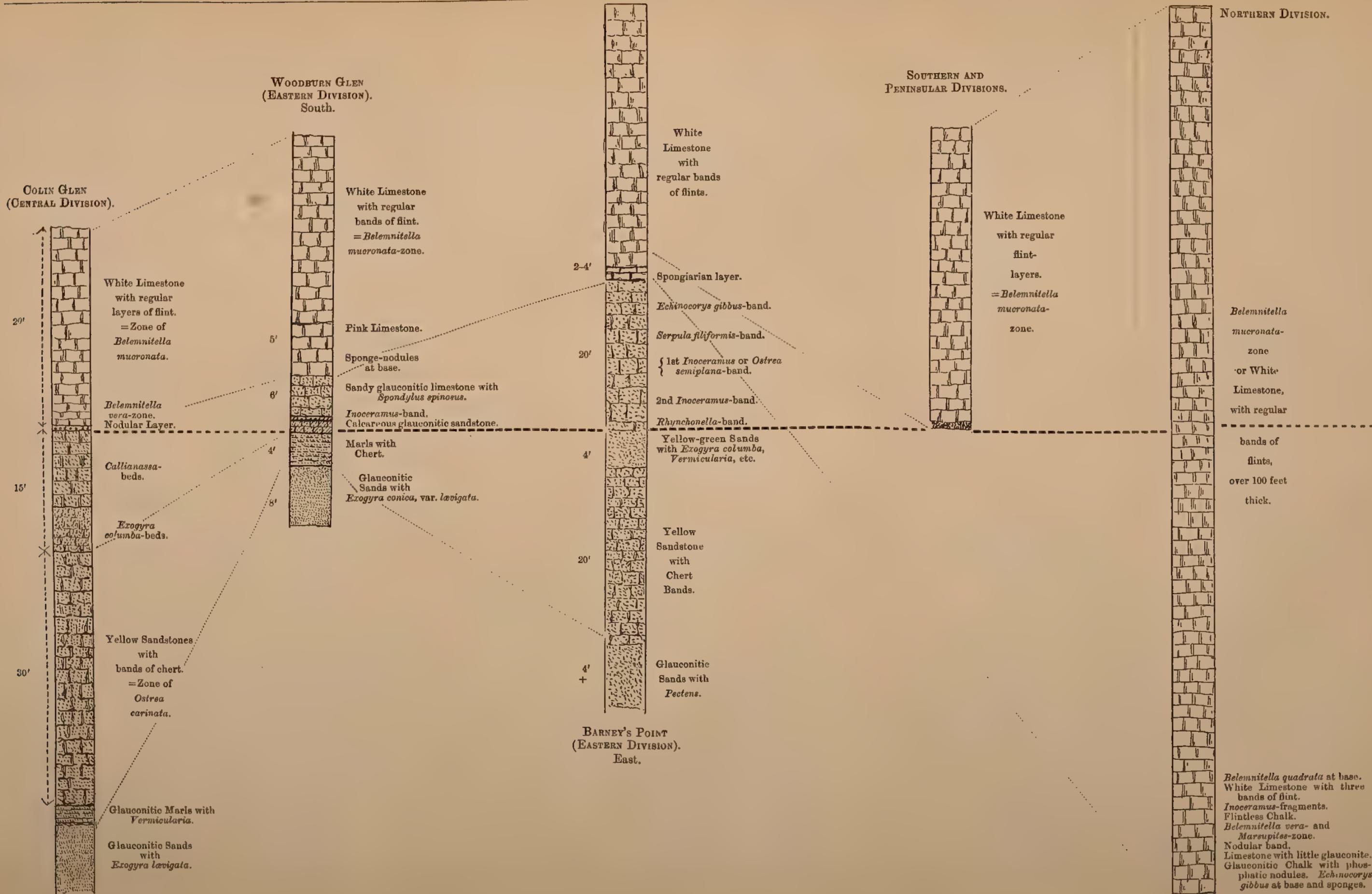
SERIES OF DIVISIONAL SE



at thickness of the detrital beds in the the unconformity represented by the broken line.



COMPARATIVE SERIES OF DIVISIONAL SECTIONS IN THE CRETACEOUS STRATA OF COUNTY ANTRIM.



NOTE.—This table shows the thickening of the limestones northward, the great thickness of the detrital beds in the Central, and of the calcareous beds in the Eastern Division, respectively below and above the unconformity represented by the broken line.



37. DEPOSITS of the BAJOCIAN AGE in the NORTHERN COTTESWOLDS :  
*The CLEEVE HILL PLATEAU.* By S. S. BUCKMAN, Esq., F.G.S.  
 (Read June 23rd, 1897.)

## [PLATE XLVI—Map.]

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## I. INTRODUCTION.

THE present essay is in continuation of a former paper which described deposits of similar date in the Mid-Cotteswolds.<sup>1</sup> The district now under discussion consists of an outlying isolated plateau, cut off from the main mass of the Cotteswolds on the east by the deep valley at Sevenhampton, and separated from the Mid-Cotteswolds by the Vale of Whittington.<sup>2</sup> The best-known portion of this plateau is called Cleeve Cloud or Cleeve Hill; other portions include the hills above Whittington and Hewlett's Hill. For the purpose of the present paper the whole will be named the Cleeve Hill plateau.

The literature relating to the district is not extensive. The latest detailed section is that of Cleeve Hill given by Wright.<sup>3</sup> As, however, the sequence of the strata set forth by that author differs so considerably from that which will be described in the present communication, it is not thought desirable to discuss his section in detail, or to combat his views. An almost entirely new reading will be presented now.

One more point may be referred to. A postscript to my communication on the 'Mid-Cotteswolds' (p. 461) first gave a short summary of the sequence found at Cleeve Hill. Further researches fully tended to bear out this sequence; and then, within the last

<sup>1</sup> 'The Bajocian of the Mid-Cotteswolds,' *Quart. Journ. Geol. Soc.* vol. li. (1895) p. 388. Further references will be given simply as 'Mid-Cotteswolds.'

<sup>2</sup> This is a lateral valley of the Coln, made by a former tributary of that river. Its western end is now deepened to form the valley of the Chelt.

<sup>3</sup> 'Monograph of the Lias Ammonites,' p. 155 (*Palæont. Soc.* 1879).

few months, an important portion of the Rolling Bank quarry has been opened up, showing, in one exposure, confirmation of what was before an inductive surmise from the piecing together of several.

## II. THE SECTIONS OF THE DEPOSITS.

It is desirable to commence with the southern portion of the Cleeve Hill plateau, at the hills above Whittington village, where the following sequence of deposits may be found:—

		Ft. ins.
1. <i>Whittington: Ragstone Quarry and Fields; about 600 yards nearly north of the Church.</i>		
UPPER TRIGONIA-GRIT.	1. Shelly ragstone.	
T. PHILLIPSIANA-AND BOURGUETIA-BEDS.	2. Greyish and yellowish-green sandstone, with <i>Terebratula Buckmaniana</i> . <sup>1</sup> Several pieces of this matrix are much bored by annelids. Also stones of a more or less ironshot matrix..... about	23 0
WITCHELLIA-BEDS.	3. Shelly ironshot with <i>Acanthothyris</i> ... about	3 0
NOTGROVE FREE-STONE.	4. A whitish oolitic stone. A <i>Sonninia</i> of the <i>fissilobata-ovalis</i> type was found at the bottom. This deposit is fully exposed in the quarry .....	18 0
GRYPHITE-GRIT.	5. A shelly ragstone with <i>Gryphææ</i> and small, smooth pectens, exposed for about .....	3 0
	(The quarry has been worked about 6 feet deeper, and the spoil-heaps show a sandstone with <i>Terebratula Uptoni</i> . The horizon of this fossil at Charlton Common is 7 feet below the top of the Gryphite-grit.)	

*Note.*—The details of Beds 1–3 were obtained by breaking the stones in the soil of the field to the northward, measuring the rise of the ground, and allowing for the dip.

In the Cold Comfort district, which lies about 2 miles to the south-east, the Upper *Trigonia*-grit rests on the *Witchellia*-beds.<sup>2</sup> Here is found an additional amount of about 20 feet of deposit separating these two beds.

About 6 furlongs to the north-east, where the 'White Way' runs through Puckham Wood—close to the fault which has let in the so-called Stonesfield Slate beds of Bathonian age,—the Notgrove Freestone may be seen at the south side of the road near the top of the hill. Higher up the hill, in a field behind, the *Phillipsiana*-beds may be recognized, not only by the distinctive matrix, but by *Terebratula Buckmaniana* and other fossils. The same beds may be discovered in the stones of the field just above Wontley<sup>3</sup> Farm, about 1 mile 5 furlongs farther north; they are

<sup>1</sup> Concerning this species, see 'Mid-Cotteswolds,' p. 454.

<sup>2</sup> 'Mid-Cotteswolds,' pp. 416, 417.

<sup>3</sup> The 1-inch Survey Map has Huntley; the 6-inch, Wontley. The latter is correct. It is the dialect *wont* or *woont*, a mole, from the Anglo-Saxon *wand*.

close to the 1000-foot contour-line. The other beds between these and the Harford Sands inclusive (see p. 615) may also be found there.

It is now advisable to go to Cleeve Hill itself, and of the numerous exposures to be seen on the Common to give the following generalized section of results. Afterwards it will be stated where the different beds may be examined to the best advantage.

2. *Cleeve Hill : a generalized section.*

			Ft. ins.	Ft. ins.
OLYPEUS- AND UPPER TRIGONIA-GRITS.	I. 1.	Yellow ragstones with <i>Terebratula globata</i> . In the lower part are numerous <i>Trigonia</i> and <i>Rhynchonella angulata</i> ..... about	.....	15 0
	TEREBRATULA PHILLIPSIANA- BEDS.	II. 1.	Bluish-grey, sandy stone, sharp fracture. Bored by annelids and <i>Lithodomi</i> .....	0 4
2.		Similar stone, not bored, but somewhat rounded in places, and with sand-pockets .....	0 6	
3.		Similar deposit; 3 beds with sandy partings. <i>Terebratula Phillipsiana</i> , var., sparingly [Upton].....	5 0	
4.		Similar splintery grey limestone with <i>Terebratula Phillipsiana</i> and <i>T. Buckmaniana</i> abundant. ' <i>Rhynchonella quadriplicata</i> ,' <i>Acanthothyris</i> . Two beds with sandy partings, and a sandy base with oysters .....	2 3	
5.		Similar massive stone. <i>Terebratula Phillipsiana</i> , ' <i>Rhynchonella quadriplicata</i> ' [Upton]. Large ' <i>Bourguetia striata</i> ' .....	2 0	10 1
BOURGUETIA- BEDS.	III. 1.	Greyish shelly stone with brownish patches and infillings. <i>Ctenostreon pectiniforme</i> or <i>proboscideum</i> , <i>Bourguetia</i> <sup>1</sup> .....	2 3	
	2.	Grey stone in several beds. Lamellibranchiata are numerous and particularly noticeable for their unusually large size. Large, much-plicate <i>Ostrea</i> , <i>Myoconcha</i> , etc. Large <i>Nautilus</i> .....	7 0	
	3.	Grey shelly limestone, somewhat bored.....	1 6	
	4.	Limestone .....	0 9	
	5.	And there is presumably of this deposit about another.....	2 0	13 6

<sup>1</sup> A large, umbilicate, much-compressed, crassicostate *Stephanoceras* was found by Mr. C. Upton 2 feet 9 inches below the *Terebratula Buckmaniana*-bed. Its matrix and position indicate this bed No. 1.

			Ft. ins.	Ft. ins.
WITCHELLIA-BED.	IV. 1.	A considerably ironshot stone. In the upper and much-ironshot part are found specimens of a small <i>Acanthothyris</i> rather frequently. About the middle <i>Witchellia</i> sp., and also <i>Terebratula Wrighti</i> about 1½ feet above the Notgrove Freestone, some specimens also occurring in a bed of marl. Thickness of this deposit about .....	.....	4 0
NOTGROVE FREESTONE.	V. 1.	White oolite. The average result of various measurements gives the thickness stated; there is no complete exposure .....	.....	20 0
GRYPHITE-GRIT.	VI. 1.	Ragstone with numerous <i>Gryphææ</i> . There is no complete exposure. The thickness may be estimated... ..	.....	5 0
TEREBRATULA BUCKMANI-GRIT.	VII. 1.	Grey shelly limestone about.....	12 0 <sup>1</sup>	
	2.	Grey clay-band with small <i>Gryphææ</i> .	1 0	
	3.	Grey limestone about .....	4 0	
			-----	17 0
LOWER TRIGONIA-GRIT.	VIII. 1.	Ironshot oolite, numerous lamelli-branchiata, <i>Aulacothyris Meriani</i> , about 2 feet 6 inches from the base. No complete exposure. Thickness perhaps .....	.....	7 0
SNOWSHILL CLAY.	IX. 1.	Greyish purple marl.....	0 3	
	2.	Very stiff, soapy blue clay.....	0 6	
	3.	Sticky brown clay enclosing grey stone-band, 2 inches thick, shelly, with black streaks .....	0 7	
			-----	1 4
HARFORD SANDS.	X. 1.	Greyish-yellow, sandy, somewhat calcareous stone, <i>Terebratula</i> cf. <i>submaxillata</i> .....	2 0	
	2.	Whitish and greyish-yellow, fine, siliceous sand .....	3 0	
			-----	5 0
UPPER FREE-STONE.	XI.	Pinkish limestone at the top.		

Such is the sequence at Cleve Hill of the 'intervening beds'—the deposits which part the Upper *Trigonia*-grit from the Upper Freestone. Upon them remarks may now be made, and the places where they can be seen to advantage may be noted.

### III. NOTES CONCERNING THE VARIOUS DEPOSITS (the 'intervening beds' between Upper Freestone and Upper *Trigonia*-grit).

#### (a) The Harford Sands.

The sequence connecting these sands with the Lower *Trigonia*-grit may be seen on the western side of the hill, just below the Rolling Bank. About 1½ foot of white and yellow sand is exposed; then

<sup>1</sup> This estimate is uncertain.

there is a break, and a little lower down the bed described as Upper Freestone is seen. The relation of the sands and Lower *Trigonia*-grit may also be seen on the eastern side of the hill above 'The Ring,' near the 1000-foot contour-line. Relative position, but not actual sequence, may be observed at 'Roadstone Hole.'

The sands cover a considerable part of the hill, and have been extensively worked. It is reported that they were dug for use in the Staffordshire potteries, and that they were conveyed thither upon the backs of donkeys. The presence of the sand is often indicated by the gorse-bushes. The stone-bed (No. X, 1) is sometimes partially disintegrated into nodule-shaped masses,<sup>1</sup> which then have the appearance of boulders, and have been the cause of some confusion in the matter of Northern Drift. There is a specimen in the Gloucester Museum which was obtained from 'Roadstone Hole,' and preserved as an example of that drift!

### (β) The Snowhill Clay.<sup>2</sup>

This clay may be seen at the western side of the hill, lying over the Harford Sands, as noted above; the measurements given were taken therefrom. It may also be seen at 'Roadstone Hole' capping the sands just under the turf, and it seems to attain a thickness of 2 feet. At Leckhampton Hill is the first south-westerly exposure, a bed 2 inches in thickness, marked as 'Harford Sands equivalent.'<sup>3</sup> Northward it would seem that the deposit attains considerable proportions, for between Snowhill and Broadway is a stratum of this clay, whereon grow oak-trees and thorn-bushes—signs of an argillaceous bed; and it must be several feet in thickness, for there was a pit about 4 feet deep, while beyond that the ground rose considerably. Therefore, for distinction, the name 'Snowhill' has been used, because this is a bed of considerable economic importance (see p. 624). It may be remarked that the clay occurs above sand, so that the order is

Limestone (Lower *Trigonia*-grit),  
Clay (Snowhill Clay),  
Sand (Harford Sands),  
Limestone (Upper Freestone),

which is somewhat unusual.

The chief interest of the further exploration of the Northern Cotteswolds will be the development of the Harford Sands and Snowhill Clay, or beds nearly contemporaneous therewith.

<sup>1</sup> The bed consists of very fine quartz-grains and calcareous cement. The rain gradually dissolves the cement, and leaves the grains incoherent as sand.

<sup>2</sup> For notices of the clay-bed, see H. B. Woodward, 'Lower Oolitic Rocks of England,' Mem. Geol. Surv.: Jurassic Rocks, vol. iv. (1894) pp. 126, 127, 137-143. The section on p. 143 may particularly be compared with details given in this paper. The clay is classed with the Harford Sands.

<sup>3</sup> 'Mid-Cotteswolds,' p. 410. At Chedworth Wood there is 6 inches, *ibid.* p. 425.

(γ) The Lower *Trigonia*-grit.

This deposit may be seen overlying the beds below it in sequence at the places already noted. Its connexion with the *T. Buckmani*-grit may be seen at 'Roadstone Hole,' especially at the eastern end. There is, however, no complete section to show the exact thickness of the whole bed. The deposit has just the lithic<sup>1</sup> character of the same bed in the Mid-Cotteswolds, and the distinctive fossil *Aulacothyris Meriani* has been found.<sup>2</sup>

(δ) The *T. Buckmani*-grit.

This bed is worked for roadstone. Hence the name 'Roadstone Hole,' applied by the workmen to the quarry, where its relation to the Lower *Trigonia*-grit may be observed. There is shown, about 4 feet above that bed, a seam of marly clay similar to the deposit in which *Terebratula Buckmani* is found in the Mid-Cotteswolds; but that fossil I have not found in it here. However, it occurs on the spoil-heap of the 'Roadstone,' where *Terebratula Uptoni* and an *Acanthothyris* have also been found.

The beds of roadstone at 'Roadstone Hole' are inclined at a steep angle of about 55°, dipping to the north, and on account of their disturbed and tumbled condition it is difficult to say what their exact thickness may be. No section shows their relation to the Gryphite-grit.

## (ε) The Gryphite-grit.

The greater part of this grit,<sup>3</sup> and its connexion with the Notgrove Freestone, may be clearly seen in the quarry above, and to the east of, the Rolling Bank, near the Ordnance-datum 972 on the 6-inch map. Similar observations may be made at the Whittington quarry. Just south of the Rolling Bank the Gryphite-grit, with Notgrove Freestone above it, is obscurely shown.

## (ζ) The Notgrove Freestone.

The connexion of this bed with the overlying *Witchellia*-grit may be seen in the Rolling Bank Quarry, as well as in the quarry to the east thereof. No section allows of its full thickness being accurately measured. The nearest approximation is obtained at the Whittington quarry; and estimates show that it may be somewhat thicker near the Rolling Bank. The section (Diagr. I, p. 614) showing the quarries east of the Rolling Bank, and the relation of this to overlying beds, also indicates how the thickness may be measured approximately.

<sup>1</sup> 'Lithic,' pertaining to stone; 'lithological' signifies pertaining to the science of stone, which is not the required meaning.

<sup>2</sup> 'Mid-Cotteswolds,' p. 413.

<sup>3</sup> There is 5 feet of Gryphite-grit; and that is the whole thickness of the bed at Leckhampton Hill ('Mid-Cotteswolds,' p. 410). About 4 feet of Notgrove Freestone is exposed above that east of the Rolling Bank.

(η) The *Witchellia*-grit.

This bed may be seen in connexion with overlying beds at the southern end of the Rolling Bank quarry, but the tumbled and much-inclined condition of the strata makes exact measurement difficult. Its general relation to the overlying strata may also be seen in the quarries east of the Rolling Bank on the same line of fault.

The bed is similar to the deposit described at Cold Comfort,<sup>1</sup> perhaps rather more ironshot. It has yielded characteristic fossils, namely: *Terebratula Wrighti*, an *Acanthothyris*, and species of *Witchellia*, all of which identify it with the Cold Comfort deposit. The exact thickness of this grit is not yet ascertainable.

(θ) The *Bourquetia*- and *Terebratula Phillipsiana*-beds.

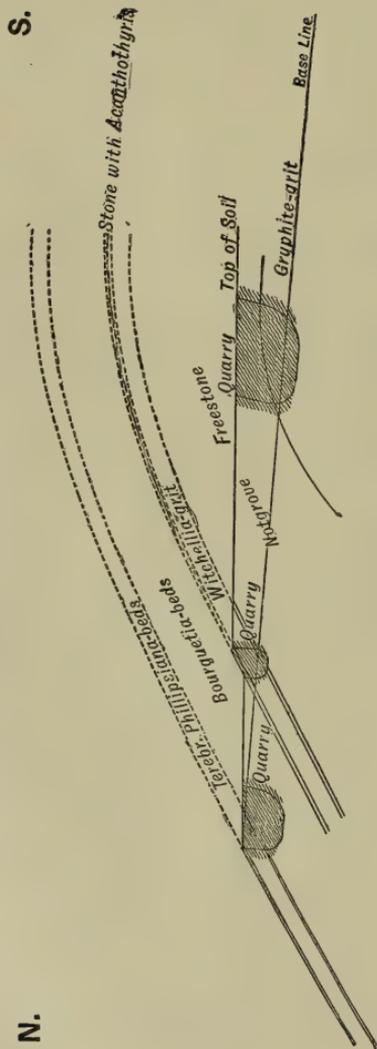
These beds form the particularly interesting feature of the Cleeve Hill plateau, and the recognition of their true position is the most important point in the geology of the district (see Diagr. I, p. 614). These deposits are not found on the southern side of the Chelt Valley, for instance at Cold Comfort, and there is considerable justification for the statement that they are not to be found anywhere else in the Cotteswolds, except upon the Cleeve Hill plateau. Therefore, as the Cotteswold rocks have particular characters of their own, and a somewhat special fauna, because they were deposited in an area which had somewhat imperfect connexion with other areas of the same date, it may be said that many of the fossils which the *Bourquetia*- and *Phillipsiana*-beds yield are not to be found anywhere else except upon the Cleeve Hill plateau. The *Bourquetia*-beds are to be distinguished from the *Phillipsiana*-beds by a difference of matrix. They yield numerous species of unusually large lamellibranchiata, and broken specimens of a large *Bourquetia* are not uncommon. One *Stephanoceras* has been obtained (p. 609, footnote).

The *Phillipsiana*-beds are easily recognized by their bluish sandy matrix. They yield chiefly species of brachiopoda, namely: *Terebratula Phillipsiana*, *T. Buckmaniana*, a *Zeilleria* cf. *Leckenbyi*, and an *Acanthothyris*. The Upper *Trigonia*-grit lies non-sequentially upon the *Phillipsiana*-beds, because their top is considerably bored; moreover, the boring must have taken place after the beds had consolidated to become as hard as their contained shells, because the bore-tubes pass through stone or shell with equal indifference.

The date of the *Phillipsiana*- and *Bourquetia*-beds is probably the *Sauzei* hemera. The *Stephanoceras* obtained agrees closely with species of this date from Dundry and Dorset. It is presumable that the *Phillipsiana*-beds do not represent any part of the *Humphriesianum*-zone, and that therefore the non-sequence between these beds and the Upper *Trigonia*-grit was occasioned by denudation during the hemeræ of *Humphriesianus* and *niortensis*—that at any rate there are, at Cleeve Hill, no remains of any deposits laid down during one or both hemeræ.

<sup>1</sup> 'Mid-Cotteswolds,' p. 417.

Diagram I.—Quarries east of the Rolling Bank.



[Scale, vertical and horizontal: 1 mm. = 2 feet.]

The shaded portions show what was actually visible in the quarries, from which the succession and thickness of the strata may be ascertained, as in the diagram. The Notgrove Freestone works out at about 26 feet thick.

Therefore the sequence of Bajocian deposits is still incomplete in the Cotteswolds.

To show how partial is the preservation of the *Bourguetia*- and *Phillipsiana*-beds it may be noticed that at Farmcott Wood, on the top of Sudeley Hill, 4 miles east of the Rolling Bank, these beds and the *Witchellia*-grit have disappeared, and the Upper *Trigonia*-grit rests directly upon Notgrove Freestone, whereof 15 feet is shown. In a southward direction the same superposition is found in 5½ miles—at Leckhampton<sup>1</sup> and at Rough Hill Bank.<sup>2</sup> What was effected by Bajocian denudation to the north will never be known, because all the strata have been removed in the excavation of the Severn Valley. What may be found to the north-east has yet to be learnt; but a preliminary survey gives little hope of any strata being found to fill the gap, or even of any other occurrence of beds between the Notgrove Freestone and the Upper *Trigonia*-grit.

The relation of the *Bourguetia*- and *Phillipsiana*-beds to the *Witchellia*-grit, and thence to the Gryphite-grit, was first learnt in the quarries east of the Rolling Bank. The details which they afford are shown in Diagr. I, drawn to a true scale. The shaded portions show the beds as they are exposed in the quarries, and the continuing lines indicate the surmises which are to be made therefrom.

The recent extension of the Rolling Bank quarry has confirmed the sequence illustrated, but it has not enabled any better measurements of actual thickness to be made than those which are possible from this diagram.

#### IV. THE SEQUENCE OF COTTESWOLD 'INFERIOR OOLITE' ROCKS.

A sequential list of certain Cotteswold deposits is given in the paper on Dundry Hill,<sup>3</sup> together with the dates assignable to each according to a chronological system. There have now to be recorded certain additions and emendations, so that the following sequence is presented:—

CHRONOLOGICAL TERMS.		STRATIGRAPHICAL TERMS.
BATHONIAN.	<i>Garantianæ.</i> (Non-sequence.)	Upper <i>Trigonia</i> -grit.
	<i>Sauzei.</i>	<i>Phillipsiana</i> -beds. <i>Bourguetia</i> -beds.
BAJOCIAN.	<i>Witchellia.</i>	<i>Witchellia</i> -beds. Notgrove Freestone.
	<i>Sonniniæ.</i>	Gryphite-grit. <i>Buckmani</i> -grit.
	<i>Discite.</i>	Lower <i>Trigonia</i> -grit.
	<i>Concavi.</i>	Snowhill Clay.
AALENIAN.	<i>Bradfordensis.</i>	Harford Sands. Upper Freestone.

<sup>1</sup> 'Mid-Cotteswolds,' p. 410.

<sup>2</sup> *Ibid.* p. 423.

<sup>3</sup> Quart. Journ. Geol. Soc. vol. lii. (1896) p. 704, table vi.



Table vi., published with the Dundry paper, should be amended in accordance with this, and then will be obtained the fullest sequence of deposits which has been yet noticed in the Cotteswolds. It is interesting to observe that the Cotteswold 'Inferior Oolite' which was parted into three divisions by Murchison in 1834<sup>1</sup> is now divided into 17 portions of varied lithic aspect, with particular faunal features. Of these divisions, 14 lie beneath the Upper *Trigonia*-grit; and of the 14, different localities show each their own particular number to be present. Thus, in a south-to-north traverse, there may be tabulated as present beneath the Upper *Trigonia*-grit:

At Uley Bury,	Birdlip,	Leckhampton,	Cleeve Hill,
2	5	10	14 divisions.

This record illustrates the difference effected mainly by denudation prior to the deposition of the Upper *Trigonia*-grit.

#### V. CORRELATION OF THE CLEEVE HILL DEPOSITS WITH THOSE OF OTHER LOCALITIES.

With the alterations noted above, the Cleeve Hill deposits may be correlated with those of Dundry and Dorset-Somerset according to the table given in the paper on Dundry Hill just quoted. Only those slight alterations and the addition of the Snowhill Clay are required.

#### VI. THE STRUCTURE OF PART OF CLEEVE HILL.

The approximate structure of the upper part of the Cleeve Hill plateau, from the top of Hewlett's Hill to the Rolling Bank quarry, and to the knoll immediately beyond that, is illustrated in Diagr. II.<sup>2</sup> Not quite a straight line has been followed—rather some details off the line have been brought into the general line, the better to show the sequence of the strata and their position.<sup>3</sup> It may be seen that there are seven faults noted; three of these, but one is scarcely worthy of the name, are shown in the Rolling Bank itself. There may be other faults hidden.

Of these faults, No. 1, near Hewlett's Hill, is shown by old workings

<sup>1</sup> 'Geology of Cheltenham,' p. 10.

<sup>2</sup> A note may be made concerning what I have called the *Nerinea*-bed, although it is outside the scope of this paper. It shows some fine *Nerinea*, and it also yields a *Terebratula* so closely like *T. fimbria* that it would be called that fossil. However, certain peculiar characters distinguish it from the *Terebratula fimbria* of the Oolite Marl—it is, in fact, a biologically earlier fossil, and is the parent of the Oolite Marl shell. The bed in which it occurs is a fossiliferous, somewhat pisolitic, sandy vein in the Lower Freestone. I am not at present able to say how far the bed is situated below the Oolite Marl, or above the Pea Grit. Possibly it has been hitherto considered as Oolite Marl. The interest attaching to it is biological, in connexion with the fimbriate *Terebratula*.

<sup>3</sup> The surface of the ground, with the approximate height shown, is such as would be found by any one making a traverse along the hill-top from Hewlett's to beyond the Rolling Bank.

of Harford Sand on the same level as a freestone-quarry. No. 2 can only be surmised from the stones of the field. No. 3 seems to extend in a north-westerly direction from just before the southern entrance to Cleeve Common (by Upper Hill Farm), and to be nearly in the line of a valley-like depression, of which perhaps it may be the cause. No. 4 is plainly shown at 'Roadstone Hole,' where the strata are tilted at an angle of about  $55^{\circ}$ . No. 7 is at the northern end of the Rolling Bank, where the Upper *Trigonia*- and *Clypeus*-beds are let down level with beds of the Lower Freestone—a fall of about 100 feet; this fault extends across the hill.

At the southern end of the Rolling Bank quarry, another fault, No. 5, has lately been opened to view.<sup>1</sup> By this fault the *Phillipsiana*-beds are tilted at a steep angle against the *Clypeus*-grit of the other part of the quarry; and in such a manner that, on about this level, all the strata from the *Phillipsiana*-beds to the Gryphite-grit are passed in succession in a southward direction. But there is another feature of interest about this fault: it is separated from the rest of the quarry by a fissure into which has dropped a mass of vertically-bedded conglomerate. It yields the following section:—

	Ft.	ins.
1. Rubble of the <i>Clypeus</i> -grit with some red clay, and calcareous infiltrations .....	1	6
2. Fine gravel with much red clay, the gravel not waterworn ...	1	8
3. Limestone, lumps of <i>Clypeus</i> -grit, and some red marl, <i>Terebratula globata</i> , <i>Rhynchonella hampenensis</i> .....	2	0

The whole is much cemented together by a calcareous deposition from percolating rainwater.

The relationship of this section to the other beds is shown in the diagram (III) facing this page. Bed No. 3 is apparently the same as that marked No. 3 on the left—it is the top of the *Clypeus*-grit. Above that, on the left, the band of red clay is particularly noticeable, associated somewhat irregularly with fine gravel; over that is more rubble, of apparently the *Clypeus*-grit, and mixed with that again is rubble of the *Phillipsiana*-beds.

The explanation, therefore, appears to be this:—The northern portion (A) of the Rolling Bank quarry fell in after the Fullers' Earth Clay had been removed from Cleeve Hill, and after a relic of it—the red clay—had been worked up with some top rubble of the *Clypeus*-grit, but before the *Clypeus*-grit had been removed. This fall caused the fissure to open, and also tilted the beds of portion B. By this tilting the uppermost beds of portion B slid into the fissure, while the *Clypeus*-, Upper *Trigonia*-, and part of the *Phillipsiana*-grits of portion B slid over to C and perhaps extended towards A. These beds have subsequently been removed by the same agency as that which has removed all the *Clypeus*- and Upper *Trigonia*-grits from Cleeve Hill, except where they have been protected by being thus let in by a fault.

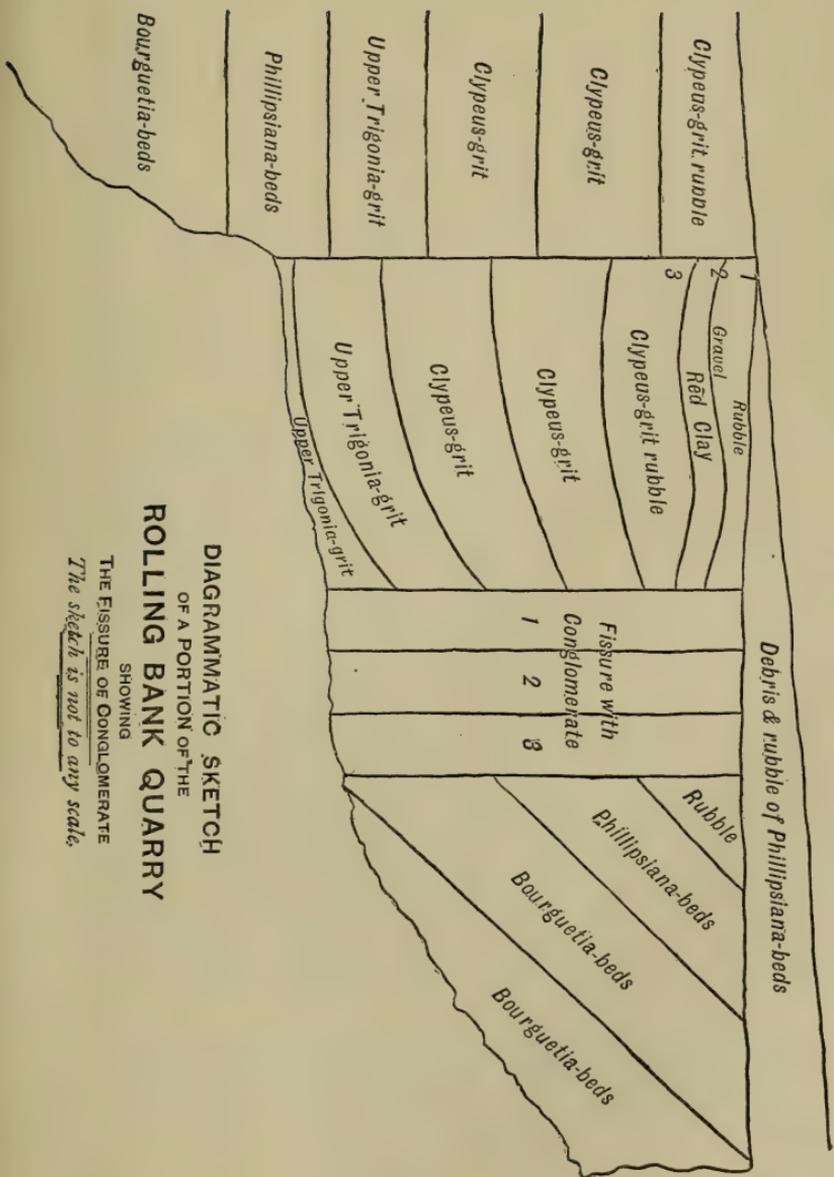
<sup>1</sup> No. 6 is quite a small fault in the Rolling Bank.

Diagram III.

A.

C.

B.



DIAGRAMMATIC SKETCH  
OF A PORTION OF THE  
ROLLING BANK QUARRY

SHOWING  
THE FISSURE OF CONGLOMERATE  
*The sketch is not to any scale.*

## VII. THE BAJOCIAN DENUDATION.

The presence of the *Phillipsiana*- and *Bourguetia*-beds at the Cleeve Hill plateau supplies certain further details concerning the Bajocian denudation: namely, that at Cleeve Hill there was spared an additional amount of about 45 feet of strata more than at Leckhampton. That hill again has about 34 feet more than at Cranham (Buckholt) Wood, beyond Birdlip. Therefore, in comparison with that locality, Cleeve Hill shows about 79 more feet of rock beneath the Upper *Trigonia*-grit; and, as the distance is about 9 miles, the average fall, or amount removed, is about 9 feet per mile. This amount of fall would be so small a departure from the horizontal that it can be easily understood how the Upper *Trigonia*-grit was laid down upon different rocks with a false appearance of conformity to each of them. A view of the Bajocian denudation, and the position of the Upper *Trigonia*-grit relatively to underlying beds from beyond Birdlip to Cleeve Hill, is shown in Diagr. IV, facing this page. In this diagram the almost regular line of the Bajocian denudation should be noted.<sup>1</sup>

With regard to the bed which underlies the Upper *Trigonia*-grit, it should be remarked that whether freestone, sandstone, or otherwise, it is always considerably bored, that the shells which the bed contains are bored, that the top of the bed is more or less planed off, and that oysters are frequently found forming a thin layer on this planed top.

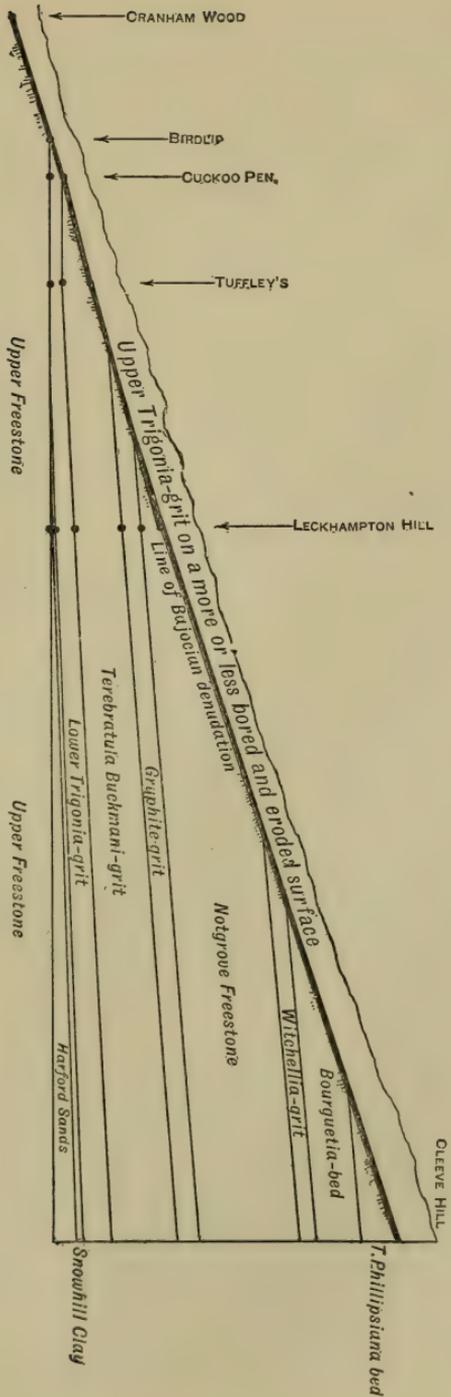
The fact that at Cleeve Hill as at Dundry,<sup>2</sup> and at Sandford Lane near Sherborne, the denudation occurs on the top of beds which can be dated as *Sauzei* hemera is a matter of some interest in connexion with the treatise which Dr. M. Vaček wrote to show that the greatest stratigraphical non-sequence was between strata of the *Murchisonæ*- and *Sowerbyi*-zones,<sup>3</sup> and that therefore that was the proper place for a division between Lias and Oolite. These localities do not accord therewith, and still less does Osborne in Dorset, where a non-sequence is not found. But the fact is that no stratigraphical details can decide a matter of geological division—such phenomena are local, and they are not contemporaneous. The only method by which an uniform geological system of division, universally applicable, can be accomplished is by making it dependent on palæontological, and independent of stratigraphical matters.

<sup>1</sup> At Leckhampton Hill the Upper Freestone has a planed-off top surface, is somewhat bored, and has pitlike excavations which are filled with Snowhill Clay. There are no Harford Sands. In the Stroud area the Upper Freestone is much bored, so that from Leckhampton southward there was an Aalenian denudation of the Upper Freestone. See also 'Mid-Cotteswolds,' p. 430, table vi.

<sup>2</sup> 'Dundry Hill,' Quart. Journ. Geol. Soc. vol. lii. (1896) p. 704, table vi., & p. 711.

<sup>3</sup> 'Ueber die Fauna der Oolithe von Cap St. Vigilio, verbunden mit einer Studie über die obere Liasgrenze, pt. ii.' Abh. k.-k. geol. Reichsanst., vol. xii. (1886) pp. 120-209.

Diagram IV.—The Bajocian Denudation: Birdlip to Cleve Hill.



Scale: Horizontal, 15 mm. or 6 inch = 1 mile. Vertical, 1 mm. = 2 feet.

[For 'Snowhill Clay' read 'Snowshill Clay'.]

A map (Pl. XLVI) has been constructed to show over what portions of Cotteswold country the Upper *Trigonia*-grit comes into actual contact with particular rocks. The lines which are drawn upon the map give, so far as evidence and justifiable supposition may indicate, the limits of each particular rock, so that the lowest boundary-line defines where the last trace of a particular bed is found beneath the Upper *Trigonia*-grit. It will be seen that with a little exception, in passing from west to east, the Upper *Trigonia*-grit rests successively upon the strata from the *Phillipsiana*-beds to the Oolite Marl<sup>1</sup>—the outer line marking what is presumed to be the extreme boundary of the Oolite Marl.

The reasons which have led to the drawing of the boundary-lines in the present positions may be briefly stated as follows:—

1. Direct evidence, furnished by actual exposures.
2. Indirect evidence, such as may be obtained by constructing diagrams from the exposures of various localities (see Diagr. IV of this paper, p. 621, and that given in 'The Bajocian of the Mid-Cotteswolds,' Quart. Journ. Geol. Soc. vol. li. 1895, p. 430, table vi).
3. Inference,—that there would be more or less of a parallelism between the courses of the different lines, so that an unknown contour of one may be approximately determined from a known contour of another.

1. The direct evidence speaks for itself; and the actual exposures are marked in the map, with the name of the bed upon which the Upper *Trigonia*-grit rests, except in certain cases enclosed in brackets where the actual contact has not been recorded, as, for example, Edgeworth. The actual exposures observed are recorded upon my own authority; but the following notes have also been considered; they are recorded in the map in inverted commas:—

1857. LYCETT, 'Cotteswold Hills.' Thin band of Oolite Marl beneath upper ragstones at Ball's Green, near Nailsworth, p. 50.

1857. HULL, 'Geology of the Country round Cheltenham.' Ragstone on Oolite Marl, Turkdean, p. 38. Ragstone on Freestone, 5 feet from Upper Lias at Sherborne, p. 40. Ragstone on Upper Lias at Stow, Rissington, and Burford, pp. 40 and 47. Oolite Marl at Condicote, p. 37.

1870. J. H. TAUNTON. Sapperton Tunnel; Proc. Cotteswold Nat. Field Club, vol. v. p. 268,—records the find of *Terebratula fimbria*.

1894. H. B. WOODWARD, 'Lower Oolitic Rocks of England,' Mem. Geol. Surv.: Jurassic Rocks, vol. iv. Oolite Marl at Yanworth Common, p. 127; Harford Sands at Bourton Clump, p. 143; Gryphite-grit [? Lower *Trigonia*-grit] and Harford Sands, east of Stanway Hill Barn, p. 137; Oolite Marl west of Blockley, p. 141.

C. UPRON, information;—Upper *Trigonia*-grit on Oolite Marl by roadside near Long Wood, between Selsley and Nymphsfield.

<sup>1</sup> It also rests on lower rocks; but their limits have not been attempted in the present case.

2. Indirect evidence. Not all the possible sections which might be constructed have been examined; but, as an instance, the course of the *Witchellia*-grit-line towards Cheltenham may be quoted. This is on the evidence of the section from Leckhampton to Cleeve.

3. Inference. The south-easterly extension of the *Witchellia*-grit-line is based on the idea of parallelism with the known extension of Notgrove Freestone. The north-easterly curvature of the Oolite-Marl line towards Birdlip is based partly on the same idea of parallelism, partly on the fact that the Upper *Trigonia*-grit is close to the *Terebratula fimbria*-line at Cranham Wood and at Bull Bank, by Miserden.

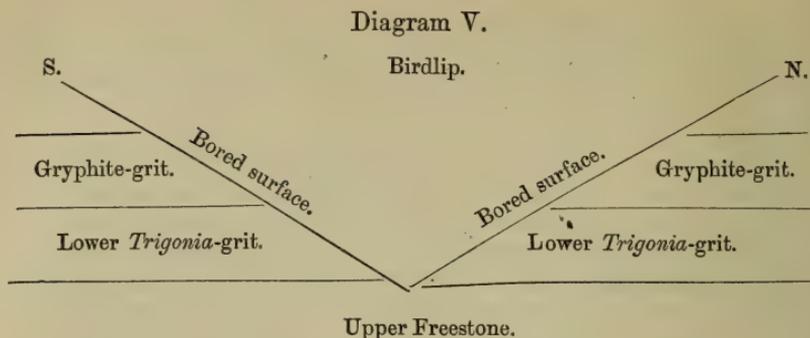
The assumed courses across the vale are shown by dotted lines,<sup>1</sup> but all the lines on the map are to be regarded as approximative. Further exploration of the country will no doubt show the necessity for some modification of the lines, and considering the nature of the task, with the difficulty of finding suitable exposures, this may be reasonably expected. Such alteration in the matter of details will not, however, be really important, in regard to the general view which the map affords of the distribution of the rocks upon which the Upper *Trigonia*-grit rests. It may be confessed that the line which is most speculative is the boundary-line of the Oolite Marl; but the evidence upon which it is drawn is given in the map.

The attempt to construct this map shows how very much there is yet to be learnt concerning the geology of the Cotswolds. Particularly is this the case with the large stretch of country north-east of Cleeve Hill and north of the Banbury & Cheltenham Railway. Of this country we have very few details—practically no more than an outline. For this reason I could make no attempt to map it with reference to the Bajocian denudation. But probably another reason will prevent any such map from being constructed in detail, and that is the greater removal of the Upper *Trigonia*-grit by recent denudation—the farther north they are the more have the ‘upper beds’ suffered.

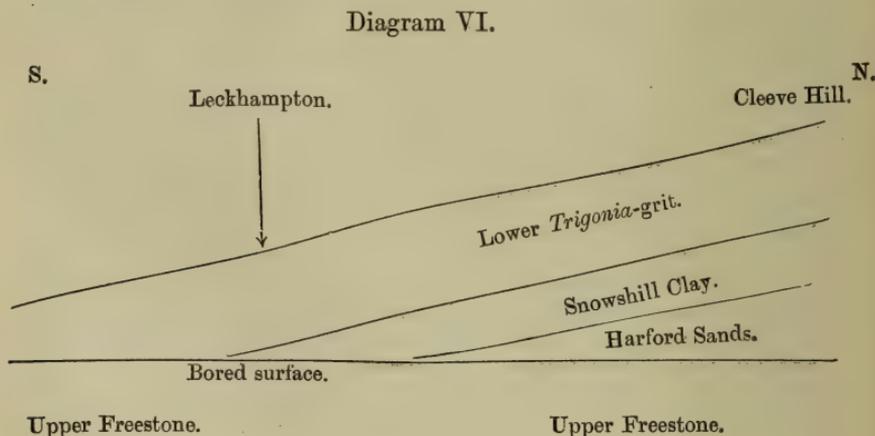
#### VIII. DENUDATION AND OVERLAP.

A noticeable distinction may be drawn between the cause of the absence of the lower Ragstones—the Lower *Trigonia*- and Gryphite-grits—from the Birdlip district, and the absence of the Harford Sands and Snowhill Clay south of Leckhampton. The former is due to denudation, the latter is due to absence of deposit. In the former case, coming either from north or south towards Birdlip it is found that always the upper stratum is removed while the surface of the bed which may be present exhibits borings and signs of erosion. This is illustrated in the following diagram:—

<sup>1</sup> The irregular line denotes the edge of the Cotswold escarpment.



In the latter case the bored surface is underneath, for there was an Aalenian denudation of the Upper Freestone; and the lower stratum is found to fail while the upper one continues. Hence an upper bed overlaps a lower one, as the Harford Sands are found at Cleeve, with the other deposits, but only a thin bed of Snowhill Clay is found at Leckhampton; while neither are present to the south. So the case stands thus:—



This difference, in connexion with any absence of deposits, requires to be carefully noted.

#### IX. A WATER-RETAINING BED.

It is generally taught that between the Fullers' Earth above and the Upper Lias below there is no impervious or water-retaining deposit. Exception must be taken to this statement in several cases; but it is particularly incorrect with regard to the Northern Cotswolds. The Snowhill Clay is an impervious bed; and its position lies about the middle of what is indefinitely called 'Inferior Oolite.' In a district where water is obtainable only with difficulty

the Snowhill Clay becomes of considerable economic importance. Its presence has governed the situation of farmhouses and cottages.

The Snowhill Clay is the bed which throws off water for a cottage just north of Puckham Farm, and the water from this spring is taken to the farm itself, although that farm is situated not very far above 'Upper Lias.' The Clay also throws off water for the gamekeeper's cottage immediately west of Puckham Wood. Moreover it furnishes the sole water-supply for Wontley Farm. All these places are on the Cleeve Hill plateau, and the supply is said to be constant.

At the Seven Wells, about  $1\frac{1}{2}$  mile south of the Fish Inn, Broadway, and about the same distance north-eastward of Snowhill, there are copious springs of water thrown out by the Snowhill Clay, used for the supply of the farmhouse. These 'Seven Wells' are said never to have failed, and the people of the locality claim them as 'the source of the Thames.' Mr. H. B. Woodward<sup>1</sup> apparently considers that these springs issue from the Upper Lias; but there is in the field below them a quarry of sand, which would be in the position of the Harford Sands, and this again accords with the general lie of the beds in the district round.

No doubt many other farms in the Northern Cotteswolds owe their water-supply to the impervious character of the Snowhill Clay.

#### X. ANCIENT GEOGRAPHY OF THE CLEEVE HILL PLATEAU.

There are many dry valleys intersecting the Cleeve Hill plateau. Some of them point to a time when the plateau was covered by an impervious bed of Fullers' Earth Clay, upon which reposed perhaps a portion of the Great Oolite; the valleys were excavated by streams thrown off by the Clay.<sup>2</sup> When the capping of Fullers' Earth Clay was removed these valleys became dry. Others, however, may have become only partially dry then, because streams may have issued from the top of the Snowhill Clay. But the Snowhill Clay has in its turn been removed, and then the valleys became dry down to the outcrop of the Upper Lias.<sup>3</sup>

On Sevenhampton Common a stream issues from the top of Fullers' Earth Clay from beneath Great Oolite. Several of the dry valleys above Whittington commence just about where Fullers' Earth Clay would be if it were present, and so they may have been excavated by

<sup>1</sup> 'Lower Oolitic Rocks of England,' Mem. Geol. Surv.: Jurassic Rocks, vol. iv. (1894) p. 504.

<sup>2</sup> E. Witchell, 'On the Denudation of the Cotteswolds,' Proc. Cottesw. Nat. Field Club, vol. iv. (1868) p. 227.

<sup>3</sup> With a rainfall of very much greater magnitude—beyond the absorption-power of the most pervious Cotteswold strata—the idea of a former clay-capping may not be necessary. Then the rain would flow as surface-water off the water-logged pervious strata, and in so doing would cut channels, which would in time become valleys—much on the same principle as the channels cut in a wide gravelled courtyard by heavy rain at the present day. This surmise would fit in with the idea that the flat top of the Cotteswolds is a line of marine denudation.

streams thrown out by a former capping of that clay. At Wontley Farm there is a noticeable dry valley, and the portion of it above the Snowhill Clay may have been excavated by a stream from the Fullers' Earth. Here, too, is found a spring from the Snowhill Clay; but with the present rainfall, some 27 inches per annum, there is not sufficient water to form a stream down the valley: it becomes lost. But no doubt the rainfall was very much greater when the Cotteswolds were—as the name implies—a great wooded tract of country.<sup>1</sup>

The large size of the Cotteswold valleys in proportion to the streams which flow down them is generally very noticeable. To account for the size of the valleys requires two suppositions—a more extensive drainage-area, and a greater rainfall. In many cases the former may be granted readily, in some cases it cannot be: the greater rainfall is then the conclusion arrived at. It may be doubtful whether a more arboreal character would, in a climate like the present, increase the rainfall sufficiently, though it might make much difference. Of course a far more humid climate may also be surmised—the so-called 'Pluvial Period.'

Decrease of rainfall must be considered in connexion with any denudation of an impervious stratum: because, with a decreasing rainfall, a valley would become dry very much sooner in relation to the amount of denudation—that is, it would become dry while there still remained of the impervious stratum much more than if the rainfall were greater. In other words, with a greater rainfall more of the impervious stratum would have to be removed before the spring dried up. Valleys which are now dry, but have been excavated by streams issuing from a former clay-capping, are a common feature of the Cotteswolds.

However, the interest which attaches to the Cleeve Hill examples, particularly to the valleys leading to Postlip, is the depth to which they have been excavated, owing to the rapid fall of the streams from the top of the hill into the valley of the Severn. Yet we must assume that the streams which originally excavated the Postlip valleys did not flow into the Severn, but formed part of the drainage of the Thames. The shape of the Cleeve Hill plateau at Corndean, and by Wadfield Farm, gives evidence of this; and, further, the Sevenhampton valley must have been excavated by a stream which came from the north, from a former extension of the Cotteswold plateau over the country beyond Winchcombe and Toddington: it was a tributary of the Coln. The Postlip streams would have been tributaries of the Sevenhampton stream.

Further, the valley which is at the southern end of the Cleeve Hill plateau—part of which is now the valley of the Chelt—must have been also excavated by a stream tributary to the Coln. It flowed

<sup>1</sup> Cotteswold, *Coed*, a wood (Welsh); *wold*, a wood (Anglo-Saxon). But I would suggest that the Anglo-Saxon name is a corruption of an older Welsh name, like, say, *Coed-y-swll*—the wood of the plain. *Swll* is 'a flat space,' and the flat, plain-like appearance of the top of the Cotteswolds is very noticeable. The native pronunciation is 'Cot-sul.'

eastward from a former westerly extension of the Cotteswolds. The 700-foot contour-line of the Chelt Valley supports this idea.<sup>1</sup> It may be further surmised that the western escarpment of the Cleeve Hill plateau formed one side of a river-valley along which this stream flowed.<sup>2</sup>

All this, of course, was at a period when the Cotteswolds had a much greater extension over the valleys of the Severn and the Warwickshire Avon. At that time the Thames must have been not only a far larger, but a very much longer river than it is now.

### XI. MAP OF THE CLEEVE HILL PLATEAU.

With this communication is presented a map of the district referred to. No attempt has been made to map the limits of the various deposits, because, owing to the faults, this must be a work of some labour. The map, however, is given as a guide to a district wherein it is difficult to state with exactness the sites of the exposures. The beds shown by the different exposures—or at least by the principal quarries—are marked upon the map; and besides that, where other evidence of the nature of the substratum has been obtained, the name of the deposit has been entered. Some of the faults have also been indicated. (See p. 628.)

### XII. CONCLUSION AND SUMMARY.

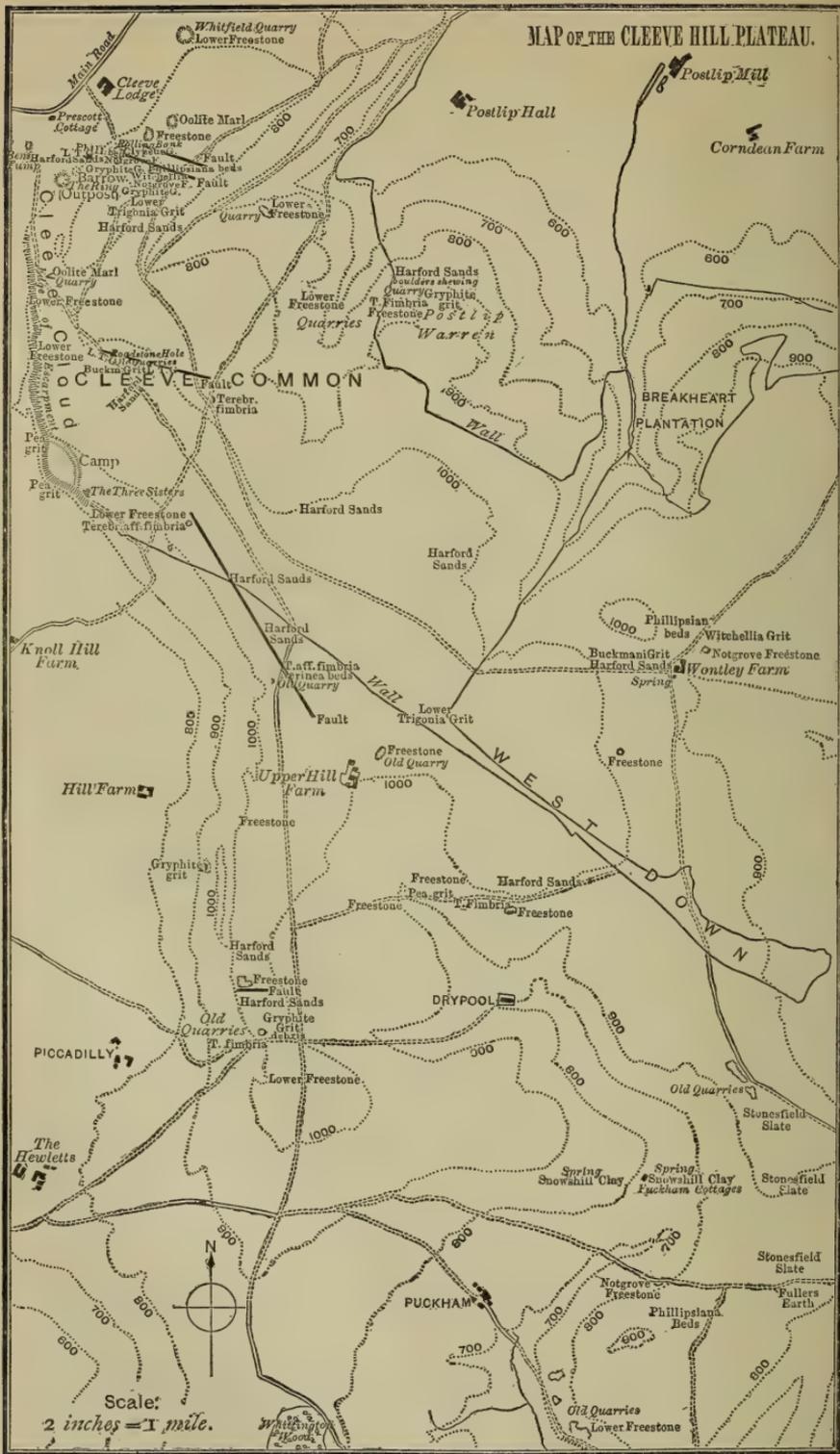
This paper deals with a part of the Northern Cotteswolds, and it is hoped to supplement it in the future by some account of the remaining portion of that little-known district. The present communication deals only with some of the rocks exposed at the Cleeve Hill plateau<sup>3</sup>; but it treats of that portion about which most misapprehension has occurred, and whose position in the series it has been always a very difficult point to determine. The work in the Mid-Cotteswolds, and particularly the recognition of the position of the *Witchellia*-grit at Cold Comfort, gave the necessary clue to the unravelling of the Cleeve Hill sequence. The interesting point is that at Cleeve Hill there should be found so much more rock beneath the Upper *Trigonia*-grit. There are the *Phillipsiana*-, *Bourquetia*-, and *Witchellia*-beds, of which no trace is found at Leckhampton; and there is a thick deposit of Notgrove Freestone, of which Leckhampton shows but the smallest remnant.

<sup>1</sup> The present streams on the east and south of the Cleeve Hill plateau could not have excavated all those valleys, because they rise from 200 to 300 feet below the top edges thereof.

<sup>2</sup> The western side of Cleeve Hill would be analogous to the eastern side of the Sevenhampton Valley. The latter, supposing the Cleeve Hill plateau to be by any means removed, would become the outer Cotteswold escarpment, and would be the relic of an old river-valley.

<sup>3</sup> Much has yet to be learnt about the others, especially concerning the Pea-grit series.

MAP OF THE CLEEVE HILL PLATEAU.



There are, however, additional matters of interest; meanwhile the following summary of the present paper may be given:—

1. That the lower beds of the northern part of the Rolling Bank quarry overlie the *Witchellia*-grit.
2. That these deposits of about 20 feet in thickness, with their lithic and faunal differences, may be conveniently distinguished as *Terebratula Phillipsiana*- and *Bourguetia*-beds.
3. That these beds may be approximately dated as *Sauzei* hemera.
4. That these beds have not been found beyond the Cleeve Hill plateau.
5. That the Upper *Trigonia*-grit lies non-sequentially upon these beds.
6. That a distinct clay-deposit may be recognized at Cleeve Hill, separating the Lower *Trigonia*-grit and the Harford Sands; and that it may be named Snowhill Clay.
7. That this deposit is more developed in the farther Northern Cotteswolds; that it is a water-retaining bed even on the Cleeve Hill plateau, and that it is, therefore, a stratum of economic importance.
8. Further facts concerning the Bajocian denudation are set forth; and a map (Pl. XLVI) is given showing the area of the different deposits upon which Upper *Trigonia*-grit was laid down.
9. Some notes on the ancient geography of Cleeve Hill, especially in regard to its old lines of drainage, are presented.
10. A sketch-map of the principal portion of the Cleeve Hill plateau is given. It shows the positions of the different quarries; and the principal strata which they contain are also marked therein.

#### PLATE XLVI.

Map of the Bajocian Denudation, showing the area of the different beds upon which the Upper *Trigonia*-grit was deposited; on the scale of 4 miles to the inch.











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- WOOLACOTT, D., Explan. of Claxheugh section, Co. Durham [*title only*], xcix.
- WORTH, R. N., obituary of, lxii.
- Worthington Mine (Ontario), rocks of, 44, 45, 60, 63.

- Wrekin (Shropshire), pre-Cambr. rocks of, lxxxi. 'Younger Granites' of Sudbury district, 61.
- Y Graig (Anglesey), sections descr., 351, 353. *Zamiopteris* (?) cf. *glossopteroides*, 504 & pl. xli. figs. 4-5.
- Yellow Sandstones (Cretac.) of Co. Antrim, 542, 549 *et seq.*; chem. & micromineral. comp. of, 572-574; seq. & correl. of, 589-591. Zircon in Antrim Cretac. rocks, 572 *et seq.* & tables ii-iii.
- Zwart Koppies (Transvaal), *Lepidodendron* found at, 313, 314, 315.

END OF VOL. LIII



# PROCEEDINGS

OF THE

## GEOLOGICAL SOCIETY OF LONDON.

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SESSION 1896-97.

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November 4th, 1896.

Dr. HENRY HICKS, F.R.S., President, in the Chair.

The PRESIDENT referred to the loss which the Society had sustained by the decease of Prof. A. H. GREEN, M.A., F.R.S., who had served for some years on the Council, and was Vice-President at the time of his death. His wide knowledge of science, his perfect uprightness of character, and his genial good-nature were greatly valued by all those who had the privilege of coming into contact with him.

The PRESIDENT further announced that the Council had that afternoon passed the following resolution:—

‘The Council of the Geological Society are deeply sensible of the loss which they have sustained in the death of Prof. GREEN, M.A., F.R.S., one of their Members, and a Vice-President of the Society. In placing on record their acknowledgment of the services which he has often rendered to the Society, they desire to express their heartfelt sympathy with Mrs. Green and the family in their sudden bereavement.’

The PRESIDENT announced that Lady PRESTWICH, in fulfilment of the terms of a bequest of her late husband, had offered to the Society 260 bound volumes of geological tracts from his Library. Also that a sum of £800 had been bequeathed to the Society by Sir Joseph Prestwich, the interest to be applied to the triennial award of a medal and fund: this bequest to take effect subsequent to the decease of Lady Prestwich.

The List of Donations to the Library was read.

The SECRETARY announced that the Rev. P. B. BRODIE, M.A., F.G.S., had presented to the Society a framed platinotype portrait of himself; that Capt. G. E. A. Ross, F.G.S., had presented eight lithographic portraits of distinguished geologists; and that Miss HAWKINS had presented a portrait of her late father, Waterhouse Hawkins, Esq.

The following communications were read:—

1. 'Additional Note on the Sections near the Summit of the Furka Pass (Switzerland).' By T. G. Bonney, D.Sc., LL.D., F.R.S., V.P.G.S., Professor of Geology in University College, London.

2. 'Geological and Petrographical Studies of the Sudbury Nickel District (Canada).' By T. L. Walker, Ph.D., M.A. (Communicated by J. J. H. Teall, Esq., M.A., F.R.S., Sec.G.S.)

3. 'On the Distribution in Space of the Accessory Shocks of the Great Japanese Earthquake of 1891.' By Charles Davison, Sc.D., F.G.S.

The following specimens, etc., were exhibited:—

Rock-specimens and microscopic sections, exhibited by Prof. T. G. Bonney, D.Sc., LL.D., F.R.S., V.P.G.S., in illustration of his paper.

Photographs taken by C. E. Monckton, Esq., exhibited by Horace W. Monckton, Esq., F.L.S., F.G.S.

Working Maps of the Secondary Rocks of Cutch, scale: 1 inch = 1 mile, exhibited by the Rev. J. F. Blake, F.G.S.

Sapphires and other precious stones from Withersfield, Central Queensland, exhibited by Prof. R. Tate, F.L.S., F.G.S., on behalf of Thos. Parker, Esq., of Rockhampton.

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November 18th, 1896.

Dr. HENRY HICKS, F.R.S., President, in the Chair.

Robert Brown, Esq., Desheyhur, *via* Barrakur, E.I.R., Bengal, India; and Douglas Stuart Spens Stewart, Esq., B.Sc., Victoria University, Manchester, were elected Fellows of the Society.

The List of Donations to the Library was read.

The following communications were read :—

1. 'On *Cycadeoidea gigantea*, a new Cycadean Stem from the Isle of Portland.' By A. C. Seward, Esq., M.A., F.G.S., University Lecturer in Botany, Cambridge.

2. 'The Fauna of the Keisley Limestone.—Part II. Conclusion.' By F. R. Cowper Reed, Esq., M.A., F.G.S.

The following specimens, etc., were exhibited :—

Lantern-slides, exhibited by A. C. Seward, Esq., M.A., F.G.S., in illustration of his paper.

Specimens exhibited by F. R. Cowper Reed, Esq., M.A., F.G.S., in illustration of his paper.

*Ammonites* cf. *Siemensi*, Inferior Oolite Series, Holm, Portree, collected by H. B. Woodward, Esq., F.R.S., F.G.S., and exhibited by the Director-General of H.M. Geological Survey.

*Ammonites* near to *Humphriesianus*, Inferior Oolite, Scorybeck, Portree, exhibited on behalf of Mrs. Robertson, Portree, by H. B. Woodward, Esq., F.R.S., F.G.S.

Sheet 10 of the Geological Survey Index Map of England and Wales, scale: 4 miles = 1 inch, presented by the Director-General of H.M. Geological Survey.

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December 2nd, 1896.

Dr. HENRY HICKS, F.R.S., President, in the Chair.

Edgar C. Agabeg, Esq., Gourangdi, Seetarampore, P.O., E.I.R., Bengal; Jonathan Barnes, Esq., 1 Trafalgar Street, Broughton, Manchester; Thomas Barron, Esq., Geological Survey Office, Cairo, Egypt; Hugh John Llewellyn Beadnell, Esq., Geological Survey Office, Cairo, Egypt; Lawrence Birks, Esq., 20 Dublin Street, Edinburgh; Reginald Marr Brydone, Esq., 152 Cambridge Street, S.W.; Peter Francis Daniel, Esq., Greymouth, New Zealand; Albert Hubert Halder, Esq., 6 Drapers' Gardens, E.C., and Bulawayo, Rhodesia; Henry Arthur Hinton, Esq., 42 Brownswood Road, Green Lanes, N.; William Firth Holroyd, Esq., River Cottage, Lower Broughton; William MacLean Homan, Esq., Christiania; Burton Samuel James, Esq., 3 Douglas Villas, Streatham Common, S.W.; Henry Kay, Esq., Allen Road, Wolverhampton; E. Seaborn Marks, Esq., Astwood

House, 111 Cromwell Road, South Kensington, S.W.; Gerald N. Marks, Esq., Astwood House, 111 Cromwell Road, South Kensington, S.W.; William O'Connor, Esq., Church Villa, Pentre, Glamorganshire; Thomas Parker, Esq., Tynedale, Rockhampton, Queensland; Edward Wyndham Penruddocke, Esq., 87 South Street, Eastbourne; Alfred Edward Salter, Esq., 14 Amersham Road, New Cross, S.E.; Major William Slade Vincent, 10 Bury Street, St. James's, S.W.; and Cecil Frederic Webb, Esq., 2 Brougham Terrace, West Derby Road, Liverpool, were elected Fellows of the Society.

The List of Donations to the Library was read.

The SECRETARY announced that FRANK OWEN, Esq., F.G.S., had presented to the Society a photographic portrait of his late grandfather, Sir Richard Owen.

The following communications were read:—

1. 'Another possible Cause of the Glacial Epoch.' By Prof. Edward Hull, M.A., LL.D., F.R.S., F.G.S.

2. 'On the Affinities of the Echinothuridæ, and on *Pedinothuria* and *Helikodiadema*, two New Subgenera of Echinoidea.' By J. W. Gregory, D.Sc., F.G.S.

3. 'On *Echinocystis* and *Palæodiscus*, two Silurian Genera of Echinoidea.' By J. W. Gregory, D.Sc., F.G.S.

A Special General Meeting was held at 7.45 P.M., before the Ordinary Meeting, at which W. WHITAKER, Esq., B.A., F.R.S., was elected a Member of Council, and Sir ARCHIBALD GEIKIE, D.Sc., D.C.L., F.R.S., a Vice-President of the Society, in place of Prof. A. H. Green, deceased.

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December 16th, 1896.

Dr. HENRY HICKS, F.R.S., President, in the Chair.

William Alfred Brend, Esq., B.A., 6 Argyll Road, Kensington, W.; Robert Hawthorn Kitson, Esq., B.A., Elmet Hall, Roundhay, Leeds; James Christian Eisentwith Lawson, Esq., Finchley Lodge, North Finchley, London, N.; Howard Nasmith Perrin, Esq., B.A., King's College, Cambridge; and John Roberts, Esq., 28 Fisher Street, Swansea, were elected Fellows of the Society.

The List of Donations to the Library was read.

The following communications were read :—

1. 'On the Subdivisions of the Carboniferous Series in Great Britain, and the True Position of the Beds mapped as the Yoredale Series.' By Dr. Wheelton Hind, F.R.C.S., F.G.S.

2. 'Note on Volcanic Bombs in the Schalsteins of Nassau.' By Prof. E. Kayser, Ph.D., For.Corr.G.S. (Communicated by the Secretary.)

The following specimens, etc. were exhibited :—

Fossils exhibited by Dr. Wheelton Hind, F.R.C.S., F.G.S., and by Jonathan Barnes, Esq., F.G.S., in illustration of the paper by the first-named.

Photographs of Quarries and specimens of Volcanic Bombs in Schalsteins from Nassau, exhibited by Prof. E. Kayser, Ph.D., For.Corr.G.S., in illustration of his paper.

Volcanic Bomb from Falcon Crag, near Keswick, exhibited by J. Postlethwaite, Esq., F.G.S.

Flint Implements (?) and Stones derived from the Boulder Clay on the Coast at Runton, Norfolk, exhibited by W. J. Harrison, Esq., F.G.S.

Sheet 232, Abergavenny, Solid and Drift, of the 1-inch Map (New Series) of the Geological Survey, by J. R. Dakyns, A. Strahan, and W. Gibson, 1896; also Sheet 8 of the 4 miles-to-the-inch Index Map, 1896, presented by the Director-General of that Survey.

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January 6th, 1897.

Dr. HENRY HICKS, F.R.S., President, in the Chair.

Barclay Bonthron, Esq., Newton House, Newton of Falkland Fifeshire; Henry Arthur Pringle, Esq., Norseman, Western Australia; Thomas Penrose Prout, Esq., Prospect Terrace, St. Agnes, Cornwall; and the Rev. J. Newton Vanstone, 12 Vancouver Road, Catford S.E., were elected Fellows; M. E. Dupont, of Brussels; Dr. Anton Fritsch, of Prague; Prof. A. de Lapparent, of Paris; and Dr. Hans Reusch, of Christiania, were elected Foreign Members; and Prof. A. Hyatt, of Cambridge, Mass., a Foreign Correspondent of the Society.

The following Fellows, nominated by the Council, were elected Auditors of the Society's Accounts for the preceding year :—HORACE W. MONCKTON, Esq., F.L.S., and Dr. J. W. GREGORY.

The List of Donations to the Library was read.

The following communications were read :—

1. 'On the Structure of the Skull of a Pliosaur.' By C. W. Andrews, Esq., B.Sc., F.G.S.
2. 'On the Pembroke Earthquakes of August 1892 and November 1893.' By Charles Davison, Sc.D., F.G.S.
3. 'Changes of Level in the Bermuda Islands.' By Prof. Ralph S. Tarr. (Communicated by the Secretary.)

The following specimens, etc., were exhibited :—

An Ice-scratched (Neolithic) Celt, from Malton, Yorkshire, exhibited by the Rev. R. Ashington Bullen, F.G.S.

Teeth of *Pliosaurus* from Ely and Potton, and of *Plesiosaurus*, *Ichthyosaurus*, and *Iguanodon*; Rib of a Saurian in Stonesfield Slate; *Plocoscypbia* and *Ventriculites* from Folkestone; part of Vertebra of *Elephas* dredged from the Dogger Bank; and Vertebrate Remains from Eastern Peru, exhibited by W. F. Gwinnell, Esq., F.G.S.

Sheets 2, 4, and 5 of the Geological Survey Index Map of England and Wales, presented by the Director-General of that Survey.

Photographs taken in Bermuda, exhibited by Prof. Ralph S. Tarr, in illustration of his paper.

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January 20th, 1897.

Dr. HENRY HICKS, F.R.S., President, in the Chair.

Anthony Richard Cragg, Esq., Maristowe Cottage, Roborough, South Devon; Edmund Alderson Sandford Fawcett, Esq., 20 Thornton Hill, Wimbledon; and Joseph Lomas, Esq., 16 Mellor Road, Birkenhead, were elected Fellows of the Society.

The List of Donations to the Library was read.

The following communications were read :—

1. 'On Glacial Phenomena of Palæozoic Age in the Varanger Fiord.' By Aubrey Strahan, Esq., M.A., F.G.S.
2. 'The Raised Beaches and Glacial Deposits of the Varanger Fiord.' By Aubrey Strahan, Esq., M.A., F.G.S.

Specimens of glaciated rocks and raised-beach material, and photographs were exhibited in illustration of the above-mentioned papers by the author.

A SPECIAL GENERAL MEETING was held at 7.45 P.M., before the Ordinary Meeting, when the following Resolutions were proposed, and unanimously adopted by the Fellows present :—

To repeal Section VIII., Article 3 of the Bye-Laws, and enact as follows :—The Foreign Members shall be selected from the list of Foreign Correspondents, or from among distinguished Fellows who are not British subjects, and may be recommended by Fellows in the same manner as already provided in the case of Foreign Correspondents.

That Section XIII., Article 19 of the Bye-Laws be altered as follows :—Whenever the balance in the hands of the Banker shall exceed the sum requisite for the probable or current expenses of the Society, the Council shall invest the excess in such securities as are authorized for the investment of Trust Funds under the Trustee Act, 1893, or any Acts amending or replacing the same.

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February 3rd, 1897.

Dr. HENRY HICKS, F.R.S., President, in the Chair.

Charles Vincent Bellamy, Esq., Roseau, Dominica, British West Indies; James Bisset, Esq., B.A., 5 East India Avenue, London, E.C.; the Rev. Henry Blashell Foster, 46 Palace Street, Buckingham Gate, S.W.; Josiah Rodda Hosken, Esq., Georgetown, British Guiana; John Ellis Hughes, Esq., Ingfield House, Marston, near Huddersfield; and Harry W. Lake, Esq., 32 Shaftesbury Avenue, W., were elected Fellows of the Society.

The List of Donations to the Library was read.

The following communications were read :—

1. 'The Subgenera *Petalograptus* and *Cephalograptus*.' By Miss G. L. Elles. (Communicated by J. E. Marr, Esq., M.A., F.R.S., F.G.S.)

2. 'On some Superficial Deposits in Cutch.' By the Rev. J. F. Blake, M.A., F.G.S.

The following specimens were exhibited :—

Specimens of *Petalograptus* and *Cephalograptus*, exhibited by J. E. Marr, Esq., M.A., F.R.S., F.G.S., in illustration of the paper by Miss G. L. Elles.

Rock-specimens from Cutch and a photograph of Bhuj, Cutch, exhibited by the Rev. J. F. Blake, M.A., F.G.S., in illustration of his paper.

## ANNUAL GENERAL MEETING,

February 19th, 1897.

Dr. HENRY HICKS, F.R.S., President, in the Chair.

### REPORT OF THE COUNCIL FOR 1896.

It is once more the pleasant duty of the Council to place on record the uninterrupted financial prosperity of the Society, and they have, in addition, to congratulate the Society on the fact that, for the first time in a period of five years, there is an increase in the number of Fellows. It had been pointed out already that the decrease in numbers mentioned in previous reports was proceeding at a diminishing ratio, and there appears good reason to hope that the upward tendency now recorded will steadily continue.

During 1896 the number of Fellows elected into the Society was 62, of whom 48 paid their Admission Fees before the end of the year. Fees were also received during the past twelvemonth from 11 Fellows, who had been elected in 1895, the total accession of new Fellows in 1896 being therefore 59.

On the other hand, there was a total loss of 47 Fellows during the twelvemonth under review—26 by death, 18 by resignation, and 3 removed from the List because of non-payment of their Annual Contributions. It is satisfactory to note that the last-named cause accounts for the removal of so very few names from the List, as compared with former years.

From the foregoing figures it will be seen that the actual increase in the number of Fellows is 12 (as compared with decreases of 1 in 1895, 11 in 1894, 46 in 1893, and 19 in 1892).

Of the 26 Fellows deceased 7 had compounded for their Annual Contributions, 17 were Contributing Fellows, and 2 were Non-Contributing Fellows.

On the other hand 8 Fellows during the past year became

Compounders. The total accession of Contributing Fellows is thus seen to be 51, and the total loss being 38 (18 + 17 + 3), the increase in the number of Contributing Fellows is 13.

Turning now to the Lists of Foreign Members and Foreign Correspondents, the Fellows may recollect that at the end of 1895 there was 1 vacancy in the List of Foreign Members and 2 in the List of Foreign Correspondents. In 1896 three Foreign Members died. The vacancies thus left were in part filled by the election of 1 Foreign Member and 2 Foreign Correspondents, but at the end of the year there were still 3 vacancies in the List of Foreign Members and 1 in the List of Foreign Correspondents.

The Council need hardly remind the Fellows that they have, at a recent Special General Meeting, sanctioned a modification of the Bye-Laws such as will allow of the transfer of distinguished men of science who are not British subjects, but have nevertheless become Fellows, to the List of Foreign Members.

The total number of Fellows, Foreign Members, and Foreign Correspondents, which on December 31st, 1895, was 1318, had increased by the end of 1896 to 1329.

Proceeding now to the consideration of the Society's annual Income and Expenditure, the figures for 1896 may be summarized as follows:—

The total Receipts, including the balance of £851 15s. 5*d.* brought forward from last year, amounted to £3728 0s. 5*d.*, being £465 12s. 5*d.* more than the estimated Income for that year. On the other hand, the total Expenditure during 1896 amounted to £2959 17s. 5*d.*, being less by £302 10s. 7*d.* than the estimated Expenditure for that year.

The actual excess of Expenditure over current Receipts in 1896 was £83 12s. 5*d.*, but the following statement, as well as a glance at the Balance Sheet, will show that this excess is entirely due to Expenditure of a non-recurring character.

At the end of 1895 a Balance of £851 15s. 5*d.* was available for extraordinary Expenditure. During 1896 the sum of £218 15s. 3*d.* was expended on the Electric Lighting Installation in the principal Apartments of the Society, £63 7s. 6*d.* was paid for an Electric Lantern and fittings, £89 3s. 10*d.* was the cost of the Redecoration of the Basement, and £156 15s. was paid to the printers for work in connexion with Part I. of the General Index to the first Fifty Volumes of the Quarterly Journal. These items of non-recurring Expenditure account for a total of £528 1s. 7*d.* Nevertheless, there still remained at the end of 1896 a Balance of £768 3s. 0*d.* available for extraordinary expenditure.

The Council have pleasure in announcing the completion of Vol. LII. of the Society's Quarterly Journal and the commencement of Vol. LIII. In bulk and in number of illustrations Vol. LII. conspicuously exceeded the average volume of the Quarterly Journal during many years past.

The Fellows have now in their hands, in addition to the February number of the Journal, the Record of Geological Literature added

to the Society's Library during 1896, and Part I. (A—La) of the General Index to the first Fifty Volumes of the Quarterly Journal. Every effort will be made to hasten the publication of the second Part of the Index: the Fellows are doubtless fully aware of the fact that, in no less degree than the work of compilation, the work of seeing the Index through the press is both arduous and intricate, but the Council are hopeful that the general utility of the Index will be found proportionate to the labour and time bestowed upon its preparation.

The want of some means by which deserving Fellows of the Geological Society, whose circumstances have from some cause become reduced, could be aided in paying their Annual Contributions had long been felt. The Council have therefore decided to institute, by means of voluntary subscriptions from the Fellows, a Capital Fund, to be called the Geological Relief Fund, of which the Council will be Trustees. It is proposed that the interest accruing from this Fund should from time to time be applied by the Council in aid of deserving Fellows. The response to the appeal for subscriptions has not, so far, been quite as general as the Council had ventured to hope; but they trust that it is sufficient to mention this fact, to induce those Fellows who have not yet subscribed, to furnish the means of placing the Relief Fund on a sound and secure basis.

The question of the desirability of transferring the Society's collections to the Trustees of the British Museum, was brought up for consideration at a Special General Meeting on May 20th last, and after a prolonged discussion the previous question was carried by 35 Ayes to 12 Noes.

The following Awards of Medals and Funds have been made by the Council:—

The Wollaston Medal is awarded to Mr. W. H. Hudleston, in recognition of his valuable services in promoting Geological Science.

The Murchison Medal, with a sum of Ten Guineas, is awarded to Mr. Horace B. Woodward, in recognition of the value of his work among many departments of the science, and especially in connexion with the Neozoic rocks.

The Lyell Medal, with a sum of Twenty-five Pounds, is awarded to Dr. George J. Hinde, in recognition of the great value of his work in Invertebrate Palæontology.

The Bigsby Medal is awarded to Mr. Clement Reid, in testimony of high appreciation of the value of his researches among the newer rocks of Britain.

The Balance of the Proceeds of the Wollaston Fund is awarded to Mr. F. A. Bather, for his researches in Invertebrate Palæontology, and to assist him in further investigations.

The Balance of the Proceeds of the Murchison Fund is awarded to Mr. S. S. Buckman, in recognition of the value of his work among the rocks and fossils of Mesozoic age, and to assist him in further researches.

A moiety of the Balance of the Proceeds of the Lyell Fund is awarded to Mr. W. J. Lewis Abbott in recognition of his labours among the post-Tertiary deposits, and to aid him in further work.

The other moiety of the Balance of the Proceeds of the Lyell Fund is awarded to Mr. J. Lomas, in recognition of his researches among the post-Tertiary deposits, and the rocks of North-western England, and to assist him in further investigations.

#### REPORT OF THE LIBRARY AND MUSEUM COMMITTEE FOR 1896.

Your Committee have again to announce that many additions of value and importance have been made to the Library, and now, as in the past, the Donations far exceed in amount the Purchases.

During 1896 the Library received, by Donation, 113 Volumes of separately published works, 394 Pamphlets and detached Parts of works, 166 Volumes and 206 detached Parts of serial publications (Transactions, Memoirs, Proceedings, etc.), and 16 Volumes of Newspapers. The total of accessions to the Library by Donation is thus seen to amount to 279 Volumes, 394 Pamphlets, and 206 detached Parts. In addition, 78 Sheets of Maps have been presented by various Donors.

Attention may be directed to such gifts, among others, as the second part of the International Geological Map of Europe, comprising five sheets; the Austrian Survey Map of the Neighbourhood of Vienna in six sheets; Everett's Geological Map of Australia, presented by the Victorian Department of Mines; and the nearly complete Index Map of the Geological Survey of England and Wales.

Turning from Maps to Books, especially prominent are the 2nd edition of Phillips's 'Ore Deposits' rewritten and enlarged by Prof. H. Louis; Prof. Judd's 'Student's Lyell'; Inostranzev's 'Across the Main Range of the Caucasus'; Rosenbusch's 'Mikroskopische Physiographie,' 3rd edition, vol. ii. Part 2; Vol. XI. of the Royal Society's Catalogue of Scientific Papers (Pet—Zyb); an interesting collection of 260 Volumes of Tracts presented by Lady Prestwich, in fulfilment of the wishes of the late Sir Joseph Prestwich; and many other valuable donations.

The Rev. P. B. Brodie presented the Society with a large framed photographic portrait of himself; a portrait in oils of the late Prof. Huxley was presented by Sir John Evans; a large portrait in sepia of Prof. Bonney was presented by a group of subscribers; a photograph of the late Sir Richard Owen was presented by his grandson, Mr. Frank Owen; a small portrait of the late Waterhouse Hawkins was given by his daughter, Miss Hawkins; and eight lithographic portraits of distinguished geologists were presented by Capt. G. E. A. Ross.

The Books, Maps, and Portraits enumerated above were the gift of 205 Personal Donors, 90 Government Departments and other Public Bodies, and 177 Societies and Editors of Periodicals.

The Purchases made on the recommendation of the Standing Library Committee amounted to 56 Volumes and 15 Parts of separately published works, 26 Volumes and 23 Parts of works published serially, and 11 Sheets of Maps of the French Geological Survey.

The total expenditure incurred in connexion with the Library during the past twelvemonth is as follows:—

	£	s.	d.
Books, Periodicals, etc. purchased . . . . .	68	16	5
Binding of Books and Mounting of Maps . . . . .	75	0	1
	£143 16 6		

The following Lists contain the Names of Government Departments, Public Bodies, Societies, Editors, and Personal Donors, from whom Donations to the Library have been received during the past year:—

#### I. GOVERNMENT DEPARTMENTS AND OTHER PUBLIC BODIES.

- Alabama.—Geological Survey of Alabama. Montgomery.  
 American Museum of Natural History. New York.  
 Austria.—Kaiserlich-Königliche Geologische Reichsanstalt. Vienna.  
 ——. Kaiserlich-Königliches Naturhistorisches Hofmuseum. Vienna.  
 Baden.—Grossherzogliches Ministerium des Innern. Geologische Landesanstalt. Heidelberg.  
 Bavaria.—Königlich Bayerisches Oberbergamt. Munich.  
 Belgium.—Musée Royal d'Histoire Naturelle. Brussels.  
 Buenos Aires. Museo Nacional.  
 California.—State Mining Bureau. San Francisco.  
 California University. Berkeley.  
 Cambridge (Mass.).—Museum of Comparative Zoology, at Harvard College.  
 Canada.—Geological and Natural History Survey. Ottawa.  
 Chicago.—'Field' Columbian Museum.  
 Costa Rica.—Museo Nacional. San José.  
 Europe.—Commission Géologique Internationale. Berlin.  
 Finland.—Finlands Geologiska Undersökning. Helsingfors.  
 France.—Dépôt de la Marine. Paris.  
 ——. Ministère des Travaux Publics. Paris.  
 ——. Muséum d'Histoire Naturelle. Paris.  
 ——. Service de la Carte Géologique. Paris.  
 Great Britain.—Admiralty. London.  
 ——. Army Medical Department. London.  
 ——. British Museum (Natural History). London.  
 ——. Geological Survey. London.  
 ——. Home Office. London.  
 ——. India Office. London.  
 ——. Ordnance Survey. Southampton.  
 ——. The Lords Commissioners of Her Majesty's Treasury. London.  
 Greece.—Observatoire National. Athens.  
 Hesse.—Grossherzogliches Ministerium des Innern. Geologische Landesanstalt. Darmstadt.  
 Holland.—Departement van Kolonien. The Hague.  
 Houghton (Mich.).—Michigan Mining School.  
 Hungary.—Königliche Ungarische Geologische Anstalt (Magyar Földtani Tarsulat). Budapest.

- Illinois.—State Museum of Natural History. Springfield.  
 India.—Geological Survey. Calcutta.  
 Iowa.—Geological Survey. Des Moines.  
 Italy.—Reale Comitato Geológico d'Italia. Rome.  
 Japan.—Geological Survey. Tokio.  
 Kingston (Canada).—Queen's College.  
 La Plata Museum. La Plata.  
 Lausanne University.  
 London.—City of London College.  
 —. University College.  
 Lund Museum. Denmark.  
 Mexico.—Comision Geológica de Mexico. Mexico.  
 Milwaukee Museum.  
 Minnesota.—Geological and Natural History Survey. Minneapolis.  
 Missouri.—Geological Survey of Missouri. Jefferson City.  
 New South Wales.—Agent-General for, London.  
 —. Australian Museum. Sydney.  
 —. Department of Lands. Sydney.  
 —. Department of Mines. Sydney.  
 —. Geological Survey. Sydney.  
 New York State Library. Albany.  
 New York State Museum. Albany.  
 New Zealand.—Department of Mines. Wellington.  
 Norway.—Norges Geologiska Undersökning. Christiania.  
 Nova Scotia.—Department of Mines. Halifax.  
 Owens College. Manchester.  
 Pennsylvania.—Geological Survey. Harrisburg.  
 Perak Government. Taiping.  
 Pisa.—Royal University.  
 Portugal.—Comissão Geologica de Portugal. Lisbon.  
 Prussia.—Königliche Preussische Geologische Landesanstalt. Berlin.  
 —. Königliches Ministerium für Handel und Gewerbe. Berlin.  
 Queensland.—Department of Mines. Brisbane.  
 —. Geological Survey. Brisbane.  
 Roumania.—Museum of Geology and Palæontology. Bucharest.  
 Russia.—Comité Géologique. St. Petersburg.  
 —. Section géologique du Cabinet de S.M. l'Empereur. St. Petersburg.  
 Saxony.—Geologische Landesuntersuchung des Königreichs Sachsen. Leipzig.  
 —. Königliches Finanz-Ministerium. Leipzig.  
 South Australia.—The Agent-General for, London.  
 Spain.—Comision del Mapa Geológico. Madrid.  
 Sweden.—Sveriges Geologiska Undersökning. Stockholm.  
 Switzerland.—Commission der Geologischen Karte. Berne.  
 Tokio.—Imperial University.  
 —. —. —, College of Science.  
 Tufts College, Massachusetts.  
 United States Department of the Interior. Washington.  
 United States Geological Survey. Washington.  
 United States National Museum. Washington.  
 United States Treasury (Mint) Department. Washington.  
 Upsala University.  
 —. —. Mineralogical and Geological Institute.  
 Victoria.—Department of Agriculture. Melbourne.  
 —. Department of Mines. Melbourne.  
 Washington (D.C.).—Smithsonian Institution.  
 Western Australia.—Agent-General for, London.  
 —. Department of Mines. Perth.  
 —. Geological Survey. Perth.  
 Wisconsin University. Madison.

## II. SOCIETIES AND EDITORS.

- Adelaide.—Royal Society of South Australia.  
 Alnwick.—Berwickshire Naturalists' Club.  
 Bahia.—Instituto Geographico e Historico.  
 Barnsley.—Midland Institute of Mining, Civil and Mechanical Engineers

- Bath Natural History and Antiquarian Field Club.  
 Belfast Natural History and Philosophical Society.  
 Belgrade.—Annales Géologiques de la Péninsule Balkanique.  
 Berlin.—Deutsche Geologische Gesellschaft.  
 —. Gesellschaft Naturforschender Freunde.  
 —. Königliche Preussische Akademie der Wissenschaften.  
 —. Zeitschrift für Praktische Geologie.  
 Birmingham.—Mason College.  
 Bombay Branch of the Royal Asiatic Society.  
 Bordeaux.—Société Linnéenne.  
 Boston (Mass.).—American Academy of Arts and Sciences.  
 Boston Society of Natural History.  
 Brussels.—Société Belge de Géologie, de Paléontologie et d'Hydrologie.  
 —. Société Malacologique de Belgique.  
 Budapest.—Földtani Közlöny (Geological Magazine).  
 Buenos Aires.—Instituto Geografico Argentino.  
 —. Sociedad Científica Argentina.  
 Caen.—Société Linnéenne de Normandie.  
 Calcutta.—Indian Engineering.  
 —. Asiatic Society of Bengal.  
 Cape Town.—South African Philosophical Society.  
 Cardiff.—South Wales Institute of Engineers.  
 Chelmsford.—Felsted School Scientific Society.  
 Chicago.—Journal of Geology.  
 Christiania.—Nyt Magazin for Naturvidenskaberne.  
 —. Videnskabernes Selskab.  
 Cincinnati Society of Natural History.  
 Colombo.—Ceylon Branch of the Royal Asiatic Society.  
 Copenhagen.—Kongelige Danske Videnskabernes Selskab.  
 Cordoba.—Academia Nacional de Ciencias.  
 Cracow.—Académie des Sciences (Akademja Umiejtosci).  
 Darmstadt.—Verein für Erdkunde.  
 Dorpat.—Naturforscher Gesellschaft bei der Universität Jurjew.  
 Douglas.—Isle of Man Natural History and Antiquarian Society.  
 Dresden.—Naturwissenschaftliche Gesellschaft 'Isis.'  
 —. Verein für Erdkunde.  
 Dublin.—Royal Dublin Society.  
 —. Royal Irish Academy.  
 Edinburgh.—Geological Society.  
 —. Royal Scottish Geographical Society.  
 —. Royal Society.  
 Ekaterinburg.—Société Ouralienne d'Amateurs des Sciences Naturelles.  
 Frankfurt a. M.—Senckenbergische Naturforschende Gesellschaft.  
 Glasgow.—Mitchell Library.  
 —. Natural History Society.  
 Gloucester.—Cotteswold Naturalists' Field-Club.  
 Gratz.—Naturwissenschaftlicher Verein für Steiermark.  
 Haarlem.—Société Hollandaise des Sciences.  
 Halifax.—Yorkshire Geological and Polytechnic Society.  
 Halle.—Kaiserliche Leopoldinisch-Carolinische Deutsche Akademie der Naturforscher.  
 Hamilton (Canada).—Hamilton Association.  
 Havre.—Société Géologique de Normandie.  
 Hermannstadt.—Siebenbürgischer Verein für Naturwissenschaften.  
 Hertford.—Hertfordshire Natural History Society.  
 Johannesburg.—Geological Society of South Africa.  
 Lausanne.—Société Géologique Suisse.  
 —. Société Vaudoise des Sciences Naturelles.  
 Leeds.—Philosophical Society.  
 Leicester Literary and Philosophical Society.  
 Leipzig.—Naturwissenschaftlicher Verein für Sachsen und Thüringen.  
 —. Zeitschrift für Krystallographie und Mineralogie.  
 —. Zeitschrift für Naturwissenschaften.  
 Liège.—Société Géologique de Belgique.  
 —. Société Royale des Sciences.  
 Lille.—Société Géologique du Nord.  
 Lisbon.—Sociedade de Geographia.  
 Liverpool.—Geological Association.

- Liverpool.—Literary and Philosophical Society.  
 London.—Academy.  
 —. Athenæum.  
 —. British Association for the Advancement of Science.  
 —. Chemical News.  
 —. Chemical Society.  
 —. Colliery Guardian.  
 —. East India Association.  
 —. Geological Magazine.  
 —. Geologists' Association.  
 —. Institution of Civil Engineers.  
 —. Iron and Steel Institute.  
 —. Iron and Steel Trades' Journal.  
 —. Knowledge.  
 —. Linnean Society.  
 —. London, Edinburgh, and Dublin Philosophical Magazine.  
 —. Mineralogical Society.  
 —. Nature.  
 —. Palæontographical Society.  
 —. Physical Society.  
 —. Royal Agricultural Society.  
 —. Royal Astronomical Society.  
 —. Royal College of Surgeons.  
 —. Royal Geographical Society.  
 —. Royal Institution.  
 —. Royal Meteorological Society.  
 —. Royal Microscopical Society.  
 —. Royal Photographic Society of Great Britain.  
 —. Royal Society.  
 —. Sanitary Institute.  
 —. Society of Arts.  
 —. Society of Biblical Archæology.  
 —. Society of Public Analysts.  
 —. Victoria Institute.  
 —. Zoological Society.  
 Madison (Wis.).—Wisconsin Academy of Sciences.  
 Manchester Geological Society.  
 —. Literary and Philosophical Society.  
 Melbourne.—Royal Society of Victoria.  
 Milan.—Reale Istituto Lombardo di Scienze e Lettere.  
 —. Società Italiana di Scienze Naturali.  
 Montreal.—Natural History Society.  
 Moscow.—Société Impériale des Naturalistes.  
 Munich.—Königliche Bayerische Akademie der Wissenschaften.  
 Nancy.—Académie de Stanislas.  
 New Haven (Conn.).—American Journal of Science.  
 —. Connecticut Academy of Arts and Sciences.  
 New York.—Academy of Sciences.  
 —. American Institute of Mining Engineers.  
 Newcastle-upon-Tyne.—North of England Institute of Mining and Mechanical Engineers.  
 Northampton.—Northamptonshire Natural History Society.  
 Oporto.—Sociedade Carlos Ribeiro.  
 Ottawa.—Royal Society of Canada.  
 Padua.—Reale Accademia di Scienze, Lettere ed Arti.  
 Palermo.—Annales de Géologie et de Paléontologie.  
 —. Reale Accademia di Scienze, Lettere ed Arti.  
 Paris.—Académie des Sciences.  
 —. Annuaire Géologique Universel.  
 —. Revue Scientifique.  
 —. Société Française de Minéralogie.  
 —. Société Géologique de France.  
 —. Spelunca.  
 Penzance.—Royal Geological Society of Cornwall.  
 Philadelphia.—Academy of Natural Sciences.  
 —. American Philosophical Society.  
 —. Wagner Free Institute of Science.  
 Pisa.—Società Toscana di Scienze Naturali.

- Plymouth.—Devonshire Association for the Advancement of Science.  
 — Institution, and Devon and Cornwall Natural History Society.  
 Rochester (N.Y.).—Academy of Sciences.  
 — Geological Society of America.  
 Riga.—Naturforscher Verein.  
 Rome.—Reale Accademia dei Lincei.  
 — Società Geologica Italiana.  
 Rugby School Natural History Society.  
 Salt Lake City.—Utah University Quarterly.  
 Santiago.—Deutscher Wissenschaftlicher Verein.  
 — Sociedad Nacional de Minería.  
 — Société Scientifique du Chili.  
 Scranton (Pa.).—Colliery Engineer.  
 St. John (N.B.).—Natural History Society.  
 St. Petersburg.—Académie Impériale des Sciences.  
 — Russische Kaiserliche Mineralogische Gesellschaft.  
 Stockholm.—Geologiska Förening.  
 — Kongliga Svenska Vetenskaps Akademi.  
 Stonyhurst Magazine.  
 Stuttgart.—Neues Jahrbuch für Mineralogie, Geologie und Paläontologie.  
 — Verein für Vaterländische Naturkunde in Württemberg.  
 Sydney.—Australasian Association for the Advancement of Science.  
 — Linnean Society of New South Wales.  
 — Royal Society of New South Wales.  
 Topeka.—Transactions of the Kansas Academy of Science.  
 Toronto.—Canadian Institute.  
 Toulouse.—Société d'Histoire Naturelle.  
 Truro.—Royal Institution of Cornwall.  
 Turin.—Reale Accademia delle Scienze.  
 Vienna.—Berg- und Hüttenmännisches Jahrbuch.  
 — Kaiserliche Akademie der Wissenschaften.  
 — Kaiserlich-königliche Zoologisch-botanische Gesellschaft.  
 — Mineralogische und Petrographische Mittheilungen.  
 Warsaw.—Annuaire Géologique et Minéralogique de la Russie.  
 Wellington (N.Z.).—New Zealand Institute.  
 Wiesbaden.—Nassauischer Verein für Naturkunde.  
 York.—Natural History Journal.  
 — Yorkshire Philosophical Society.

### III. PERSONAL DONORS.

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 Woodward, H.  
 Woodward, H. P.  
 Woodward, H. P.

Yale, C. G.

Zeiller, R.

COMPARATIVE STATEMENT OF THE NUMBER OF THE SOCIETY AT THE  
CLOSE OF THE YEARS 1895 AND 1896.

	Dec. 31st, 1895.		Dec. 31st, 1896.
Compounders .....	305	.....	306
Contributing Fellows.....	867	.....	880
Non-contributing Fellows..	69	.....	67
	<hr/>		<hr/>
	1241		1253
Foreign Members .....	39	.....	37
Foreign Correspondents....	38	.....	39
	<hr/>		<hr/>
	1318		1329

*Comparative Statement explanatory of the Alterations in the Number of Fellows, Foreign Members, and Foreign Correspondents at the close of the years 1895 and 1896.*

Number of Compounders, Contributing and Non- contributing Fellows, December 31st, 1895 ..	}	1241		
Add Fellows elected during former year and paid in 1896 .....			}	11
Add Fellows elected and paid in 1896 .....				
		<hr/>	1300	
Deduct Compounders deceased .....		7		
Contributing Fellows deceased .....		17		
Non-contributing Fellows deceased .....		2		
Contributing Fellows resigned .....		18		
Contributing Fellows removed .....		3		
		<hr/>	47	
			<hr/>	
			1253	
Number of Foreign Members and Foreign Correspondents, December 31st, 1895 ....	}	77		
Deduct Foreign Members deceased .....			3	
Foreign Correspondent elected .....	}	1		
Foreign Member .....				
		<hr/>	4	
		<hr/>		
			73	
Add Foreign Member elected .....		1		
Foreign Correspondents elected .....		2		
		<hr/>	76	
		<hr/>		
			1329	
		<hr/>	<hr/>	

## DECEASED FELLOWS.

*Compounders (7).*

Brockbank, W., Esq.  
 Green, Prof. A. H.  
 Hall, Captain Marshall.  
 Lyall, G., Esq.

Miller, H., Esq.  
 Penrose, J. F., Esq.  
 Roper, F. C. S., Esq.

*Resident and other Contributing Fellows (17).*

Armstrong, W., Esq.  
 Birch, R. W. P., Esq.  
 Carrington, T., Esq.  
 Church, J., Esq.  
 De Salis, W. F., Esq.  
 Dorning, E., Esq.  
 Dymond, A. W., Esq.  
 Gover, Rev. Canon W.  
 Litton, R. T., Esq.

Müller, Baron F. von.  
 Paulin, R., Esq.  
 Pike, E. R., Esq.  
 Prestwich, Sir J.  
 Robertson, Dr. D.  
 Slack, H. J., Esq.  
 Thompson, F. A., Esq.  
 Worth, R. N., Esq.

*Non-contributing Fellows (2).*

Gough, Viscount.

| Sharp, W., Esq.

*Foreign Members (3).*

Beyrich, Dr. H. E.  
 Daubrée, M. A.

| Whitney, Prof. J. D.

---

## FELLOWS RESIGNED (18).

Bigge, M. R., Esq.	Northcott, Dr. W. C.
Brickenden, Maj. R. T. W. L.	Panton, Prof. J. H.
Coltman, W. B., Esq.	Rowe, Rev. G. F. H.
Coltman, W. H., Esq.	Sanford, W. A., Esq.
Frecheville, R. J., Esq.	Savile, A. G., Esq.
Jolly, W., Esq.	Spencer, W., Esq.
Leese, J., Esq.	Waugh, H., Esq.
Mackay, J. C., Esq.	Whitehead, J., Esq.
Newton, E. W., Esq.	Wills, H. T., Esq.

## FELLOWS REMOVED (3).

McKnight, F., Esq.	Williams, R. H., Esq.
Ramsay, E. P., Esq.	

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*The following Personage was elected from the List of Foreign Correspondents to fill the vacancy in the List of Foreign Members during the year 1896:—*

Professor Albert Heim, of Zürich.

*The following Personages were elected Foreign Correspondents during the year 1896:—*

Professor S. L. Penfield, of New Haven, Conn., U.S.A.  
 Professor J. Walther, of Jena.

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After the Reports had been read, it was resolved :—

That they be received and entered on the Minutes of the Meeting, and that such parts of them as the Council shall think fit be printed and circulated among the Fellows.

It was afterwards resolved :—

That the thanks of the Society be given to Sir A. Geikie and R. Lydekker, Esq., retiring from the office of Vice-President.

That the thanks of the Society be given to J. J. H. Teall, Esq., retiring from the office of Secretary.

That the thanks of the Society be given to Horace T. Brown, Esq., Sir A. Geikie, Dr. J. W. Gregory, T. V. Holmes, Esq., and F. Rutley, Esq., retiring from the Council.



After the Balloting-glasses had been duly closed, and the Lists examined by the Scrutineers, the following gentlemen were declared to have been duly elected as the Officers and Council for the ensuing year :—

## OFFICERS AND COUNCIL.—1897.

*PRESIDENT.*

Henry Hicks, M.D., F.R.S.

*VICE-PRESIDENTS.*

Prof. T. G. Bonney, D.Sc., LL.D., F.R.S.

Lieut.-General C. A. McMahon.

J. J. H. Teall, Esq., M.A., F.R.S.

Henry Woodward, LL.D., F.R.S.

*SECRETARIES.*

R. S. Herries, Esq., M.A.

J. E. Marr, Esq., M.A., F.R.S.

*FOREIGN SECRETARY.*

Sir John Evans, K.C.B., D.C.L., LL.D., F.R.S.

*TREASURER.*

W. T. Blanford, LL.D., F.R.S.

## COUNCIL.

H. Bauerman, Esq.

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F.R.S.

Prof. W. Boyd Dawkins, M.A., F.R.S.

Sir John Evans, K.C.B., D.C.L.,  
LL.D., F.R.S., F.L.S.

F. W. Harmer, Esq.

R. S. Herries, Esq., M.A.

Henry Hicks, M.D., F.R.S.

Rev. Edwin Hill, M.A.

Prof. E. Hull, M.A., LL.D., F.R.S.

Prof. J. W. Judd, C.B., LL.D., F.R.S.

R. Lydekker, Esq., B.A., F.R.S.

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J. E. Marr, Esq., M.A., F.R.S.

Prof. H. A. Miers, M.A., F.R.S.

Horace W. Monckton, Esq., F.L.S.

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*ASSISTANTS IN OFFICE, LIBRARY, AND MUSEUM.*

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Clyde H. Black.

LIST OF  
THE FOREIGN MEMBERS

OF THE GEOLOGICAL SOCIETY OF LONDON, IN 1896.

Date of Election.	
1848.	James Hall, Esq., <i>Albany, State of New York, U.S.A.</i>
1856.	Professor Robert Bunsen, For. Mem. R.S., <i>Heidelberg.</i>
1857.	Professor H. B. Geinitz, <i>Dresden.</i>
1867.	Professor A. Daubrée, For. Mem. R.S., <i>Paris. (Deceased.)</i>
1871.	Dr. Franz Ritter von Hauer, <i>Vienna.</i>
1874.	Professor Albert Gaudry, <i>Paris.</i>
1875.	Professor Fridolin Sandberger, <i>Würzburg.</i>
1876.	Professor H. E. Beyrich, <i>Berlin. (Deceased.)</i>
1877.	Dr. Carl Wilhelm von Gümbel, <i>Munich.</i>
1877.	Dr. Eduard Süss, <i>Vienna.</i>
1879.	M. Jules Marcou, <i>Cambridge, Mass., U.S.A.</i>
1879.	Dr. J. J. S. Steenstrup, For. Mem. R.S., <i>Copenhagen.</i>
1880.	Professor Gustave Dewalque, <i>Liège.</i>
1880.	Baron Adolf Erik Nordenskiöld, <i>Stockholm.</i>
1880.	Professor Ferdinand Zirkel, <i>Leipzig.</i>
1883.	Professor Otto Martin Torell, <i>Stockholm.</i>
1884.	Professor G. Capellini, <i>Bologna.</i>
1884.	Professor A. L. O. Des Cloizeaux, For. Mem. R.S., <i>Paris.</i>
1885.	Professor Jules Gosselet, <i>Lille.</i>
1886.	Professor Gustav Tschermak, <i>Vienna.</i>
1887.	Professor J. P. Lesley, <i>Philadelphia, Pa., U.S.A.</i>
1887.	Professor J. D. Whitney, <i>Cambridge, Mass., U.S.A. (Deceased.)</i>
1888.	Professor Eugène Renevier, <i>Lausanne.</i>
1888.	Baron Ferdinand von Richthofen, <i>Berlin.</i>
1889.	Professor Ferdinand Fouqué, <i>Paris.</i>
1889.	Geheimrath Professor Karl Alfred von Zittel, <i>Munich.</i>
1890.	Professor Heinrich Rosenbusch, <i>Heidelberg.</i>
1891.	Dr. Charles Barrois, <i>Lille.</i>
1892.	Professor Gustav Lindström, <i>Stockholm.</i>
1893.	Professor Waldemar Christofer Brøgger, <i>Christiania.</i>
1893.	M. Auguste Michel-Lévy, <i>Paris.</i>
1893.	Dr. Edmund Mojsisovics von Mojsvár, <i>Vienna.</i>
1893.	Dr. Alfred Gabriel Nathorst, <i>Stockholm.</i>
1894.	Professor George J. Brush, <i>New Haven, Conn., U.S.A.</i>
1894.	Professor Edward Salisbury Dana, <i>New Haven, Conn., U.S.A.</i>
1894.	Professor Alphonse Renard, <i>Ghent.</i>
1895.	Professor Wilhelm Dames, <i>Berlin.</i>
1895.	Professor Grove K. Gilbert, <i>Washington, U.S.A.</i>
1895.	M. Friedrich Schmidt, <i>St. Petersburg.</i>
1896.	Professor Albert Heim, <i>Zürich.</i>

LIST OF  
THE FOREIGN CORRESPONDENTS

OF THE GEOLOGICAL SOCIETY OF LONDON, IN 1896.

Date of  
Election.

1866. Professor Victor Raulin, *Montfaucon d'Argonne*.  
 1874. Professor Iginio Cocchi, *Florence*.  
 1874. Dr. T. C. Winkler, *Haarlem*.  
 1879. M. Édouard Dupont, *Brussels*.  
 1879. Dr. Émile Sauvage, *Boulogne-sur-Mer*.  
 1881. Professor E. D. Cope, *Philadelphia, Pa., U.S.A.*  
 1882. Professor Louis Lartet, *Toulouse*.  
 1882. Professor Alphonse Milne-Edwards, *Paris*.  
 1884. M. Alphonse Briart, *Morlanwelz*.  
 1884. Professor Hermann Credner, *Leipzig*.  
 1884. Baron C. von Eittingshausen, *Gratz. (Deceased.)*  
 1887. Senhor J. F. N. Delgado, *Lisbon*.  
 1887. Professor A. de Lapparent, *Paris*.  
 1888. M. Charles Brongniart, *Paris*.  
 1888. Professor Anton Fritsch, *Prague*.  
 1888. M. Ernest Van den Broeck, *Brussels*.  
 1889. Dr. Hans Reusch, *Christiania*.  
 1889. M. R. D. M. Verbeek, *Padang, Sumatra*.  
 1890. M. Gustave F. Dollfus, *Paris*.  
 1890. Herr Felix Karrer, *Vienna*.  
 1890. Professor Adolph von Könen, *Göttingen*.  
 1891. Professor Emanuel Kayser, *Marburg*.  
 1892. Professor Johann Lehmann, *Kiel*.  
 1892. Major John W. Powell, *Washington, D.C., U.S.A.*  
 1893. Professor Marcel Bertrand, *Paris*.  
 1893. Professor Aléxis Pavlow, *Moscow*.  
 1893. M. Ed. Rigaux, *Boulogne-sur-Mer*.  
 1893. Dr. Sven Leonhard Törnquist, *Lund*.  
 1893. Dr. Charles Abiathar White, *Washington, D.C., U.S.A.*  
 1894. Professor Joseph Paxson Iddings, *Chicago, Ill., U.S.A.*  
 1894. M. Perceval de Loriol-Lefort, *Campagne Frontenex*.  
 1894. Dr. Francisco P. Moreno, *La Plata*.  
 1894. Dr. A. Rothpletz, *Munich*.  
 1894. Professor J. H. L. Vogt, *Christiania*.  
 1895. Professor Paul Groth, *Munich*.  
 1895. Dr. K. de Kroustchoff, *St. Petersburg*.  
 1895. Professor Albrecht Penck, *Vienna*.  
 1896. Professor S. L. Penfield, *New Haven, Conn., U.S.A.*  
 1896. Professor J. Walther, *Jena*.
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## AWARDS OF THE WOLLASTON MEDAL

UNDER THE CONDITIONS OF THE 'DONATION FUND'

ESTABLISHED BY

WILLIAM HYDE WOLLASTON, M.D., F.R.S., F.G.S., ETC.

'To promote researches concerning the mineral structure of the earth, and to enable the Council of the Geological Society to reward those individuals of any country by whom such researches may hereafter be made,'—'such individual not being a Member of the Council.'

- |                                     |   |
|-------------------------------------|---|
| 1831. Mr. William Smith.            | 1866. Sir Charles Lyell.                              |
| 1835. Dr. G. A. Mantell.            | 1867. Mr. G. Poulett Scrope.                          |
| 1836. M. Louis Agassiz.             | 1868. Professor Carl F. Naumann.                      |
| 1837. } Capt. T. P. Cautley.        | 1869. Dr. H. C. Sorby.                                |
| } Dr. H. Falconer.                  | 1870. Professor G. P. Deshayes.                       |
| 1838. Sir Richard Owen.             | 1871. Sir A. C. Ramsay.                               |
| 1839. Professor C. G. Ehrenberg.    | 1872. Professor J. D. Dana.                           |
| 1840. Professor A. H. Dumont.       | 1873. Sir P. de M. Grey Egerton.                      |
| 1841. M. Adolphe T. Brongniart.     | 1874. Professor Oswald Heer.                          |
| 1842. Baron L. von Buch.            | 1875. Professor L. G. de Koninck.                     |
| 1843. } M. Élie de Beaumont.        | 1876. Professor T. H. Huxley.                         |
| } M. P. A. Dufrenoy.                | 1877. Mr. Robert Mallet.                              |
| 1844. Rev. W. D. Conybeare.         | 1878. Dr. Thomas Wright.                              |
| 1845. Professor John Phillips.      | 1879. Professor Bernhard Studer.                      |
| 1846. Mr. William Lonsdale.         | 1880. Professor Auguste Daubrée.                      |
| 1847. Dr. Ami Boué.                 | 1881. Professor P. Martin Duncan.                     |
| 1848. Rev. Dr. W. Buckland.         | 1882. Dr. Franz Ritter von Hauer.                     |
| 1849. Sir Joseph Prestwich.         | 1883. Dr. W. T. Blanford.                             |
| 1850. Mr. William Hopkins.          | 1884. Professor Albert Gaudry.                        |
| 1851. Rev. Prof. A. Sedgwick.       | 1885. Mr. George Busk.                                |
| 1852. Dr. W. H. Fitton.             | 1886. Professor A. L. O. Des<br>Cloizeaux.            |
| 1853. } M. le Vicomte A. d'Archiac. | 1887. Mr. J. Whitaker Hulke.                          |
| } M. E. de Verneuil.                | 1888. Mr. H. B. Medlicott.                            |
| 1854. Sir Richard Griffith.         | 1889. Professor T. G. Bonney.                         |
| 1855. Sir H. T. De la Beche.        | 1890. Professor W. C. Williamson.                     |
| 1856. Sir W. E. Logan.              | 1891. Professor J. W. Judd.                           |
| 1857. M. Joachim Barrande.          | 1892. Baron Ferdinand von<br>Richthofen.              |
| 1858. } Herr Hermann von Meyer.     | 1893. Professor N. S. Maskelyne.                      |
| } Mr. James Hall.                   | 1894. Geheimrath Professor Karl<br>Alfred von Zittel. |
| 1859. Mr. Charles Darwin.           | 1895. Sir Archibald Geikie.                           |
| 1860. Mr. Searles V. Wood.          | 1896. Dr. Eduard Süss.                                |
| 1861. Professor Dr. H. G. Bronn.    | 1897. Mr. W. H. Hudleston.                            |
| 1862. Mr. R. A. C. Godwin-Austen.   |   |
| 1863. Professor Gustav Bischof.     |   |
| 1864. Sir R. I. Murchison.          |   |
| 1865. Dr. Thomas Davidson.          |   |

## AWARDS

OF THE

BALANCE OF THE PROCEEDS OF THE WOLLASTON  
'DONATION FUND.'

- |                                    |                                    |
|------------------------------------|------------------------------------|
| 1831. Mr. William Smith.           | 1865. Mr. J. W. Salter.            |
| 1833. Mr. William Lonsdale.        | 1866. Dr. Henry Woodward.          |
| 1834. M. Louis Agassiz.            | 1867. Mr. W. H. Baily.             |
| 1835. Dr. G. A. Mantell.           | 1868. M. J. Bosquet.               |
| 1836. Professor G. P. Deshayes.    | 1869. Mr. W. Carruthers.           |
| 1838. Sir Richard Owen.            | 1870. M. Marie Rouault.            |
| 1839. Professor C. G. Ehrenberg.   | 1871. Mr. R. Etheridge.            |
| 1840. Mr. J. De Carle Sowerby.     | 1872. Dr. James Croll.             |
| 1841. Professor Edward Forbes.     | 1873. Professor J. W. Judd.        |
| 1842. Professor John Morris.       | 1874. Dr. Henri Nyst.              |
| 1843. Professor John Morris.       | 1875. Professor L. C. Miall.       |
| 1844. Mr. William Lonsdale.        | 1876. Professor Giuseppe Seguenza. |
| 1845. Mr. Geddes Bain.             | 1877. Mr. R. Etheridge, Jun.       |
| 1846. Mr. William Lonsdale.        | 1878. Professor W. J. Sollas.      |
| 1847. M. Alcide d'Orbigny.         | 1879. Mr. Samuel Allport.          |
| 1848. { Cape-of-Good-Hope Fossils. | 1880. Mr. Thomas Davies.           |
| { M. Alcide d'Orbigny.             | 1881. Dr. R. H. Traquair.          |
| 1849. Mr. William Lonsdale.        | 1882. Dr. G. J. Hinde.             |
| 1850. Professor John Morris.       | 1883. Professor John Milne.        |
| 1851. M. Joachim Barrande.         | 1884. Mr. E. Tulley Newton.        |
| 1852. Professor John Morris.       | 1885. Dr. Charles Callaway.        |
| 1853. Professor L. G. de Koninck.  | 1886. Mr. J. S. Gardner.           |
| 1854. Dr. S. P. Woodward.          | 1887. Mr. B. N. Peach.             |
| 1855. Drs. G. and F. Sandberger.   | 1888. Mr. J. Horne.                |
| 1856. Professor G. P. Deshayes.    | 1889. Mr. A. Smith Woodward.       |
| 1857. Dr. S. P. Woodward.          | 1890. Mr. W. A. E. Ussher.         |
| 1858. Mr. James Hall.              | 1891. Mr. R. Lydekker.             |
| 1859. Mr. Charles Peach.           | 1892. Mr. O. A. Derby.             |
| 1860. { Professor T. Rupert Jones. | 1893. Mr. J. G. Goodchild.         |
| { Mr. W. K. Parker.                | 1894. Mr. Aubrey Strahan.          |
| 1861. Professor A. Daubrée.        | 1895. Mr. W. W. Watts.             |
| 1862. Professor Oswald Heer.       | 1896. Mr. Alfred Harker.           |
| 1863. Professor Ferdinand Senft.   | 1897. Mr. F. A. Bather.            |
| 1864. Professor G. P. Deshayes.    |                                    |
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## AWARDS OF THE MURCHISON MEDAL

AND OF THE

PROCEEDS OF THE 'MURCHISON GEOLOGICAL FUND,'

ESTABLISHED UNDER THE WILL OF THE LATE

SIR RODERICK IMPEY MURCHISON, BART., F.R.S., F.G.S.

'To be applied in every consecutive year in such manner as the Council of the Society may deem most useful in advancing Geological Science, whether by granting sums of money to travellers in pursuit of knowledge, to authors of memoirs, or to persons actually employed in any enquiries bearing upon the science of Geology, or in rewarding any such travellers, authors, or other persons, and the Medal to be given to some person to whom such Council shall grant any sum of money or recompense in respect of Geological Science.'

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|--|--|
| 1873. Mr. William Davies. <i>Medal.</i>    | 1887. Rev. P. B. Brodie. <i>Medal.</i> |
| 1873. Professor Oswald Heer.               | 1887. Mr. Robert Kidston.              |
| 1874. Dr. J. J. Bigsby. <i>Medal.</i>      | 1888. Professor J. S. Newberry.        |
| 1874. Mr. Alfred Bell.                     | <i>Medal.</i>                          |
| 1874. Professor Ralph Tate.                | 1888. Mr. Edward Wilson.               |
| 1875. Mr. W. J. Henwood. <i>Medal.</i>     | 1889. Professor James Geikie.          |
| 1875. Professor H. G. Seeley.              | <i>Medal.</i>                          |
| 1876. Mr. A. R. C. Selwyn.                 | 1889. Professor G. A. J. Cole.         |
| <i>Medal.</i>                              | 1890. Professor Edward Hull.           |
| 1876. Dr. James Croll.                     | <i>Medal.</i>                          |
| 1877. Rev. W. B. Clarke. <i>Medal.</i>     | 1890. Mr. E. Wethered.                 |
| 1877. Rev. J. F. Blake.                    | 1891. Professor W. C. Brögger.         |
| 1878. Dr. H. B. Geinitz. <i>Medal.</i>     | <i>Medal.</i>                          |
| 1878. Professor Charles Lapworth.          | 1891. Rev. R. Baron.                   |
| 1879. Professor F. M'Coy. <i>Medal.</i>    | 1892. Professor A. H. Green.           |
| 1879. Mr. J. W. Kirkby.                    | <i>Medal.</i>                          |
| 1880. Mr. R. Etheridge. <i>Medal.</i>      | 1892. Mr. Beeby Thompson.              |
| 1881. Sir Archibald Geikie. <i>Medal.</i>  | 1893. Rev. O. Fisher. <i>Medal.</i>    |
| 1881. Mr. F. Rutley.                       | 1893. Mr. G. J. Williams.              |
| 1882. Professor J. Gosselet. <i>Medal.</i> | 1894. Mr. W. T. Aveline. <i>Medal.</i> |
| 1882. Professor T. Rupert Jones.           | 1894. Mr. George Barrow.               |
| 1883. Professor H. R. Göppert.             | 1895. Professor Gustav Lind-           |
| <i>Medal.</i>                              | ström. <i>Medal.</i>                   |
| 1883. Mr. John Young.                      | 1895. Mr. A. C. Seward.                |
| 1884. Dr. H. Woodward. <i>Medal.</i>       | 1896. Mr. T. Mellard Reade.            |
| 1884. Mr. Martin Simpson.                  | <i>Medal.</i>                          |
| 1885. Dr. Ferdinand von Römer.             | 1896. Mr. Philip Lake.                 |
| <i>Medal.</i>                              | 1897. Mr. Horace B. Woodward.          |
| 1885. Mr. Horace B. Woodward.              | <i>Medal.</i>                          |
| 1886. Mr. W. Whitaker. <i>Medal.</i>       | 1897. Mr. S. S. Buckman.               |
| 1886. Mr. Clement Reid.                    |  |

## AWARDS OF THE LYELL MEDAL

AND OF THE

PROCEEDS OF THE 'LYELL GEOLOGICAL FUND,'

ESTABLISHED UNDER THE WILL AND CODICIL OF THE LATE  
SIR CHARLES LYELL, BART., F.R.S., F.G.S.

The Medal 'to be given annually' (or from time to time) 'as a mark of honorary distinction and as an expression on the part of the governing body of the Society that the Medallist (who may be of any country or either sex) has deserved well of the Science,'—'not less than one third of the annual interest [of the fund] to accompany the Medal, the remaining interest to be given in one or more portions at the discretion of the Council for the encouragement of Geology or of any of the allied sciences by which they shall consider Geology to have been most materially advanced, either for travelling expenses or for a memoir or paper published, or in progress, and without reference to the sex or nationality of the author, or the language in which any such memoir or paper may be written.'

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|---|---|
| 1876. Professor John Morris.<br><i>Medal.</i>     | 1888. Mr. A. H. Foord.                              |
| 1877. Dr. James Hector. <i>Medal.</i>             | 1888. Mr. Thomas Roberts.                           |
| 1877. Mr. W. Pengelly.                            | 1889. Professor W. Boyd Dawkins.<br><i>Medal.</i>   |
| 1878. Mr. G. Busk. <i>Medal.</i>                  | 1889. M. Louis Dollo.                               |
| 1878. Professor W. Waagen.                        | 1890. Professor T. Rupert Jones.<br><i>Medal.</i>   |
| 1879. Professor Edmond Hébert.<br><i>Medal.</i>   | 1890. Mr. C. Davies Sherborn.                       |
| 1879. Professor H. A. Nicholson.                  | 1891. Professor T. McKenny<br>Hughes. <i>Medal.</i> |
| 1879. Dr. Henry Woodward.                         | 1891. Dr. C. J. Forsyth-Major.                      |
| 1880. Sir John Evans. <i>Medal.</i>               | 1891. Mr. G. W. Lamplugh.                           |
| 1880. Professor F. A. von Quenstedt.              | 1892. Mr. G. H. Morton. <i>Medal.</i>               |
| 1881. Sir J. W. Dawson. <i>Medal.</i>             | 1892. Dr. J. W. Gregory.                            |
| 1881. Dr. Anton Fritsch.                          | 1892. Mr. E. A. Walford.                            |
| 1881. Mr. G. R. Vine.                             | 1893. Mr. E. T. Newton. <i>Medal.</i>               |
| 1882. Dr. J. Lycett. <i>Medal.</i>                | 1893. Miss C. A. Raisin.                            |
| 1882. Rev. Norman Glass.                          | 1893. Mr. A. N. Leeds.                              |
| 1882. Professor Charles Lapworth.                 | 1894. Professor John Milne.<br><i>Medal.</i>        |
| 1883. Dr. W. B. Carpenter. <i>Medal.</i>          | 1894. Mr. William Hill.                             |
| 1883. Mr. P. H. Carpenter.                        | 1895. Rev. J. F. Blake. <i>Medal.</i>               |
| 1883. M. E. Rigaux.                               | 1895. Mr. Percy F. Kendall.                         |
| 1884. Dr. Joseph Leidy. <i>Medal.</i>             | 1895. Mr. Benjamin Harrison.                        |
| 1884. Professor Charles Lapworth.                 | 1896. Mr. A. Smith Woodward.<br><i>Medal.</i>       |
| 1885. Professor H. G. Seeley.<br><i>Medal.</i>    | 1896. Dr. W. F. Hume.                               |
| 1885. Mr. A. J. Jukes-Browne.                     | 1896. Mr. C. W. Andrews.                            |
| 1886. Mr. W. Pengelly. <i>Medal.</i>              | 1897. Dr. G. J. Hinde. <i>Medal.</i>                |
| 1886. Mr. D. Mackintosh.                          | 1897. Mr. W. J. Lewis Abbott.                       |
| 1887. Mr. Samuel Allport. <i>Medal.</i>           | 1897. Mr. J. Lomas.                                 |
| 1887. Rev. Osmond Fisher.                         |   |
| 1888. Professor H. A. Nicholson.<br><i>Medal.</i> |   |

## AWARDS OF THE BIGSBY MEDAL,

FOUNDED BY THE LATE

DR. J. J. BIGSBY, F.R.S., F.G.S.

To be awarded biennially 'as an acknowledgment of eminent services in any department of Geology, irrespective of the receiver's country; but he must not be older than 45 years at his last birthday, thus probably not too old for further work, and not too young to have done much.'

1877. Professor O. C. Marsh.	1889. Mr. J. J. Harris Teall.
1879. Professor E. D. Cope.	1891. Dr. George M. Dawson.
1881. Dr. Charles Barrois.	1893. Professor W. J. Sollas.
1883. Dr. Henry Hicks.	1895. Mr. Charles D. Walcott.
1885. Professor Alphonse Renard.	1897. Mr. Clement Reid.
1887. Professor Charles Lapworth.	

## AWARDS OF THE PROCEEDS OF THE BARLOW-JAMESON FUND,

ESTABLISHED UNDER THE WILL OF THE LATE

DR. H. C. BARLOW, F.G.S.

'The perpetual interest to be applied every two or three years, as may be approved by the Council, to or for the advancement of Geological Science.'

1880. Purchase of microscope.	1892. Professor Charles Mayer-Eymar.
1881. Purchase of microscope-lamps.	1893. Purchase of Scientific Instruments for Capt. F. E. Youngusband.
1882. Baron C. von Ettingshausen.	1894. Mr. Charles Davison.
1884. Dr. James Croll.	1896. Mr. J. Wright.
1884. Professor Leo Lesquereux.	1896. Mr. J. Storrice.
1886. Dr. H. J. Johnston-Lavis.	
1888. Museum.	
1890. Mr. W. Jerome Harrison.	

ESTIMATES *for*

## INCOME EXPECTED.

	£	s.	d.	£	s.	d.
Compositions.....	171	0	0			
Due for Arrears of Admission Fees .....	88	4	0			
Admission Fees, 1897 .....	240	0	0			
				328	4	0
Arrears of Annual Contributions .....	120	0	0			
Annual Contributions, 1897, from Resident Fel- lows, and Non-Residents, 1859 to 1861 ....	1610	0	0			
Annual Contributions in advance .....	35	0	0			
				1765	0	0
Dividends on £2000 India 3 per cents. ....	60	0	0			
Dividends on £2250 London and North-Western Railway 4 per cent. Preference Stock .....	90	0	0			
Dividends on £2800 London and South-Western Railway 4 per cent. Preference Stock .....	112	0	0			
Dividends on £300 London, Brighton, and South Coast Railway 5 per cent. Preference Stock..	15	0	0			
Dividends on £1295 Midland Railway 4 per cent. Preference Stock .....	51	16	0			
				328	16	0
Sale of Quarterly Journal, including Longman's Account .....	150	0	0			
Sale of Geological Map, including Stanford's Account .....	5	0	0			
Sale of Transactions, Library Catalogue, General Index, Hochstetter's 'New Zealand,' and List of Fellows .....	5	0	0			
				160	0	0
				2753	0	0
Balance against Society .....	504	15	0			
				£3257	15	0

*Note.*—The following Funds are available for Extraordinary Expenditure.

	£	s.	d.
Balance at the Bankers', Dec. 31st, 1896 .....	761	13	11
Balance in the Clerk's hands, Dec. 31st, 1896 .....	6	9	1
	£768	3	0

the Year 1897.

## EXPENDITURE ESTIMATED.

	£	s.	d.	£	s.	d.
House Expenditure:						
Taxes .....	0	15	0			
Fire Insurance .....	15	0	0			
Electric Lighting .....	15	0	0			
Gas .....	20	0	0			
Fuel .....	25	0	0			
Furniture and Repairs .....	35	0	0			
House-repairs and Maintenance .....	50	0	0			
Annual Cleaning .....	15	0	0			
Washing and Sundries .....	25	0	0			
Tea at Meetings .....	15	0	0			
				215	15	0
Salaries and Wages, etc.:						
Assistant Secretary .....	300	0	0			
"    Half Premium of Life Insurance .....	10	15	0			
Assistant Librarian .....	150	0	0			
Assistant Clerk .....	85	0	0			
House Porter and Upper-Housemaid .....	91	12	0			
Under-Housemaid .....	42	12	0			
Errand Boy .....	33	16	0			
Charwoman and Occasional Assistance .....	10	0	0			
Accountant's Fee .....	10	10	0			
				734	5	0
Library (Books and Binding) .....				225	0	0
Museum .....				5	0	0
Office Expenditure:						
Stationery .....	25	0	0			
Miscellaneous Printing .....	30	0	0			
Postages and other Expenses .....	90	0	0			
				145	0	0
Publications:						
Geological Map .....	10	0	0			
Quarterly Journal .....	900	0	0			
"    Commission, Postage, and Addressing .....	100	0	0			
Record of Geological Literature .....	100	0	0			
List of Fellows .....	35	0	0			
Abstracts, including Postage .....	110	0	0			
				1255	0	0
				2580	0	0
Index to Quarterly Journal (Vols. 1-50) .....	250	0	0			
Electric Lighting Installation. (Remainder payable as per Contract.) .....	27	15	0			
Completion of Redecoration of Society's Apart- ments .....	400	0	0			
				677	15	0
				£3257	15	0

W. T. BLANFORD, *Treasurer.*

January 26th, 1897.

*Income and Expenditure during the*

## RECEIPTS.

	£	s.	d.	£	s.	d.
Balance in Bankers' hands, 1 January, 1896 .	835	5	10			
Balance in Clerk's hands, 1 January, 1896 .	16	9	7			
				<u>851</u>	15	5
Compositions . . . . .				270	18	0
Arrears of Admission-fees . . . . .	69	6	0			
Admission-fees . . . . .	296	2	0			
				<u>365</u>	8	0
Arrears of Annual Contributions . . . . .				127	1	6
Annual Contributions of 1896 :						
Resident Fellows . . . . .	1569	15	0			
Non-Resident Fellows . . . . .		6	0			
				<u>1576</u>	1	0
Annual Contributions in advance . . . . .				52	10	0
Taylor & Francis: Advertisements in Journal, Vol. 51..					6	4
Publications :						
Sale of Journals, Vols. 1-51 . . . . .	83	7	1			
"    Vol. 52* . . . . .	72	6	1			
Sale of Transactions . . . . .			14			0
Sale of Geological Literature . . . . .			7			6
Sale of Library Catalogue . . . . .			16			0
Sale of Geological Map † . . . . .			8			9
Sale of Ormerod's Index . . . . .			3			0
Sale of Hochstetter's 'New Zealand' . . . . .			4			0
Sale of List of Fellows . . . . .			13			0
				<u>158</u>	19	5
Dividends on L. & N. W. Railway Stock . .	87	0	0			
"    L. & S. W. Railway Stock . .	108	5	4			
"    L. B. & S. C. Railway Stock . .	14	10	0			
"    Midland Railway Stock . . . .	50	1	6			
"    India 3 p. c. Stock . . . . .	58	0	0			
				<u>317</u>	16	10
Income Tax :						
Repayment of Tax under Schedule C for the year						
1895-96 . . . . .				7	3	11
*Due from Messrs. Longmans, in addition to the						
above, on Journal, Vol. 52 . . . . .	£60	4	10			
†Due from Stanford, on account of Geological						
Map . . . . .	£ 4	14	6			

We have compared this Statement  
with the Books and Accounts presented  
to us, and find them to agree.

(Signed) J. W. GREGORY,  
HORACE W. MONCKTON, } *Auditors.*

January 26th, 1897.

£3728 0 5

Year ended December 31st, 1896.

PAYMENTS.			
House Expenditure:		£	s. d.
Taxes .....		15	0
Fire Insurance .....		15	0 0
Electric Lighting Installation .....	218	15	3
Electric Lighting .....		11	6
Gas .....	28	6	0
Fuel.....	15	19	0
Furniture and Repairs .....	27	4	7
Electric Lantern and Fittings.....	63	7	6
House Repairs (including Redecoration of Basement) .....	115	5	8
Annual Cleaning .....		10	15 0
Washing and Sundries .....	23	15	4
Tea at Meetings.....	16	9	8
		<hr/>	
		536	4 6
 Salaries and Wages, etc.:			
Assistant Secretary .....	300	0	0
"    Half Premium of Life Insurance	10	15	0
Assistants in Library, Office, and Museum...	230	0	0
House Porter and Upper-Housemaid .....	89	19	9
Under-Housemaid .....	43	19	6
Errand Boy .....	32	15	0
Charwoman and Occasional Assistance .....	10	3	5
Accountant's Fee .....	10	10	0
		<hr/>	
		728	2 8
 Official Expenditure:			
Stationery .....	25	19	3
Miscellaneous Printing .....	30	19	0
Postages and Sundry Expenses .....	78	18	9
		<hr/>	
		135	17 0
Library .....		143	16 6
 Publications:			
Journal, Vols. 1-51.....	8	16	7
"    Vol. 52 .....	911	15	5
"    "    Commission, Postage, and Addressing. ....	92	17	11
	<hr/>	1004	13 4
Record of Geological Literature .....	96	3	9
List of Fellows .....	35	18	3
Abstracts, including Postage .....	113	9	10
Index to Quarterly Journal (Vols. 1-50)...	156	15	0
		<hr/>	
		1415	16 9
Balance in Bankers' hands, 31 Dec. 1896..	761	13	11
Balance in Clerk's hands, 31 Dec. 1896 ..	6	9	1
		<hr/>	
		768	3 0

‘WOLLASTON DONATION FUND.’ TRUST ACCOUNT.

RECEIPTS.		PAYMENTS.	
£	s.	£	s.
Balance at Bankers', January 1st, 1896.	23	15	0
Dividends on the Fund invested in £1073 Hampshire County 3 per cent. Stock	31	2	4
Repayment of one year's Income Tax	1	0	8
	£55	18	0
		Cost of striking Gold Medal awarded to Prof. E. Suess	10
		Award to Mr. A. Harker	13
		Balance at Bankers', December 31st, 1896	32
			3
			0
		£55	18
			0

‘MURCHISON GEOLOGICAL FUND.’ TRUST ACCOUNT.

RECEIPTS.		PAYMENTS.	
£	s.	£	s.
Balance at Bankers', January 1st, 1896	20	12	8
Dividends on the Fund invested in £1334 London and North-Western Railway 3 per cent. Debenture Stock	38	13	8
Repayment of one year's Income Tax	1	5	9
	£60	12	1
		Award to Mr. P. Lake	28
		Mr. T. M. Reade, and Medal	10
		Cost of Medal	17
		Balance at Bankers', December 31st, 1896	20
			12
			7
		£60	12
			1

‘LYELL GEOLOGICAL FUND.’ TRUST ACCOUNT.

RECEIPTS.		PAYMENTS.	
£	s.	£	s.
Balance at Bankers', January 1st, 1896	53	6	11
Dividends on the Fund invested in £2010 1s. 0d. Metropolitan 3½ per cents.	68	0	4
Repayment of one year's Income Tax	2	5	4
	£123	12	7
		Award to Mr. A. S. Woodward, and Medal	25
		Mr. W. F. Hume	22
		Mr. C. W. Andrews	22
		Cost of Medal	1
		Balance at Bankers', December 31st, 1896	53
			5
			7
		£123	12
			7

‘BARLOW-JAMESON FUND.’ TRUST ACCOUNT.

RECEIPTS.		PAYMENTS.	
	£ s. d.		£ s. d.
Balance at Bankers', January 1st, 1896 .....	52 15 0	Award to Mr. A. Harker .....	6 15 0
Dividends on the Fund invested in £468 Great Northern Railway 3 per cent. Stock .....	13 11 6	” Mr. J. Wright .....	20 0 0
Repayment of one year's Income Tax .....	9 0 0	” Mr. J. Stornie .....	20 0 0
		Balance at Bankers', December 31st, 1896 .....	20 0 6
	<u>£66 15 6</u>		<u>£66 15 6</u>

‘BIGSBY FUND.’ TRUST ACCOUNT.

RECEIPTS.		PAYMENTS.	
	£ s. d.		£ s. d.
Balance at Bankers', January 1st, 1896 .....	4 12 7	Balance at Bankers', December 31st, 1896 .....	10 18 5
Dividends on the Fund invested in £210 Cardiff 3 per cent. Stock .....	6 1 10		
Repayment of one year's Income Tax .....	4 0 0		
	<u>£10 18 5</u>		<u>£10 18 5</u>

(Signed) J. W. GREGORY,  
HORACE W. MONCKTON, } *Auditors.*

W. T. BLANFORD, *Treasurer.*

January 26th, 1897.

VALUATION OF THE SOCIETY'S PROPERTY; December 31st, 1896.

PROPERTY.	£	s.	d.
Due from Longmans & Co., on account of Journal, Vol. LII. etc. ....	60	4	10
Due from Stanford, on account of Geological Map ....	4	14	6
Balance in Bankers' hands, Dec. 31st, 1896 .....	761	13	11
Balance in Clerk's hands, Dec. 31st, 1896 .....	6	9	1
<b>Funded Property:—</b>			
£2000 India 3 per Cents .....	2082	13	0
£2250 London & North-Western Railway 4 per cent. Consolidated Preference Stock .....	2898	10	6
£2800 London & South-Western Railway 4 per cent. Preference Stock .....	3607	7	6
£500 London, Brighton, & South Coast Railway 5 per cent. Consolidated Preference Stock .....	502	15	3
£1295 Midland Railway 4 per cent. Preference Stock .....	1850	19	6
Arrears of Admission-fees .....	88	4	0
Arrears of Annual Contributions .....	120	0	0
<i>N.B.—The above does not include the value of the Collections, Library, Furniture, and Stock of unsold Publications.]</i>			
	<u>£11,983</u>	<u>12</u>	<u>1</u>
	<u>£11,983</u>	<u>12</u>	<u>1</u>

W. T. BLANFORD, Treasurer.

January 26th, 1897.

*Note.*—The investments in Stocks are valued at their cost price. Their selling-price on December 31st, 1896, at the quotations of the day, would increase the above total by more than £1500.

## AWARD OF THE WOLLASTON MEDAL.

In presenting the Wollaston Medal to W. H. HUDLESTON, Esq., M.A., F.R.S., F.L.S., the PRESIDENT addressed him as follows:—

Mr. HUDLESTON,—

It is extremely gratifying to me that it has fallen to my lot to present to you, on behalf of the Council of the Geological Society, the highest award which it is in their power to bestow on distinguished geologists. You have laboured long and assiduously in the cause of science, and have enriched geological knowledge in its chemical, mineralogical, palæontological, and stratigraphical departments. The first paper which you communicated to this Society appears to be that ‘On the Chemical Analysis of the Cambrian Rocks,’ which you were good enough to undertake at my request in the year 1875. You had previously communicated papers to the Geologists’ Association—one on the Yorkshire Oolites, and another, in conjunction with Mr. Hilton Price, on the Thames Valley Deposits. Another valuable chemical paper should be referred to, namely, ‘On the Chemical Composition of the Rocks of the Lizard,’ which appeared as an Appendix to a paper by Prof. Bonney in 1877; and in that year also you, in conjunction with Prof. Blake, contributed a highly important paper to this Society on the Corallian Rocks of England. The Addresses delivered by you as President of the Geologists’ Association, of the Devonshire Association for the Advancement of Science, Literature, and Art, and of this Society, show much critical power and demonstrate your ability to convey a great amount of valuable information in a limited space. You are further to be congratulated upon having recently completed the important memoir published by the Palæontographical Society—‘A Monograph on the Inferior Oolite Gasteropoda,’—which contains no less than 514 pages and 44 quarto plates. The great value of your work amongst the Jurassic rocks is so generally admitted that I need not refer to the other papers contributed by you to various Societies.

In conclusion I can only say that it gives me very much pleasure to hand to you this Medal, which is presented by the Council as a token of their recognition of the eminent services rendered by you to Geological Science.

Mr. HUDLESTON, in reply, said:—

Mr. PRESIDENT,—

On this occasion my warmest thanks are due to the Council, on whom the duty of awarding the Wollaston Medal has this year devolved, for their generous interpretation of my past geological career. To have received a distinction such as the foremost geologists of any country might be proud to accept, and to be enrolled in that famous band of recipients which is headed by the Father of English Geology, is indeed to me an unexpected honour and gratification. If anything were needed to enhance the pleasure of the moment, it is to be found in the circumstance that I receive the Medal from the hands of an old friend and contemporary, whose scientific career possesses so many points of resemblance with my own. For, if I have done some work in Mesozoic geology, you, Sir, are well known, both in Europe and America, for your researches among the older Palæozoic rocks.

This particular award serves to show that researches concerning the mineral structure of the earth are not necessarily limited to professional enterprise, but that both the Council and the Society are ready to recognize the utility of independent work, whether special, or of a more general character. Our science has its ramifications in so many others, that, whether we consider Geology in its tectonic, its petrographical, or its palæontological aspect, it is incumbent upon those who cultivate it to endeavour to acquire, to some extent, a knowledge of cognate subjects. Not that I would venture to lay claim to the accomplishment of much original work in any of the above departments; although I may have contributed something towards a knowledge of the stratigraphy and palæontology of the Jurassic rocks of England, and more especially of my native county.

During the last quarter of a century the Geological Society and the Geologists' Association have, each of them, afforded me a congenial scientific home. If in that interval it has been my good fortune to have furthered the cause which we all have at heart, such service has been more than repaid by the benefits derived from mutual intercourse. Nor do I forget the advantages afforded by my relations with the Palæontographical Society, whose resources have been useful to more than one Wollaston medallist.

In offering my thanks once more to the Council and also to the Fellows here present for the cordiality with which the Award has been received, I may truly say that this Medal will always serve as

an agreeable memento of my connexion with the Geological Society. So long as I live, it will give me pleasure to take an interest in geological questions, and if I cannot promise to participate very actively in the work of the future, I may at least say, as regards my past work, that this recognition of its merits is most ample, and leaves nothing on my part to be desired.

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AWARD OF THE WOLLASTON DONATION FUND.

The PRESIDENT then handed the Balance of the Proceeds of the Wollaston Donation Fund to F. A. BATHER, Esq., M.A., addressing him as follows:—

Mr. BATHER,—

The Council of the Geological Society have voted you the Balance of the Wollaston Fund as an expression of their appreciation of the excellent work in Palæontology which you are carrying on, and with a view to assist you in the original investigations on the Crinoidea upon which you have expended both much labour and capital.

From the time you left the University of Oxford and entered the Geological Department of the British Museum in 1887, you have specially studied this group of fossil organisms; and in a series of some 27 papers you have not only described many interesting Palæozoic and Mesozoic genera, but have proposed a method of classification, based upon the arrangement of the plates, which will be of the greatest assistance to all future workers.

The paper which you published in 1893 under the auspices of the Royal Swedish Academy, Part I. of the Crinoidea of Gothland (4to. 10 plates, pp. 200), is a work which needs only to be seen and studied to be appreciated, and has been most highly spoken of by eminent palæontologists at home and abroad. I trust this recognition by the Council of what you have already done may encourage you to still greater efforts, so that it cannot for long be said that our English Crinoidea still need a monographer.

Mr. BATHER replied in the following terms:—

Mr. PRESIDENT,—

After serving the British Museum for two years, I decided to use the knowledge thus gained, and the opportunities there offered

for an exhaustive study of the British Fossil Crinoids, a task to which I was further urged by my much-mourned friend, Herbert Carpenter. I estimated that the work would take 15 years. Half that time has now passed, and I have dealt with only a few genera from a single formation. The preliminary studies and other duties, to a few of which you, Sir, so kindly alluded, have contracted the time at my disposal within bounds that I long to enlarge. It is the more encouraging that my fellow-workers should honour thus highly the little that I have done, for I am not ashamed to say that the thought of these awards has been, and will be,

‘a spur to prick the sides of my intent.’

The student of science, however, should not think overmuch of contemporary applause. If a palæontologist, he must wrestle with his fossils, nor let them go until they have yielded all their secrets. Laborious investigation, precise description, accurate and detailed drawings: these are indispensable if he is to receive aught but abuse from a posterity even more critical than ourselves. In the continuance of work that strives, however ineffectually, to have this character, the present Award will be a material and a welcome aid.

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#### AWARD OF THE MURCHISON MEDAL.

In presenting the Murchison Medal to HORACE B. WOODWARD, Esq., F.R.S., the PRESIDENT addressed him as follows:—

Mr. WOODWARD,—

The Council have this year adjudged you the Murchison Medal, with the sum of Ten Guineas, and it is peculiarly appropriate that the Award should be made to one who has for so many years zealously worked on that Geological Survey which Sir Roderick Murchison, the founder of the Medal, so long and ably directed. It may not be generally known that, like your esteemed father, the late Dr. S. P. Woodward, F.G.S. (who was our Sub-curator in 1839), you also commenced your geological career (in November 1863) as an Assistant in the Museum of the Geological Society, at Somerset House. During the past 30 years of your labours as a field-geologist, on the Geological Survey of England and Wales, your experiences have been most varied. From Newton Abbot and

other parts of Devon, over East Somerset, the Bristol Coalfield, and the Mendips, to the Geology of Fakenham and the country around Norwich (where your grandfather, Samuel Woodward, the 'Norfolk Geologist,' laboured so earnestly 70 years ago), to Essex and the neighbouring drift-covered counties; from the Jurassic areas of Britain south of the Humber to the far-distant Jurassic areas of Sutherland and Skye,—all these and more have, in turn, claimed your careful attention. Besides your very numerous Survey memoirs, maps, and sections, all prepared with much skill, you have given us a most helpful work, 'The Geology of England and Wales.' When President of the Norwich Geological Society, the Norfolk Naturalists' Society, and the Geologists' Association, you gave important addresses, and you have contributed numerous separate geological papers, read here and elsewhere. In addition, I must especially refer to the ever-ready help which you afford, in your office at Jermyn Street (as resident geologist), to all those who call upon you for information, help which has rightly earned for you a large circle of grateful friends.

Mr. WOODWARD, in reply, said:—

Mr. PRESIDENT,—

In thanking you, Sir, and the Council of this Society, for the high honour which you have now conferred upon me, I cannot help feeling that you have regarded with great generosity whatever I have been able to accomplish. I would pass by the official or professional work. That has always been a pleasure: it has also been a duty. And I would rather believe that you have taken more into consideration the extra-official or amateur work which has been the labour of leisure hours. This much I would like to say, in reference to the second edition of my 'Geology of England and Wales,' that the impulse which led to its production was the ambition to render some service; and to do this in the way I desired was to act somewhat independently, for I received no encouragement from publishers. That their predictions were fully justified adds considerably to the gratification with which, Sir, I now receive this mark of distinction and approval from your hands.

## AWARD OF THE MURCHISON GEOLOGICAL FUND.

The PRESIDENT then handed the Balance of the Proceeds of the Murchison Geological Fund to S. S. BUCKMAN, Esq., addressing him as follows:—

Mr. BUCKMAN,—

Following in the steps of your father, Prof. James Buckman, you have devoted many years to the elucidation of the Palæontology and Geology of the Lower Oolitic rocks of Dorset and neighbouring counties. In palæontology, you have dealt with the Pelecypods, the Brachiopods, and the Ammonites of the Inferior Oolite and Bajocian, the last group especially in the monograph now being published by the Palæontographical Society. Seeing that accurate work in palæontology could not be accomplished without equally detailed stratigraphy, you have investigated, with a minuteness before unattempted for Jurassic rocks, the unravelling of their geological history, and the Society has thus received from your hands an important series of papers, amongst which I may mention those on the Cotteswold, Midford, and Yeovil Sands (1889); on the so-called Upper-Lias Clay of Down Cliffs (1890); on the Bajocian of the Sherborne District: its Relation to Subjacent and Superjacent Strata (1893); and on the Bajocian of the Mid-Cotteswolds (1895). To show their appreciation of the important work which you have already accomplished, and in the hope that you may continue to work on the lines which have yielded results so excellent, the Council have felt much pleasure in awarding you the Murchison Fund.

Mr. BUCKMAN replied as follows:—

Mr. PRESIDENT,—

I scarcely know how to thank you for the honour which you have done me in the presentation of this Award, and for the far too favourable manner in which you have spoken of such scientific work as I have been able to accomplish. You have very kindly alluded to my stratigraphical work, and have noticed its minuteness. As regards this part of my labours I have a clear conscience: it was undertaken for the purpose of understanding the genealogy of Ammonites, and its minuteness is an absolute necessity thereto. But when I think of the palæontological work to which you have

referred, I feel considerable cause for dissatisfaction. Now that some nine yearly portions have appeared in the volumes of the Palæontographical Society, I ought to be approaching the end of my labours, but I find that I am actually farther from that desirable attainment than when I began, while I have far less opportunity for continuous study. And when I look back at the earlier portion of this work, I am quite dissatisfied with the survey. I must own to serious mistakes, particularly that I had not sufficiently the courage of my own opinions, and that I gave heed to the outcry about new genera and species. That was a sad mistake; but I have amended it in the later parts of my work. In this direction I have, however, far more to perform. How much—or little—praise I may obtain thereby I know not, but the fact that you have kindly given me this Award as a recognition of my work encourages me to confidently pursue my way. It is for such encouragement that I most appreciate this Award; and I thank you sincerely for it.

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#### AWARD OF THE LYELL MEDAL.

In presenting the Lyell Medal to Dr. GEORGE JENNINGS HINDE, F.R.S., the PRESIDENT addressed him in the following terms:—

Dr. HINDE,—

The Council of the Geological Society have awarded to you the Lyell Medal, with the sum of Twenty-five Pounds, in recognition of your valuable researches in palæontology and geology, but more especially in reference to your discoveries of Fossil Sponges and other minute bodies preserved in cherts, in various formations, and the painstaking manner in which they have been elucidated by you. The experience which you gained when working as a student under Prof. H. A. Nicholson, in the University of Toronto, and later, under Prof. K. A. von Zittel, in the University of Munich (where you obtained your degree of Ph.D., for a dissertation on the Fossil Sponge-Spicules from the Chalk of Norfolk), was an excellent beginning for your subsequent more ripened work. I need only refer to your memoirs on Conodonts from the Cambro-Silurian and Devonian rocks of North America, Scotland, and the West of England, and to your various papers, to show the great value of the original work which you have done. In your 'Catalogue of the Fossil Sponges in the British Museum,' and in your memoir on 'British Fossil Sponges,'

in the Palæontographical Society, you have given us works of considerable importance. You have also published many other valuable papers which have added much to our knowledge, and all recognize that you have placed yourself in the foremost rank amongst those who have devoted themselves to the study of minute fossil organisms. The Medal could not be more worthily bestowed than upon one who has always so earnestly laboured for the advancement of truth, and I have very great pleasure in handing it to you.

Dr. HINDE, in reply, said :—

Mr. PRESIDENT,—

It gives me sincere gratification to receive at your hands the Lyell Medal, remembering that it is intended, in the words of its liberal-minded Founder, as a mark of honorary distinction and as an expression that the recipient 'has deserved well of the Science.' That so competent a tribunal as the Council of the Geological Society regards my Palæontological work as meriting this recognition, is to me a source of lively satisfaction.

I can only regret that so much of the work which it is my aim to accomplish still remains to be done: the encouragement which you have given me to persevere will not, I hope, be without result, but whilst the field of investigation is ever widening and the materials are constantly accumulating, the capacity to keep level with the work becomes, with the lapse of time, a diminishing quantity.

I wish here gratefully to acknowledge the large measure of help which has been freely given to me in the course of my work by my brother geologists and on the part of the Society, and more particularly my indebtedness to my friend and indefatigable colleague, Mr. Howard Fox, in working out our joint paper on the Radiolarian Rocks of Devon.

For the kindly, sympathetic, and very generous terms in which you, Sir, have referred to what I have done, I desire to express my warmest thanks.

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#### AWARD OF THE LYELL GEOLOGICAL FUND.

The PRESIDENT then handed one half of the Balance of the Proceeds of the Lyell Geological Fund to W. J. LEWIS ABBOTT, Esq., addressing him as follows :—

Mr. ABBOTT,—

Some twenty years ago you read an important paper on the

Formation of Agates before the Geologists' Association, and since then you have contributed much additional valuable information in regard to their origin. For many years you have also been a careful and energetic collector of fossil remains, and of the implements worked by early man; and the remarkable collection shown by you at the recent *Conversazione* in the rooms of the Society testifies to your keen and accurate discrimination. Your researches, as shown in your paper on the Ossiferous Fissures in the Valley of the Shode near Ightham, published in the *Quarterly Journal of the Society* in 1894, and in other papers published in the *Proceedings of the Geologists' Association*, the *Journal of the Anthropological Institute*, and 'Natural Science,' have greatly added to the faunas, and therefore to our knowledge of the history, of the Pleistocene and early post-Pleistocene periods.

The Council in making this Award desire not only to express to you their appreciation of the work which you have already done, but hope that it may be an incentive to further researches. It gives me much pleasure to place this Award in your hands.

Mr. ABBOTT replied as follows:—

Mr. PRESIDENT,—

I am deeply grateful to you, Sir, and the Council of the Geological Society collectively, for the great honour conferred upon me in thus appreciating the results of my labours; and to you, Sir, personally for the very kind, appreciative words with which you have supplemented it. There is, doubtless, a great reward in store for all those who in any way contribute to the stock of human knowledge—a reward which comes with the discovery of anything new. But, after all, there is something which is perhaps even greater to frailly constituted humanity than that: it is to receive such tangible proofs as this that others admit the value of one's labours. It comes as a potent antidote for weeks and months of almost barren research, a grateful compensation for midnight oil expended and pecuniary losses sustained, and a wholesome incentive to renewed energy in the future. I am all the more proud of the honour conferred upon me, in that it is associated with the name of the great Ambassador of 'the Causes now in operation': for assuredly, if there is one branch of Geology more than another calculated to make one realize the applicability of these, it is that in which I have been chiefly engaged, where we stand one foot on to-day and the other on yesterday, and note, with equal distinctness and certainty

in each, the effects not only of sea and storm, but of the very zephyrs.

But while my labours are thus rewarded, it must ever be remembered how much the value of my Pleistocene work has been enhanced by the co-operation of my esteemed colleague Mr. E. T. Newton, and I gladly welcome this opportunity of publicly expressing my deepest obligations and warmest thanks to him for his great and kindly assistance during the last sixteen or eighteen years. In conclusion, I can only express the hope that the remaining years of my life, stimulated anew by this Award, will be spent in the cause which I have so much at heart, and that the result of my labours may continue not only to give me pleasure, but prove interesting and profitable to others.

The PRESIDENT then handed the other moiety of the Balance of the Proceeds of the Lyell Geological Fund to JOSEPH LOMAS, Esq., addressing him as follows:—

Mr. LOMAS,—

The Council of this Society have this year awarded to you a moiety of the Proceeds of the Lyell Fund in testimony of the value of your work, especially in regard to the Glacial Geology of the neighbourhood of Liverpool, and of areas in North Wales, upon which you have written no less than ten papers between the years 1886 and 1896. To enable you to check the accuracy of your conclusions you have also made a study of glaciation in Switzerland and the Færöe. As showing that you have not neglected other branches of geology, I may mention also your paper on the Basaltic Dykes of Mull in 1887, and on Fossil Plants from the Carboniferous in 1895. Your recent election as President of the Liverpool Geological Society testifies to the esteem in which you are held by your fellow-workers in that city, where as a special Lecturer on Geology at University College you are responsible for most important geological teaching. It is now my privilege to be the means of handing you this Award, with the hope that it may aid you in your further researches.

Mr. LOMAS replied in the following terms:—

Mr. PRESIDENT,—

You have expressed, in much too kind words, your appreciation of my work in Glacial Geology. Recognizing that the first duty of

a student is to collect accurate data, I have done my best to observe and record the phenomena in my own district. If these observations have contributed, even in a small degree, towards the elucidation of a very difficult problem, I am amply rewarded.

We, of the Liverpool Geological Society, are proud to think that four of our Presidents have been honoured by marks of distinction bestowed on them by the mother Society. The encouragement which these Awards have afforded cannot be over-estimated. When I look down a list of those who have received this Award in former years, I cannot but think that the stimulus given has greatly influenced their subsequent careers. I trust that may be so in my own case, and I shall always endeavour to prove that your kindness has not been misplaced.

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#### AWARD OF THE BIGSBY MEDAL.

In presenting the Bigsby Medal to CLEMENT REID, Esq., F.L.S., the PRESIDENT addressed him as follows:—

Mr. REID,—

The Council of the Geological Society have awarded to you the Bigsby Medal in recognition of the excellent work which you have already accomplished, and in full confidence that it will encourage you to continue those researches with unabated vigour. Since 1874, when you joined the Geological Survey, you have been engaged in mapping many areas and various formations, but you have more especially directed your attention to Tertiary and Pleistocene Geology, and your memoir, 'On the Geology of the Country around Cromer,' has become a classical work of reference. The painstaking manner in which you have searched for evidences of plant-remains from the Pleistocene deposits merits the thanks of all, for the results have been truly remarkable and have enabled us to realize far more clearly than was previously possible the climatic conditions prevailing when they were accumulated. Besides the Survey memoirs which you have written, you have found time to contribute several important communications to this Society and valuable special notes to the papers of other authors. I feel much pleasure in being privileged to hand to you, on behalf of the Council, this Medal; and I may be allowed to express the hope that you will

continue with the same energy that has hitherto characterized you to add to our knowledge of those special branches of the science which you have already cultivated with so much success.

Mr. REID, in reply, said :—

Mr. PRESIDENT,—

The bestowal of this Award, for which I tender my warmest thanks to the Council, makes me feel that perhaps, after all, the results of my work may not be so valueless as I have sometimes feared. No doubt, compared with the magnitude of the problems which I have had before me, the results are very small; and, when viewed as a whole, must seem disconnected. I may say, however, that the published observations have more in common than would appear at first sight. They are the outcome of a continued attack, from different sides, of some of those problems, on the correct solution of which geological progress so largely depends. I allude to the question of the alternations of climate which have taken place in bygone times; the relation of these alternations to the migration, extinction, and variation of species, and to past changes in physical geography; and lastly, to the question of the rapidity with which such changes can succeed one another. In short, my somewhat ambitious task has been that of seeking a base-line for the measurement of geological time.

Towards the attainment of this end I have made but small progress; yet, while following unaccustomed paths noteworthy facts are constantly discovered, and many a line of research, almost a failure from the point of view of the original enquiry, has yet repaid the time and labour bestowed upon it. It is only, I am afraid, on such minor questions that I have, as yet, been able to throw any light. My problem still lies before me.

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## THE ANNIVERSARY ADDRESS OF THE PRESIDENT,

HENRY HICKS, M.D., F.R.S.

GENTLEMEN,—

Since our last Anniversary Meeting it has been my painful duty to announce from this chair the death of the revered and much-beloved Father of the Society and a former President, Sir Joseph Prestwich, and also that of a much-respected Member of the Council, and Vice-President, Prof. A. H. Green.

We have further to lament the deaths of some distinguished Foreign Members and Foreign Correspondents, namely:—M. Auguste Daubrée, Prof. H. E. Beyrich, Prof. J. Dwight Whitney, and Baron C. von Ettingshausen; and also of several Fellows of the Society who have done much for the advancement of science.

Sir JOSEPH PRESTWICH, who was descended from an old Lancashire family, was born at Pensbury, Clapham, on March 12th, 1812. He was educated at various preparatory schools, and in Paris, and finally at University College, London, which had then been only recently established. His early taste for scientific investigation was shown in the avidity with which he took up the study of chemistry and natural philosophy, and it is interesting to note that the love of experimental science first stimulated by the teachings of Drs. Turner and Lardner, at University College, continued throughout the whole of his life. Clearly this inclination, under ordinary circumstances, would have led him to adopt a scientific profession rather than a commercial calling; however, it was otherwise ordained, and he had to join the business of his father, a well-known wine-merchant in Mark Lane. With the house and business he remained closely connected for nearly forty years. Happily, his commercial avocations to some degree aided, instead of restricting, his pursuit of geological studies. He had to make frequent visits to France and Belgium, in both of which countries he formed lasting friendships with the leading geologists and palæontologists of the day; and he made himself personally familiar with the actual strata and fossils which they had described. Not only so, but his business among the country connexions of the firm carried him to nearly every part of the United Kingdom, and the hours unclaimed by his engagements were enthusiastically devoted to the

study of the local geology of the districts which he visited. His comprehensive eye enabled him rapidly to appreciate and to grasp the leading features, topographical and geological, of most of the areas which in those days possessed an exceptional geological interest; and those who in later years had the good fortune to accompany him to such spots were surprised to find how retentive was his memory and how intimate was his acquaintance with every pit, quarry, and rock-section that in any way illustrated the geological problem under consideration.

His first papers were on the Gamrie Ichthyolites and Shells in the Till of Banffshire, and on the Geology of Coalbrook Dale, published in the Transactions of this Society in 1835. This was followed by a series of papers on Tertiary Geology which are also to be found in the Journals of this Society.

In the winter of 1858, Dr. Hugh Falconer urged upon Mr. Prestwich's attention the desirability of investigating in the field the evidences for the discoveries of M. Boucher de Perthes of flint implements of prehistoric man in the gravel-deposits of the Valley of the Somme, which were then somewhat doubtfully received, and in April 1859 Mr. Prestwich proceeded to Abbeville, where he was joined by Mr. John Evans. Thence they went to Amiens, and in the gravel-beds of St. Acheul saw for themselves, still embedded in its matrix, one of those implements of unquestionable human workmanship, the asserted existence of which in the alluvial deposits had met with so much doubt. The previous discoveries, thus verified, and subsequently supplemented by researches conducted on lines which could with confidence be laid down, soon led to an entire revolution in the then existing ideas as to the antiquity of man. In the *Compte-rendu* of the Société Géologique de France, No. 15, Séance du 9 Novembre 1896, there is a feeling reference to his long connexion with that Society. He was introduced into it in 1838 by Constant Prévost and Deshayes; he was therefore for 58 years a Member, and in 1895 he was elected a Vice-President. His French geological work is referred to as being of the greatest importance, and as being a model for all.

Mr. Prestwich was elected a Fellow of the Geological Society as long ago as 1833, and in 1849 the Wollaston Medal was awarded to him for his researches at Coalbrook Dale and in the London Basin. He served the Society as Treasurer for many years, and as President for two years from 1870 to 1872. In 1853 he was elected a Fellow of the Royal Society, afterwards serving on its Council, and

in 1870 and 1871 he was a Vice-President of that Society. One of the Royal Medals was awarded to him in 1865 for his contributions to geological science.

While Prestwich gave his attention in the main to pure science, he did not neglect the important applications of knowledge. By his publication in 1851 of 'A Geological Inquiry respecting the Water-bearing Strata of the Country around London' he came to be recognized as the leading geological authority on the subject; and in 1867 he was appointed a Member of the Royal Commission on Metropolitan Water Supply. He also rendered valuable aid to the country by acting on the Royal Coal Commission, in connexion with which he furnished an exhaustive and at the same time suggestive Report (published in 1871) 'On the Probability of finding Coal under the newer Formations of the South of England,'—some of the anticipations in which he lived to see, at all events partially, realized. In 1874 the Institution of Civil Engineers awarded him a Telford Medal and Premium for his paper on the 'Geological Conditions affecting the Construction of a Tunnel between England and France.' On June 29th of the same year he was appointed Professor of Geology at Oxford in succession to the late Prof. Phillips, and his inaugural lecture was published under the title of 'The Past and Future of Geology, 1875.' In 1876, in investigating the conditions for a better water-supply, he pointed out that there was under Oxford an abundant source of mineral water, allied to, but stronger than those of Cheltenham and Leamington. In 1876 his elaborate paper on 'Submarine Temperatures,' which reviewed all that had been done before the *Challenger* expedition, appeared in the 'Philosophical Transactions.' The *vexata quæstio* of the 'Parallel Roads of Glen Roy' next engaged his attention, and this was followed by several other papers, amongst which may be mentioned those on 'Underground Temperatures' and on 'Volcanic Action.' In 1885 he was elected by the Institute of France a Corresponding Member of the Academy of Sciences. In 1886 the 1st vol. (Chemical and Physical) of his work on Geology was published by the Clarendon Press. The 2nd vol. (Stratigraphical and Palæontological), with a Geological Map of Europe, appeared in 1888. In the same year the University of Oxford conferred upon him the honorary degree of D.C.L. He was elected President of the International Geological Congress which held its 4th Session in London in September 1888, and in 1894 he was elected into the Reale Accademia dei Lincei of Rome.

His latest papers read before the Geological Society relate to the Preglacial drifts of the South of England, with a view to determine a base for the Quaternary Series, and to ascertain the period of the genesis of the Thames. It is also well known that, owing to some recent discoveries, he had abandoned his previous views as to the age of some of the deposits containing Palæolithic implements, and inclined to the view that man occupied this country in Glacial if not Preglacial times.

His marked individuality and stern determination to get at the truth necessarily compelled him to enter into some amount of controversy, but his generous and lovable nature prevented the possibility of any feeling of bitterness. He was, moreover, a man of deep religious reverence, and delighted in the contemplation of all that was beautiful and wonderful in nature.

After his retirement from Oxford he resided for the most part at his delightful country house, Darent Hulme, Shoreham, Kent, which he built in accordance with his own tastes some 28 years ago, and every room and wall of which brought to mind some subject of geological interest either in material or decoration. There he actively continued his scientific labours, efficiently aided and cared for by a loving wife, the niece of his old friend Dr. Hugh Falconer. In the early part of last year the honour of knighthood was conferred upon him by Her Majesty, but he was too feeble in health to accept it in person. He died on June 23rd, and was buried in the churchyard of Shoreham, near Sevenoaks. The funeral was attended by a large number of representative men of science, who had enjoyed the privilege of his friendship.

His almost life-long friend, Sir John Evans, to whose sympathetic notice in the Proceedings of the Royal Society I am indebted for several of the foregoing statements, closes it with the following remarks:—‘Of his personal amiability, his devoted friendship, and his charm of manner this is hardly the place to speak; but all those with whom he was brought into contact will agree that in Sir Joseph Prestwich we have lost not only one of the great pillars of geological science, but a geologist whose mind was as fully stored with accumulated knowledge as that of any of his contemporaries, and one who was always ready to place those stores generously and freely at the disposal of others.’

The death of Prof. A. H. GREEN on August 19th, 1896, removed from among us one of the most respected and accomplished Fellows

of the Society, and an active Member of the Council. He was elected a Fellow in 1862, and at the time of his death he was a Vice-President.

Alexander Henry Green was the son of the Rev. Thomas Sheldon Green, who was for many years Master of the Ashby Grammar School and a classical scholar of some repute. He was born at Maidstone, October 10th, 1832, and educated at his father's school, Ashby-de-la-Zouch, and at Gonville and Caius College, Cambridge. He was Sixth Wrangler in 1855, and was elected Fellow of his College the same year. In 1861 he was appointed an Assistant on the Geological Survey of England and Wales, and in 1867 he attained the rank of Geologist. During the time of his connexion with the Survey, he examined considerable areas of the Jurassic and Cretaceous rocks in the Midland counties, and of the Carboniferous rocks in Derbyshire, Yorkshire, and other northern counties. Many Survey memoirs were written wholly or in part by Mr. Green, among which are the 'Geology of Banbury' (1864), and the geological descriptions of the country around Stockport (1866), Tadcaster (1870), Dewsbury (1871), Barnsley (1878), and Wakefield (1879). The memoir on the geology of North Derbyshire, of which the first edition was published in 1869 and the second in 1887, was written chiefly by Mr. Green. His most important Survey work is the 'Geology of the Yorkshire Coalfield' (1878).

Mr. Green retired from the Geological Survey in 1874 on his appointment to the Professorship of Geology in the Yorkshire College at Leeds, to which was added, in 1885, the Professorship of Mathematics in the same College. But he completed some official Survey work after the time of his appointment at Leeds.

In 1876 he published a Manual of Physical Geology, a work which has taken a leading place as a textbook for students and teachers in this branch of the science; a third edition was issued in 1883.

For several years Prof. Green held the Lectureship on Geology at the School of Military Engineering at Chatham. In the year 1886 he was elected a Fellow of the Royal Society, and served on its Council in 1894-95. In 1888 he was appointed Professor of Geology at Oxford, as successor to the late Sir Joseph Prestwich. In 1890 he filled the office of President of Section C (Geology) at the British Association, Leeds, and delivered the customary address. Prof. Green also filled the offices of Examiner to the

University of London and Assistant Examiner to the Science and Art Department; he was, moreover, Examiner in Geology to the University of Durham, and latterly for the Home and Indian Civil Service. He had greatly endeared himself to his colleagues, and his death at a comparatively early age has been a great loss to geological science.

By the death of Monsieur AUGUSTE DAUBRÉE, which took place on May 29th, 1896, in Paris, our Society has lost one of its most distinguished Foreign Members. He was born at Metz (Lorraine) on June 25th, 1814. After passing the École Polytechnique he was admitted into the Corps des Mines in 1834, and in 1838 was appointed Ingénieur des Mines in the Bas-Rhin, and Professor of Geology and Mineralogy at the Faculty of Sciences of Strasburg, of which he became Dean in 1852. In 1861 he was (almost unanimously) elected Member of the Academy of Sciences, in succession to Prof. Cordier, whom he also succeeded as Professor of Geology at the Natural History Museum, Paris; he was nominated Inspecteur-Général des Mines in 1867, and Director of the School of Mines in 1872. Prof. Daubrée wrote more than 300 memoirs, chiefly on geological and mineralogical subjects, and on investigations allied thereto, such as the permeability of rocks by water and the effects of such infiltration in producing volcanic phenomena, the relation between thermal waters and the rocks whence they flow, the composition of meteoric masses and their classification in accordance therewith. He was also distinguished for the long-continued and sometimes dangerous experiments which he conducted in order to ascertain to what extent it was possible artificially to imitate the natural production of rocks. Prof. Daubrée had been President of the National Agricultural Society of France, Honorary President of the French Alpine Club, President of the Academy of Sciences, of the Geological, the Geographical, and the Mineralogical Societies of Paris, Honorary Ph.D. of Bologna and of Halle, Foreign Member of the Royal Society of London, of the Mineralogical Society, of the Reale Accademia dei Lincei, of the Academies of Bologna, Boston, Brussels, Copenhagen, Göttingen, Munich, Philadelphia, St. Petersburg, and Turin, of the Scientific Society of Batavia, and of the American Institute of Mining Engineers. He was also a Grand Officer of the Legion of Honour, Grand Cross, Grand Officer and Commander of numerous foreign Orders. Prof. Daubrée was elected a Foreign Member of this

Society in 1867, and to him was awarded the Wollaston Gold Medal in 1880. He was greatly esteemed and honoured by his fellow-workers in science and those who had the privilege of his acquaintance.

Dr. HEINRICH ERNST BEYRICH, who was elected a Foreign Member of this Society in 1876, died on July 9th, 1896. He was born on August 31st, 1815, at Berlin, and received his education at the Greyfriars Gymnasium. He entered the University at the early age of 16, and there he commenced the study of various branches of physical science, and was especially trained by Ch. S. Weiss in mineralogy and geognosy. Already at that time led to see the essential value of palæontology in stratigraphical investigations, he gave himself up to a course of study at Bonn, where, under Goldfuss and Nöggerath, his knowledge was much extended. With the same laudable object in view he undertook during two years long journeys through Germany and France, and in 1837 he obtained his degree of Doctor at Berlin.

Soon after the conclusion of his studies, Beyrich obtained practical employment in the Mineralogical Museum of the Berlin University, and after the death of Weiss in 1857 he was entrusted with the same position as Director of the Palæontological Collection. On the death of Rose in 1875 he became Director of the United Museums, and continued until towards the end of his 80th year to be the leader of this new organization.

Dr. Beyrich also obtained in 1865 the position of Professor of Geology and Palæontology after having already, in 1853, been elected a Member of the Berlin Academy. The particular branches of science dealt with in Dr. Beyrich's works relate principally to palæontology and stratigraphy. His comprehensive knowledge, and especially his intimate acquaintance with the neighbourhoods of the Rhenish mountains, of the Harz mountains, and the Flötz mountains in Silesia, as well as his innumerable studies in Alpine districts, make Dr. Beyrich's opinions in these branches of science most valuable. His great success as a teacher, his wide knowledge, and his power of organization placed him in the foremost rank of German geologists.

Prof. JOSIAH DWIGHT WHITNEY, the well-known American geologist and a Foreign Member of this Society, was born at Northampton, Massachusetts, on November 23rd, 1819. He graduated

at Yale in 1839, and then spent six months in the chemical laboratory of Dr. Robert Hare in Philadelphia. In 1840 he joined the Survey of New Hampshire as assistant geologist under Mr. C. T. Jackson. Two years later he went to Europe, and pursued his studies in chemistry, geology, and mineralogy. On his return to America in 1847 he investigated the geology of the Lake Superior region, being appointed with Mr. J. W. Foster to assist in making a geological survey of that district. Ultimately the completion of the survey was entrusted to Mr. Whitney and Mr. Foster, who published a 'Synopsis of the Explorations of the Geological Corps in the Lake Superior Land District in the Northern Peninsula' (Washington, 1849), and a 'Report on the Geology and Topography of a Portion of the Lake Superior Land District in the State of Michigan' (1850-51). Mr. Whitney then travelled for two years through the States east of the Mississippi for the purpose of collecting information as to the mineral wealth of the country. This led to his book 'The Metallic Wealth of the United States described and compared with that of other Countries' (Philadelphia, 1854). In 1855 he was appointed State Chemist and Professor in the Iowa University, and was associated with Mr. James Hall in the geological survey of that State, of which he published an account. From 1858 to 1860 Prof. Whitney was engaged on a geological survey of the plumbiferous region of the Upper Missouri in connexion with the official surveys of Wisconsin and Illinois, and he wrote in collaboration with Mr. James Hall a 'Report on the Geological Survey of the State of Wisconsin' (Albany, 1862). Prof. Whitney was appointed State Geologist of California in 1860, and conducted a topographical, geological, and natural history survey of that State till 1874, when the State Legislature discontinued the work. Besides various pamphlets and annual reports, Prof. Whitney issued 'Geological Survey of California' (six vols., Cambridge, 1864-70). In 1865 he was appointed Professor of Geology at Harvard University, and retained the chair till his death. The honorary degree of LL.D. was conferred on him by Yale in 1870. Prof. Whitney was one of the original members of the National Academy of Sciences named by Act of Congress in 1863, but he subsequently withdrew from that body. He was a member of a large number of scientific bodies both at home and abroad, and was a contributor to the 'American Journal of Science,' the 'North American Review,' and many other periodicals. He translated Berzelius's 'Use of the Blowpipe' (Boston, 1845), and he wrote a guide-book to the Yosemite Valley

(San Francisco, 1869). It is a significant testimony to his scientific eminence that Mount Whitney, the highest mountain in the United States, is named after him. His library of geological and geographical books is famous in the United States. He was elected a Foreign Correspondent of this Society in 1872, and a Foreign Member in 1887. He died on August 19th, 1896.

Baron CONSTANTIN VON ETTINGSHAUSEN died at Graz on February 1st, 1897, at the age of 71. He was originally a Doctor of Medicine, but devoted all his time and energies to botany and palæontology. In 1876 he was summoned to London to prepare a palæobotanical collection at the Natural History Museum, and subsequently he was repeatedly here re-arranging collections in the Museum. He was the author of several works on botanical subjects, and wrote a large number of papers, which were published in the Proceedings of the Royal Society and of this and other learned Societies. He held, up to the time of his death, the Professorship of Botany in the University of Graz, and was elected a Foreign Correspondent of this Society in 1884. Previously to this, in 1882, an Award from the Barlow-Jameson Fund had been made to him in recognition of the value of his work in palæobotany.

Viscount GOUGH, F.L.S., was born on January 18th, 1815. He was the son of Field-Marshal Hugh Gough, who brilliantly distinguished himself in the field in India and annexed the Panjâb to the British dominions. After graduating B.A. at Trinity College, Dublin, in 1836, and M.A. in 1840, he entered the Army; and after spending some time in the Grenadier Guards he went on active service, and acquitted himself in China with much distinction. He was elected a Fellow of this Society in 1850, was Vice-President of the Royal Dublin Society, and always took an active interest in science. Viscount Gough died at his residence, Booterstown, Co. Dublin, on June 2nd, 1895.

JABEZ CHURCH, M.Inst.C.E., who was elected a Fellow of this Society in 1881, was born at Chelmsford in 1845, and was the son and grandson of well-known engineers bearing the same name. He designed and constructed many important works, chiefly in connexion with the water-supply to large towns. He was for two years in succession (1882 and 1883) President of the Society of

Engineers. Upright and honourable in all his dealings, he was deservedly esteemed both professionally and privately. Mr. Church ed at his residence in Kensington, on March 20th, 1896.

MARSHALL HALL, late Captain in the Royal East Middlesex Militia, J.P. for Wilts, F.C.S., etc., was born in London on February 6th, 1831, and died at Parkstone, Dorset, April 14th, 1896.

As the only child of an eminent physician and physiologist, he was brought up in an atmosphere of science from early days, and it is to this circumstance that his *penchant* for things scientific was in a great measure due. Thus, he was at all times very handy with his microscope, which he found useful both in his chemical and mineralogical investigations. Besides his interest in science, mountaineering and yachting had strong attractions for him, and it was these three factors which largely influenced his career.

No one science could claim his exclusive allegiance; but he evinced an interest in geology when he became a Fellow of the Geological Society in 1866, most probably at the suggestion of his intimate friend, Morris. Shortly after taking this step a brief notice from his pen, in the 'Geological Magazine,' showed that he had already begun to interest himself in the glaciers of Norway, as he claimed to have made a rough survey of ice-tracts at the end of fiords where no yacht had ever been seen before.

Probably the best thing that Marshall Hall ever did for scientific investigation was by organizing the cruise of the 'Norna' in 1870. It is true that on this occasion he was ably seconded by two remarkable men, Saville Kent and Edward Fielding, to the former of whom especially the scientific credit of this most successful essay in marine zoology was due. Still, it was on the initiation, and mainly at the expense, of Marshall Hall that these results were obtained; and they are all the more striking when we remember that this expedition took place three years before the *Challenger* started on her memorable voyage.

A few years afterwards (1874) we find Marshall Hall, still full of enthusiasm, making a proposal in the Geological Magazine for a 'Swiss Geological Ramble'; and he asks the then President of the Geologists' Association (Dr. Woodward) what he would think of this extended excursion. Two years subsequently he was busily engaged, in conjunction with Sorby, Haughton, Heddle, and others, in founding the Mineralogical Society. The first contribution to the Journal of that Society (August, 1876) is a short note written

by himself and Clifton Ward 'Upon a Portion of Basalt from the Mid-Atlantic.'

From time to time he contributed short papers to the Mineralogical Society, not forgetting to suggest collaboration among mineralogists. As he was now for the most part resident in Switzerland, the rocks of the Val d'Anniviers and the Saasthal supplied him with a congenial theme. Here both his chemical knowledge and his climbing propensities were of use. Thus, in 1882 he narrates how he traced certain euphotides and serpentines to an *arête*, some 10,000 feet high, descending from the Allalinhorn, and he compares the rocks thus observed *in situ* with transported masses occurring in the neighbourhood of Veytaux and Geneva.

More recently, and since he came back to England, Marshall Hall returned with renewed ardour to an old love—the study of glaciers. His Alpine experiences helped him here. In this connexion his friend and fellow-worker, Prof. Forel, writes<sup>1</sup> that Hall had often contributed original notes to the reports on glacier-variations issued by himself. Later, in 1891, when living at Parkstone, Marshall Hall continued to follow up this subject with great eagerness, and obtained from the Alpine Club the formation of a committee charged with the care of studying the oscillations of the glaciers in different parts of the British Empire. In 1893 he contributed a short paper to the Geological Magazine on 'Glacier Observations, more especially Colonial,' being the substance of two articles which had already appeared in the Alpine Journal. He was successful also in interesting the Colonial authorities in his scheme. Finally, in 1894, at the International Geological Congress Meeting at Zürich, he initiated the formation of the Commission Internationale des Glaciers, being himself elected representative for Great Britain and the Colonies.

A wide field had in this way been found for the exercise of his energies, and there seemed every prospect that he might continue to do much good work, when, to the great sorrow of his family and numerous friends, he was carried off, after a short illness, at the age of 65, just as his plans for the universal study of glacier-action were beginning to bear fruit.

Marshall Hall is not to be estimated merely by his writings, which, like his speeches, were for the most part exceedingly brief. His strength rather lay in his faculty of bringing men together, and for this purpose his genial disposition and agreeable manners

<sup>1</sup> 'In Memoriam,' Alpine Journal, Aug. 1896, p. 176

eminently qualified him. In the heyday of life he discharged these functions in a generous and hospitable spirit. Unfortunately, as time went on, his physical infirmity of deafness, in conjunction with other causes, tended to withdraw him from society at large, though never from social intercourse. To the last he struggled bravely against all these difficulties, frequently busy, but, as he says in a letter written a few months before his death, grown older and less inclined to work. 'Not that I am often idle,' he remarks; 'things come in all of a heap, then comparative repose, then more work. There will not be much to show for sundry years, even if I get folks to do anything systematic. So far, the New Zealanders are my best men.'

Those sundry years he was not destined to realize, and now that the originator is gone will the work be continued?

[W. H. H.]

WILLIAM SHARP, M.D., F.R.S., who was elected a Fellow of this Society in 1840, was born on January 21st, 1805, at Armley, in the parish of Leeds, where, and at Little Horton and Bradford, his family had resided for several centuries. In 1821 his uncle, William Sharp, the leading surgeon in Bradford, took him as a pupil, and subsequently, in 1825, he was taken as pupil by the second William Key of Leeds, his uncle's cousin, and remained with him until Oct. 1st, when his hospital career commenced in London at Guy's and St. Thomas's Hospitals, where Sir Astley Cooper was chief. In 1826 he obtained from the Society of Apothecaries his licence to practise, at that time the only legal qualification. Remaining at the hospitals another year, he obtained the diploma of the Royal College of Surgeons; this was in 1827. He then went to Paris and attended the University lectures at the Sorbonne. In 1828 he returned to Bradford as his uncle's assistant; in 1829 he was elected Surgeon to the Infirmary; in 1833, on his uncle's death, he succeeded him and had a large practice. In 1843 he resigned his practice and went to Hull, where he gave lectures on chemistry during the winters; but four years later he removed to Rugby for the purpose of placing his sons under Dr. (afterwards Archbishop) Tait, then headmaster of Rugby. Finding that natural science had no place in the teaching at Rugby, he urged its introduction on Dr. Tait. The latter was quite willing to make the experiment, provided Dr. Sharp would become the first teacher, and, under the style of 'Reader in Natural Philosophy,' Dr. Sharp conducted the classes during 1849 and 1850. 'If,' said the late

Judge Hughes, 'Tait had done nothing else at Rugby than appointing Sharp, not without difficulty, as Reader in Natural Philosophy, he would have deserved the gratitude of every Rugby man.' Dr. Sharp was also one of the early supporters of the establishment of local museums, and read a paper on the subject before the British Association in 1839. His more important writings were on the various schools of medicine, and appeared at intervals under the title of 'Essays in Medicine.' He died in April 1896.

HENRY JAMES SLACK, F.R.M.S., who was elected a Fellow of this Society in 1849, was born on October 23rd, 1818, and died on June 16th, 1896. He was educated at Dr. Evans's School, North End, Hampstead, and at the age of seventeen he entered a wool-broker's office in the City, in which he speedily became a partner, but he retired in 1846, finding the business uncongenial to his literary and scientific inclinations. He then devoted himself to legal and forensic studies, and was in due course 'called'; but, although a keen debater and intensely fond of either a scientific or political discussion, he never practised at the bar.

Among his numerous scientific papers three only bear directly on geology, namely: 'On Cocoliths and Cocospheres in Reigate Sandstone'; 'Notes on the Comparative Geology of the Earth and Moon'; and 'Life-Changes on the Globe.' Of the Royal Microscopical Society he may be said to have been one of the founders, and he filled in succession the offices of Secretary and of President. His scientific papers mostly appeared in the 'Intellectual Observer' and 'Student,' and bear chiefly upon microscopical research. Some of his work on Infusoria was published in a small book entitled 'Marvels of Pond Life,' which passed through three editions.

THOMAS CARRINGTON, M.Inst.C.E., born on October 5th, 1841, was the eldest son of the late Thomas Carrington, J.P., of Holywell House, Chesterfield. After studying for three years under Dr. Ashby, with the view of obtaining a thorough knowledge of chemical analysis, he was articled in 1859 to Mr. G. T. Woodhouse, who was in practice as a civil and mining engineer at Derby and in Westminster. In 1873 he was appointed by the Home Office one of the three examiners, in the Yorkshire district, of candidates for certificates of competency as managers of mines. Mr. Carrington was one of the most prominent mining engineers in the Midlands,

having been engaged for thirty years as umpire, arbitrator, or otherwise in disputes between railway- and canal-companies and colliery-owners, and his ability and sound judgment in highly technical cases were widely recognized. He was specially retained by the Midland Railway Company to advise on questions relating to its large mineral traffic. He was elected a Fellow of this Society in 1864, and died on June 27th, 1896.

RICHARD NICHOLAS WORTH was elected a Fellow of the Society in 1875. He wrote much on the geology of Devonshire, particularly the neighbourhood of Plymouth, and was one of the most active and respected members of the Devonshire Association for the Advancement of Science, Literature, and Art, and was always most ready to render assistance to those who desired to study the districts with which he was familiar. His first paper appears to have been published in vol. v. Trans. Devon. Assoc. 1872, and in the Royal Society Catalogue of Scientific Papers fourteen appear under his name up to 1883. The Quarterly Journal of the Geological Society for 1876 contains a paper by him 'On certain Alluvial Deposits associated with the Plymouth Limestone.' Another in 1886 'On the Evidence of a Submarine Triassic Outlier in the English Channel off the Lizard,' and in 1889 'On the Elvans and Volcanic Rocks of Dartmoor.' He was a voluminous writer on archæological subjects connected with the county of Devon, and wrote several guide-books which have had a large circulation.

Mr. Worth died on July 3rd, 1896.

ELIAS DORNING, M.Inst.C.E., born on January 25th, 1819, was articled to the late Mr. William Benson, of Bury, in 1836. After serving a pupilage of five years, he was engaged from 1841 to 1843 as resident engineer on the Bury Waterworks. Mr. Dorning then commenced to practise on his own account in Manchester as a civil and mining engineer, surveyor, and land agent. As a consulting engineer Mr. Dorning acted for the Earl of Derby, the Earl of Sefton, the Earl of Wilton, and many other landowners in the North. He was standing arbitrator for the Corporation of Manchester. He was elected a Fellow of this Society in 1867, and died on July 18th, 1896.

By the death of Baron FERDINAND VON MÜLLER, who was elected a Fellow of this Society in 1882, Australia has lost one of her

greatest scientific men, and the world in general a great botanist. Ferdinand von Müller was born at Rostock in 1825, and was educated for the medical profession at Schleswig and Kiel. He early manifested a keen love of botany, and as soon as he had taken his M.D. degree he made an exhaustive study of the flora of Schleswig-Holstein, and became an active member of the German Association for the Advancement of Science. Being threatened with phthisis, he sought a more genial climate, and went to South Australia in 1847. He made expeditions into the interior and prosecuted botanical researches, especially into the mountain flora. He then acted as botanist to the Gregory explorations in search of Dr. Leichardt, returning from them loaded with botanical specimens. He was then appointed director of the Melbourne Botanical Gardens, a position which he retained until 1873, when he became Government botanist, and devoted himself for the rest of his life entirely to scientific work, producing a number of valuable treatises on botanical subjects which gained him a world-wide reputation. The best known of these are 'Fragmenta Phytographiæ,' 'Flora Australiensis,' and 'Plants of Victoria.' His 'Select Extra-tropical Plants' is a unique work of its kind, cataloguing plants suitable for culture in the southern part of Australia, with indications of their uses. Altogether he published no less than forty volumes in English, German, and Latin. When the International Geographical Congress assembled in Vienna, five special votes of thanks were awarded to men who had rendered exceptional services to science, and F. von Müller was one of the five. In 1861 he was elected a Fellow of the Royal Society. In 1891 he was created an hereditary baron by the King of Würtemberg and a Commander of the Order of St. James of Portugal, and was afterwards made a Knight of the Order of SS. Michael and George by Her Majesty the Queen. He was a member of 150 learned societies in Europe and America, President of the Australasian Association for the Advancement of Science in 1890, and President of the Section of Pharmacology at the second Meeting of the Intercolonial Medical Congress of Australasia in 1889. He was the first to describe scientifically the Eucalypti, of which he discovered thirty varieties, and proclaimed their hygienic and therapeutic properties, disseminating their seeds over the malarious districts of Europe. The Baron never married, and lived a very simple frugal life, spending the whole of his income on his scientific pursuits. His whole-souled devotion to his favourite study and his indefatigable industry and inexhaustible patience

were almost unique, and he combined in a remarkable manner the thoroughness of the German with the practical good sense of the English man of science: while his contributions to knowledge were of the highest value as pure science, they were also of great economic importance and helped to open up avenues of wealth to many of his fellow-colonists.

He died on October 9th, 1896.

DAVID ROBERTSON, the well-known Cumbrae naturalist, died at Millport on November 20th, 1896, at the age of 90. He was a native of Glasgow, but for the last 40 years he lived at Millport, and devoted his attention to the study of natural history with so much success that in knowledge of the fauna of the West of Scotland he was not surpassed by any other naturalist. His collection of specimens was very extensive and, indeed, unique. He worked for long in a floating marine station called *The Ark*. In company with Dr. John Murray, of the *Challenger* expedition, he dredged the greater part of the Firth of Clyde for marine specimens. Mainly through Dr. Robertson's efforts the foundation-stone of a permanent marine station was lately laid. Two years ago the University of Glasgow conferred on him the degree of LL.D. He also held several foreign diplomas. He was elected a Fellow of this Society in 1877.

WILLIAM ARMSTRONG, who was elected a Fellow of the Society in 1866, died at the ripe age of 84, on Nov. 3rd, 1896, at Pelaw House, near Chester-le-Street. He was perhaps the best known and most experienced mining engineer in the North of England, and throughout Northumberland and Durham, where the chief work of his life was done, he was known as the Father of the coal-trade. Born in 1812, he was educated at Dr. Bruce's academy, Newcastle-on-Tyne, and at Edinburgh University. He served his time with Mr. Nicholas Wood, at Killingworth, Northumberland, and quickly took a place in the first rank of the able body of mining engineers whose work it was to open up and develop the coalfields of Northumberland and Durham. He first came prominently into public notice in connexion with the hard-fought strike of 1843, known as the 'wire-rope strike,' when he practically fought for and won the introduction of wire ropes into England for mining purposes.

The Rev. WILLIAM GOVER died on Nov. 16th, 1896, at his residence in Brighton, in his 79th year. He was formerly a scholar of Corpus

Christi College, Cambridge, and took his B.A. degree in 1841, proceeding M.A. in 1845. He was ordained, in the diocese of Worcester, deacon in 1843 and priest in 1844. He held curacies in Birmingham, at St. Andrew's, Holborn, and at St. Pancras, and was for a time chaplain to the late Lord Annesley. In 1852 he became Principal of the Worcester, Lichfield, and Hereford Training College at Saltley, a post which he held till 1871. In 1867 he was appointed honorary canon of Worcester Cathedral.

He was elected a Fellow of this Society in 1866, and though he does not appear to have written much on geology, those who were acquainted with him know that he was keenly interested in the science.

WILLIAM FARNWORTH died at his residence, the Manor House, Sedgley, at the end of January 1897. He had been for many years connected with the coal and iron trades of the Midland district, where he was widely known. He was elected a Fellow of this Society in 1885.

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ON SOME RECENT EVIDENCE BEARING ON THE GEOLOGICAL AND BIOLOGICAL HISTORY OF EARLY CAMBRIAN AND PRE-CAMBRIAN TIMES.

It is now fully admitted that a very great and important advance in our knowledge of the conditions prevailing in early Cambrian and pre-Cambrian times has been made during comparatively recent years. Therefore it may be well occasionally, not only to summarize the results arrived at, but also to call to mind how and by what means these additions to our knowledge have been obtained. In doing so, also, we may hope to awaken a desire to attack those problems which still remain unsolved and to stimulate the desire for further discoveries. I have limited the period for consideration to the past 30 years, as there is in the fourth edition of 'Siluria,' published in 1867, p. 22, a very clear statement of our knowledge and the prevailing views held at that time concerning the pre-Cambrian and Cambrian rocks and the early life-history of our globe.

Summaries of special work done amongst the early Cambrian and pre-Cambrian rocks have appeared from time to time in the addresses delivered from this chair; but it has occurred to me that

a fairly connected history of the main results which have been obtained during an extended period might not be altogether unacceptable to the Fellows of the Society.

After describing the structure and order of the rocks in various areas, Sir R. Murchison in the edition quoted proceeds to say:—  
‘ Observation has now taught us of what materials the fundamental rocks of different countries consist. In Scandinavia, particularly in the central and northern parts of Norway, there is every reason to believe that, as in British North America, Bohemia, and the North-west of Scotland, crystalline rocks of Laurentian age underlie all the deposits to which the terms Cambrian and Silurian can be applied. In Bohemia, however, as in Great Britain and portions of North America, the lowest zone containing Silurian remains (“Zone primordiale” of Barrande) is underlain by very thick basements of earlier sedimentary accumulations of Cambrian age, whether sandstone, schist, or slate, which, though occasionally not more crystalline than the fossiliferous beds above them, have as yet afforded only rare indications of former beings. This is the important fact to which attention is now directed; for in such instances the geologist appeals to strata which have undergone little or no alteration. In this enormous pile or series of early subaqueous sediment, composed of mud, sand, or pebbles, the successive bottoms or shores of a former sea, all of which had been derived from pre-existing rocks, he has been unable, after many years of research, to detect more than a very few traces of former creatures. But lying upon them, and therefore evolved after them, other strata succeed, in which clear relics of a primeval ocean are discernible; whilst these again are everywhere succeeded by deposits containing many organic remains of a more advanced nature. In this way, evidences have been fairly obtained to show that the rocks bearing the name of Laurentian and Cambrian constitute the sterile natural bases of the rich deposits termed Silurian.’

It will of course be understood that the term Cambrian was restricted by Sir R. Murchison to the rocks which were older than the *Lingula*-Flags, including the Menevian beds, in which Salter and myself had previously discovered a very rich fauna in Wales. The actual line of division which was adopted in the colouring of the Survey maps was first traced out at St. David’s by Sir A. Ramsay in 1841, who refers to the fact in vol. iii. Mem. Geol. Surv. (1866) p. 7, as follows:—‘ In the same year, at St. David’s, I traced a provisional line between the black and the

purple slates, and this was afterwards adopted as the line between the Silurian and Cambrian strata.'

The Longmynd Rocks up to a comparatively recent period were always included in the Cambrian, but of late years the tendency has been to associate them with the pre-Cambrian. If they can be proved to be without doubt of pre-Cambrian age, unusual interest will be attached to them owing to the fact that many years ago Mr. Salter found in them burrows of annelids which he described under the name of *Arenicolites didyma*, and also what he considered to be a part of a trilobite under the name of *Palæopyge Ramsayi*.

### The Cambrian Period.

It had been shown by Salter and myself before the year 1867 that a very rich fauna occurred in the Menevian beds, which rested directly on the red, purple, and green grits and slates, in North and South Wales; but up to that year no organisms had been found in the latter, the only rocks recognized as Cambrian by Sir R. Murchison and the Geological Survey. Curiously, however, in that year I found in the red rocks underlying the Menevian beds at St. David's a small *Lingula*, and this was described in a paper by Mr. Salter and myself at a meeting of the Geological Society on June 19th, 1867, and fortunately in time for Sir R. Murchison to add the following note in the Appendix (p. 550) to the edition of 'Siluria' which contained the statement already referred to:—'At the meeting of the Geological Society on June 19th, 1867, Mr. J. W. Salter read an account of the discovery of a minute *Lingulella* in the red Cambrian rocks of St. David's, which there underlie the Primordial Silurian (*mihi*). According to my view (and I am entitled to judge by acquaintance with both districts), the rocks in which this small fossil was found may be paralleled in age with the uppermost or red portion of my original Cambrian of the Longmynd (1835).'

This was the first admission on the part of the Geological Survey that 'Cambrian' rocks, or those classed by them under that name in Wales, contained any evidence of the life of that period. In subsequent years I was able to show that the whole of the rocks coloured as unaltered Cambrian at St. David's to their very base contained fossils, and that the seas in which the deposits had accumulated must have teemed with life. Since then, through the researches of Dr. Callaway and Prof. Lapworth in Shropshire, and of the officers of the Geological Survey in the North-west of Scotland,

we have obtained evidences of most interesting Lower Cambrian faunas from those areas. During the whole time when the Lower Cambrian rocks were deposited it is quite evident that the general conditions were favourable to marine life; but as the deposits must have accumulated with comparative rapidity and in fairly shallow water, there are few calcareous zones, and the range of typical fossils is often great. The close of the pre-Cambrian period was undoubtedly accompanied by great physical changes, which produced very uneven land-surfaces, and the encroachment of the sea over the land was therefore necessarily interrupted and irregular. This also would in part account for the unusual range of some of the organisms, for those which hugged the shores would still remain in some areas while deeper-water forms might be almost close at hand. When it is remembered also that the pre-Cambrian land contained an unusual amount of loose and easily disintegrated volcanic material, which would be carried by streams or rivers into narrow bays, the cause of rapid accumulation becomes easily understood. In the Lower Cambrian rocks hundreds of feet of sandstones and grits constantly occur, with only here and there very thin seams of muddy deposits. The beds also are so often ripple-marked that it is clear that the depression did little more than keep pace with the accumulation. When finer sediments occur, and there are signs of a pause in the deposition, fossils are usually found in fair abundance and with evidence of fresh arrivals on the scene.

All this is proof to my mind of the incoming of forms from adjoining marine areas more suitable to their development than these constantly changing shores, where the accumulation of materials was going on so rapidly. Though we count our Cambrian deposits by thousands of feet, no one will venture, when he knows the full circumstances under which they were accumulated, to say that the majority of the animal forms now classed as characteristic of that period were not equally so of much of the pre-Cambrian period.

We may now fairly ask why it is that the pre-Cambrian rocks do not contain evidences of the earlier faunas. This question would have been much more difficult to answer a few years ago than at present. Then all, or nearly all, pre-Cambrian rocks were looked upon as metamorphosed sediments. Now all agree that the pre-Cambrian rocks with which we are acquainted are mainly of igneous origin—either intrusive or extrusive igneous rocks. And the comparatively few rocks of sedimentary origin

associated with them have been in most cases so profoundly altered, and furnish also evidence of having been deposited in areas so greatly disturbed, that it would hardly be possible to conceive circumstances less favourable to the presence or the retention of any remnants of the life of the period. When we all believed that the 20,000 or 30,000 feet tabled as the estimate of the thickness of the Laurentian rocks was a sign of the accumulation in marine areas of sediments of that thickness, it certainly seemed strange to any one who believed in evolution that no clear and undisputed evidence of the life of the era had been discovered anywhere. It seemed difficult to conceive that the great marine areas of the time could be devoid of life; for the teachings of Nature are clear enough in showing that, where the circumstances are in any way suitable, life in some form is sure to exist. There seems to be plenty of evidence to show that the sea, in late pre-Cambrian times at least, could not have varied materially in its temperature from that prevailing in Cambrian time; therefore we are led to believe that there must have been an abundance of life in the sea where there were no markedly disturbing influences at work. Why, then, is it that after so many years of diligent search we have still so poor a record of the life of the era? I think that a careful examination of the materials of which the pre-Cambrian rocks are composed, and of the contents of the Cambrian conglomerates, tends to show that, up to the present, we have not succeeded in meeting in any area with sediments which give sure indications of having been deposited under conditions favourable to animal life. In the grits and sandstones, both *in situ* and when found as fragments in the conglomerates, there are indications of worm-tubes and tracks, as in later rocks. But finer deposits and calcareous beds are so rare that we are compelled to believe that we are almost everywhere dealing with shore- and shallow-water deposits accumulating in highly-disturbed areas subject to frequent volcanic outbursts.

This question has greatly interested me since the time when we discovered that the pre-Cambrian rocks at St. David's were mainly of volcanic origin. When we first assumed that there was an important series of rocks at St. David's older than the basal Cambrian conglomerates, we believed that they were mainly ordinary sediments that had been greatly metamorphosed, following in this view the usual opinion held by petrologists and geologists at that time. In the year 1877, however, I communicated a paper to this Society in which evidence was given to show

that the majority of the pre-Cambrian rocks at St. David's were of volcanic origin; and petrological notes in confirmation of this view were added by Mr. T. Davies, Prof. Bonney, and Prof. Judd. In working out these conclusions I was also greatly assisted by Prof. Hughes, Mr. Hudleston, and the late Mr. Tawney. Up to this time the oldest volcanic rocks anywhere found in Britain were supposed to be of Lower Silurian age; and Sir A. Ramsay, in his Presidential Address to the British Association in 1880, so far from even then accepting our views, stated that 'the oldest volcanic products' of which he had any personal knowledge were of 'Lower Silurian age.' (Swansea Meeting, p. 7.)

Since that time, in several areas in Britain, it has been shown that the pre-Cambrian rocks are mainly made up of igneous materials, and even the so-called Laurentian rocks of the North-west Highlands of Scotland are now known to contain but few beds which can in any way be claimed as having had a sedimentary origin, as explained in the following quotation from Sir A. Geikie's Address delivered before this Society in the year 1891:—

'With the possible exception of a strip of ground in the Gairloch district—which includes graphite-schist, garnetiferous mica-schist, limestone, and a few other remarkable rocks—no portion of the fundamental gneiss has anywhere yielded a trace of materials that can be supposed to be of sedimentary origin. Everywhere the rock is thoroughly crystalline, and presents no structure that in any way suggests an alteration of elastic constituents. Here and there it can be traced into bands and bosses which, being either non-foliated or foliated only in a slight degree, present the ordinary characters of true eruptive masses. In Sutherland and Ross-shire these amorphous patches occur abundantly. Their external margins are not well defined, and they pass insensibly into the ordinary gneiss, the dark basic massive rocks shading off into the coarse basic gneisses, and the pegmatites of quartz and felspar which traverse them merging into bands of grey quartzose gneiss.

'So far, therefore, as present knowledge goes, the Lewisian gneiss of the North-west Highlands of Scotland was originally a mass of various eruptive rocks. It has subsequently undergone a succession of deformations from enormous stresses within the terrestrial crust, which have been investigated with great care by my colleagues of the Geological Survey.'<sup>1</sup>

<sup>1</sup> Quart. Journ. Geol. Soc. vol. xlvii. *Proc.* 68.

### The pre-Cambrian Era.

Since, therefore, the rocks of pre-Cambrian age which are exposed to view are either of igneous origin or so much changed that their origin is doubtful, it seemed to me that valuable evidence bearing on the pre-Cambrian era might be obtained by tabulating with care all the fragments of rocks which had been found in the Cambrian conglomerates in the several areas; and in the year 1890 I read a paper at the meeting of the British Association, giving the results which I had obtained up to that time. In each area it was found that fragments derived from igneous rocks occurred in considerable abundance, and it was clear that intrusive rocks of acid and basic character, lavas, and volcanic tuffs were near at hand when the Cambrian conglomerates were deposited. Quartzites and grits, such as would be derived from the destruction of granitic rocks, were also found to be abundant; but the hornstones and porcellanites, which are mainly made up of fine volcanic dust, occur very frequently in some areas, while clay-slates and calcareous fragments were comparatively rare—showing, as I have already stated, that in these pre-Cambrian areas we can hardly expect to meet with rocks which could have been deposited under conditions favourable to life.

It may now be useful to give short descriptions of the pre-Cambrian rocks found in the different areas in Britain, with lists of the fragments which have been obtained from the Cambrian conglomerates which repose upon them, or which are found in their immediate neighbourhood; for, in addition to the testimony which they furnish regarding the nature of the rocks of the pre-Cambrian era, it will be seen in a very marked manner how little change has taken place in them since the commencement of Cambrian time, when the fragments were broken off.

#### *Pembrokeshire.*

I have already referred to the fact that it was in this county that we first obtained clear evidence of pre-Cambrian volcanic rocks, and it is here perhaps that most care has been taken in defining the fragments obtained from the Cambrian conglomerates. In the slides of rocks near St. David's submitted by me in 1884 to Mr. T. Davies he detected pebbles of a granite consisting of dirty quartz with two feldspars, quartz both dirty and clear and individual feldspars both orthoclase and plagioclase, pebbles of felsite, quartz-felsite, quartz-schist, quartzite, basic igneous rocks, porcellanite, and mica much altered. In referring to the fragments of granite

he says:—‘The view that the Cambrian conglomerate at St. David’s encloses much waterworn débris of the Dimetian [*i. e.* the granite of St. David’s] is, I think, fully justified by the evidence now adduced from the examination of many slides of this rock, few of which have failed to afford evidence of the presence, not only of pebbles of a rock which under the microscope could not be distinguished from it, but also of its individual mineral constituents. The slides examined and described here are not selected ones, but have been taken as they were cut.’<sup>1</sup>

In 1886 Prof. Bonney kindly examined many slides submitted by me to him, prepared from Cambrian conglomerates obtained from different areas in Pembrokeshire, and at p. 362, *Quart. Journ. Geol. Soc.* vol. xlii. he says:—

‘A. When the Chanter’s Seat conglomerate was formed the following rocks were undergoing denudation:—

‘(1) Granitoid rocks, identical with the existing Dimetian.

‘(2) Trachytic rocks, among which were probably true lavafloes.

‘(3) Quartzites and schists, the latter resembling those which in many districts occur rather high in the Archæan series.

‘(4) Ordinary sedimentary rocks.

‘Hence there was in this district a series of rocks, some much older than others, which contributed to the formation of the Cambrian conglomerate.

‘B. The conglomerate above the Trefgarn series is formed from rocks which occur in the latter.

‘C. The peculiar characteristics distinctive of certain members of the Trefgarn series had been assumed by them when the conglomerate was formed.

‘D. Either the Dimetian is a member of an old gneissoid series or, if it is the core of a volcanic group from which the trachytic lavas had been ejected, this had been laid bare by denudation before the Cambrian conglomerate was formed. Hence in either case both the Dimetian and the felstones are pre-Cambrian.’

These notes by Mr. T. Davies and Prof. Bonney enable us to realize with fair accuracy what rocks composed the pre-Cambrian land in Pembrokeshire when the oldest of the Cambrian rocks in that area were deposited. Of course it is possible that there were other rocks in the area than those hitherto found as fragments in the conglomerates, but we have in these lists all such as would

<sup>1</sup> *Quart. Journ. Geol. Soc.* vol. xl. (1884) p. 555.

be doubtless fairly representative of the majority. Moreover, an examination of the pre-Cambrian rocks which are now found exposed tends strongly to the same conclusion. There was in Pembrokeshire a typical volcanic group which had undergone a considerable amount of structural change in pre-Cambrian times, and before any of the fragments in the Cambrian conglomerates had been broken off. Crushings and cleavage had produced brecciated and schistose structures, and along many fractured lines intrusions of basic and acid rocks had taken place. There seems to be evidence also that the volcanic outbursts broke through a floor mainly composed of granitic rocks associated probably with crystalline schists, for in the lowest of the agglomerates fragments of such rocks occur in association with pieces of lava showing definite flow-structure, which appear as if they had been torn off during the explosions. Though basic and acid fragments occur in the lowest agglomerates, the latter certainly are greatly in excess, and the immediately succeeding flows and breccias are mainly of an acid character. Higher in the series the basic rocks predominate, but there again some acid flows are intercalated with them. The more acid rocks therefore are, as I formerly suggested, if we take them as a whole, the oldest igneous rocks in Pembrokeshire. The oldest sediments also, the porcellanites, occur in association with these lavas and breccias, and they are clearly made up of stratified volcanic dust of an acid character.

Higher up there are slaty and schistose beds which are largely composed of basic dust. The slates are purplish and greenish, and it is in these that I found traces of worm-tubes and tracks. They occur in narrow bands interstratified with ashes and breccias. I have hitherto searched them in vain for traces of other fossils, and it seems to me that the conditions under which they must have been deposited were very unfavourable to the existence of organisms other than burrowing forms. The break between the Cambrian and the pre-Cambrian in Pembrokeshire is a most important one, and, in my opinion, there can be no doubt that a great lapse of time took place between the deposition of the highest of the pre-Cambrian beds and the lowest of the Cambrian.

The pre-Cambrian rocks had been raised to form dry land, had suffered from the effects of great earth-movements with accompanying structural changes in the rocks, had been exposed to sub-aerial influences, including probably that of ice-action, which assisted the process of disintegration, and had been scored by valleys and

channels before the Lowest Cambrian conglomerates had been deposited.<sup>1</sup> There must have been also an enormous amount of loose material on the land to yield the great thickness of Cambrian rocks which accumulated as the shore was being depressed. The petrological descriptions given by Mr. Davies, in the Quarterly Journal of this Society, of the volcanic group (Pebidian) as it occurs in Pembrokeshire were at the time unusually important, for until then no one had suggested that lava-flows and other volcanic rocks of so great an age occurred anywhere in Britain, and in his remarks on the fragments of rhyolite in the agglomerates he says, p. 166, vol. xxxiv. (1878):—‘. . . the whole structure of the rock, in the fluidal arrangement of the spherules, etc., is so like that of a rhyolite that it is difficult to believe that we have not before us one at least of the many interesting varieties afforded by this group. One may say with Zirkel, it is a rhyolite petrographically but not geologically.’ He also calls especial attention, at p. 164, to the difference between the incipient spherulitic arrangement in the quartz-porphyrines containing the bipyramidal quartz, which occur as dykes in the granitoid rocks and in the Pebidian, and the spherulitic structure of the rhyolites. He says that the latter often ‘weathers cream-white, the spherulitic structure when present being then perfectly exhibited on the surface. On freshly-fractured surfaces, however, it is not to be detected, even with the aid of a lens, and the very large spherules, so prominent in the weathered specimens, present but faint indications of their presence. Seen in thin sections under the microscope, however, the structure is at once recognizable, the whole mass appearing to consist of spherules, frequently arranged in well-marked bands of varying dimensions, and also confusedly grouped without any apparent arrangement.’

The dykes of quartz-porphyrine which cut through the granitoid rocks and the Lower beds of the Pebidian, but which never have been seen to penetrate the Cambrian rocks, are also interesting. They are evidently of pre-Cambrian age, and have yielded fragments to the Cambrian conglomerates. Prof. Judd, who was the first to describe specimens of these rocks for me in the year 1877, says:—‘The rock presents the most remarkable identity of character with the gold-bearing quartz-porphyrine of Cstatye, near Vöröspatak, in Transylvania, which is an eruptive rock of Neogene age. It is probably the oldest quartz-porphyrine yet noticed.’<sup>2</sup>

<sup>1</sup> See Hicks, ‘Pre-Cambrian Volcanoes and Glaciers,’ Geol. Mag. 1880, p. 488.

<sup>2</sup> Quart. Journ. Geol. Soc. vol. xxxiii. p. 236.

Were it possible to obtain evidence of the forms of life which existed when the earlier pre-Cambrian rocks were deposited, it is probable that they would differ materially from those which appeared on the scene when the Cambrian seas encroached upon this land. In time we shall doubtless meet with better evidence of the faunas of the pre-Cambrian seas than we have hitherto obtained; but I fear that it must be from areas which were less subject to volcanic and other disturbances in pre-Cambrian times than these Pembrokeshire districts.

*Caernarvonshire.*

At the same meeting of the Society (Dec. 5th, 1877) as that at which the volcanic rocks of pre-Cambrian age in Pembrokeshire were described by me, I communicated a paper on some pre-Cambrian rocks in Caernarvonshire which had been examined by Prof. Hughes, Mr. Hudleston, Mr. Homfray, and myself in the previous summer. As in the St. David's paper, I was indebted to Mr. T. Davies for very valuable petrological notes. Prof. Hughes also, in a separate paper,<sup>1</sup> gave a description of the pre-Cambrian rocks near Bangor and Caernarvon which was accompanied by petrological notes from Prof. Bonney. In these papers it was shown that the majority of the pre-Cambrian rocks of that area were either granitoid rocks, quartz-felsites, or other rocks of igneous origin, and that the Cambrian conglomerates which rested upon them were mainly derived from such rocks. At p. 151 I stated that in the 'great area of pre-Cambrian rocks extending through the heart of Caernarvonshire from below Tal-y-sarn on the south to St. Anne's Chapel near Bethesda on the north, along with another area near Caernarvon and Bangor described by Prof. Hughes, are undoubtedly portions still remaining of the old pre-Cambrian land; and in them, I believe, are to be recognized representatives of the two great unconformable series, Dimetian and Pebidian, so well shown at St. David's. With the former of these I would associate the so-called syenitic ridge (granitoid rock) at Caernarvon; and with the latter the altered beds<sup>2</sup> which rest directly on the syenitic ridge towards Bangor, and the series chiefly described in this paper to the south and north of Llyn Padarn and Moel Tryfaen. The prevailing characters in this last series indicate the metamorphism of a pre-Cambrian volcanic group of ashes and breccias rather than of true sedimentary beds, the result of denudation and alteration only.'

<sup>1</sup> Quart. Journ. Geol. Soc. vol. xxxiv. (1878) p. 137.

<sup>2</sup> Now considered to be mainly devitrified rhyolites.

Prof. Hughes, in speaking of the volcanic rocks near Bangor, says (*op. cit.*, p. 141):—‘This series can be matched almost bed for bed among the green slates and porphyries of the Lake District, and, like these, may be referred to an original volcanic origin and some subsequent metamorphism; but they do not present a sequence like the lowest part of the Cambrian, among which we find no beds that could by any process be changed into the alternating agglomerates and ashes of the Bangor volcanic series.’ In conclusion he says (p. 144):—‘On the whole, then, it seems that we have an old volcanic series of remarkably persistent character in North and South Wales (and probably we shall find, beyond the borders, that subdivisions can be made out in it, though as yet no break has been proved in the series), and that the base of the Cambrian consists of a strong conglomerate and grit, between which and the underlying series there is great probability of an unconformity.’

In his important paper (*Quart. Journ. Geol. Soc.* vol. xxxv. 1879) Prof. Bonney, after pointing out that the quartz-felsites of Llyn Padarn and Bangor exhibited every indication of an igneous origin, says (p. 319), ‘We must then refuse to these Caernarvonshire porphyries an origin different from that of other igneous rocks of similar composition, and cease to quote them as examples of what extreme metamorphism can effect,’ and ‘there is no difference of any importance, so far as I can see, between these quartz-felsites and comparatively modern rhyolites; and if I could prove that a base still remained undevitrified I would give them the latter name. That they were rhyolites in pre-Cambrian times I have no doubt.’ Some geologists have since then endeavoured to show that these rocks are of Cambrian instead of pre-Cambrian age; but the further evidence brought forward in papers by Prof. Bonney and Miss Raisin shows, I think, conclusively that they form a part of the pre-Cambrian volcanic series in Caernarvonshire, as first suggested by Prof. Hughes and myself.

In the year 1878, accompanied by Prof. Torell, Mr. Tawney, Prof. M<sup>c</sup>K. Hughes, and Dr. Sterry Hunt, I examined several other areas in Caernarvonshire, and the results were communicated to the Geological Society on Feb. 5th, 1879, an appendix on the microscopic structure of some of the rocks being added by Prof. Bonney. Of many of the rocks there referred to we spoke with some caution, and I must admit that some of these have since been shown to be of later date, while others are still of doubtful age; but those referred to as occurring in the neighbourhood of Glynllifon and

Craig-y-dinas, and described as breccias and felspathic schistose rocks, etc., are undoubtedly of pre-Cambrian age, as are also the majority of the schistose rocks in the Lleyn Promontory.<sup>1</sup>

As illustrating the general conclusions arrived at by us at that time, I will venture to quote the following remarks which occur in the paper above referred to (Quart. Journ. Geol. Soc. vol. xxxv. p. 300):—‘This condition of faulting along one side of these old rocks, with the entire loss of the succeeding groups, is such a frequent occurrence that it seems necessary to refer specially to the physical conditions or probable causes which produced this effect. One thing which has become particularly evident during our researches is the fact that all bits of pre-Cambrian rocks which have been included in succeeding sediments must have been not only in an indurated condition when broken off from the parent rocks, but, moreover, that they had even then undergone metamorphism, and the more slaty ones a species of cleavage. The lowest Cambrian rocks found are made up of bits and pebbles of these rocks, and so like are they frequently to the solid rocks below that there can be no doubt that they were the beach-pebbles when those old rocks formed coast-lines. Now these old rocks must have undergone gradual depression to receive the subsequent sediments; and as this depression could not take place in rigid or metamorphosed rocks without producing fractures, we have at once one cause for some of the faults, and reasons for coast-lines continuing for a considerable period in some cases, whilst the surrounding areas were becoming depressed to a great depth. The greatest faults, however, and those which we have most frequently to deal with, are those which occurred after the succeeding Cambrian and Silurian sediments were deposited. During the great contractions of the crust in Palæozoic time, especially towards its close, the rigid pre-Cambrian crust could not fold, enormous fractures would take place instead, and the overlying rocks would be thrown down. In some cases, as found here and at other places, the pre-Cambrian would be brought to the surface along one edge of the fracture, and its other edge would be depressed to a great depth. The fault in Ramsey Island, at St. David’s, has a downthrow of over 16,000 feet, and I think the one here can hardly be less—that is, if the usual sediments found in other areas in Caernarvonshire were ever deposited here, and there seems no reason to suppose that they were not.

<sup>1</sup> See Miss Raisin’s paper, Quart. Journ. Geol. Soc. vol. xlix. (1893) pp. 160, 163.

‘According to this view beds belonging to many different horizons in geological succession would now appear on the surface faulted against the pre-Cambrian rocks ; and this it is that occurs wherever they can be examined. I have found beds occupying every position from the lowest Cambrian to the Bala Beds in direct contact with the pre-Cambrian rocks as the result of faults. The constant recognition of these facts has been of great value in attempting to unravel so difficult a region as the Lleyn Promontory has proved to be.’

That the pre-Cambrian rocks had been greatly affected by lateral or thrust-movements before the Cambrian rocks were deposited is certain, and most of the schistosity and cleavage in them had been produced at that early time. Before I pass from the consideration of the basal Cambrian rocks in Caernarvonshire, where they are found in contact with or overlying the pre-Cambrian, especially where this is of igneous origin, I may once more call attention to some of the difficulties with which earlier observers had to contend when attempting to define the exact boundary-lines between the formations in greatly-disturbed areas. The crushings and crumplings due to earth-movements, sometimes aided by faults, produced an appearance of conformity, whilst in other cases the results were such that experienced observers had been led to look upon the broken and irregular junctions as evidences of igneous intrusions. Here, usually, the illusion had been strengthened by the fact that in the case of many of the pre-Cambrian rocks, especially the granites, much decomposition had taken place in them, mainly by atmospheric agencies, before the overlying rocks had been deposited, and the arkose derived from the granite had been at first re-arranged by water with but little additional matter.

I particularly called attention to some of these causes in my first paper on the Caernarvonshire rocks in 1877, as may be seen from the following passage :—‘The supposed intrusive nature of these ribs, and the apparent passage by gradual alteration mentioned by various observers, are mainly due to the fact that the matrix in the conglomerates has been derived from rocks immediately below or from similar ones, and from a slight subsequent change in the matrix, due, probably, to proximity to the intrusive dykes, aided by a readiness perhaps in the material to assume this change. This is clearly observed by watching the weathering of these conglomerates even when in direct contact with the porphyritic series ; for any apparent melting-away of the hard pebble is shown not to be a fact, since on very slight weathering the pebble becomes easily separable from the matrix, and its outline is as perfect as on the day

it became cemented in the mass. This appearance as if of a gradual passage from conglomerates to rocks below, and from which most of their materials must have been derived, has often presented itself to my mind in examining these basal lines of the pre-Cambrian rocks.<sup>1</sup>

In Caernarvonshire, Upper, Middle, and traces of Lower Cambrian fossils have been discovered, the latter mainly at the Penrhyn slate-quarry, near Bethesda. It is unfortunate that these have not as yet been fully worked out, but that there are zones of fossils below the beds containing *Conocoryphe Viola* described by Dr. Woodward seemed to me, when I last examined the section, quite clear. The sections of Cambrian rocks in this area agree remarkably with those found in Pembrokeshire, and I have no doubt that the underlying Cambrian conglomerates rest here also on an eroded surface of pre-Cambrian rocks.

#### *Anglesey.*

Until the year 1878 it was not suspected that the granite and gneiss-rocks in Central Anglesey were of pre-Cambrian age, but in that year, after visiting the area, I read a paper at the British Association in which I claimed the so-called intrusive granite in Central Anglesey and the associated gneiss, as well as the whole of the area marked as altered Cambrian in that island, as of pre-Cambrian age. I stated that the granitoid and gneissose rocks were at the base, and that, as at St. David's, they were succeeded by the agglomerates, breccias, greenstone-bands, and schists of the Peibidian group. In the Memoirs of the Geological Survey published in 1881, the view that the granite was intrusive in Cambrian and Silurian rocks, and that the latter had been metamorphosed into gneiss, schists, etc., was still upheld. The pre-Cambrian rocks of Anglesey have since been described by Prof. Hughes, Prof. Bonney, Dr. Callaway, Mr. Blake, and others, and it is now fully admitted that the views which we advanced in 1878 are in the main correct. In his Address to this Society in 1891, Sir A. Geikie says:—'Let me frankly say at once that in denying the existence of pre-Cambrian rocks in Anglesey, and in endeavouring to account for all the schists by the metamorphism of Cambrian and Silurian strata, my predecessor was, in my opinion, mistaken'<sup>2</sup>; and again: 'There is undoubtedly in Central Anglesey a core of gneiss which, if petrographical characters may be taken as a guide, must certainly be looked upon as Archæan.' Here he refers to the so-called axis

<sup>1</sup> Quart. Journ. Geol. Soc. vol. xxxiv. (1878) p. 151.

<sup>2</sup> *Ibid.* vol. xlvii. (1891) *Proc.* pp. 82, 83.

which I classed as Dimetian in 1878, and afterwards often mentioned as resembling the granitoid and massive gneissose rocks in the North-west of Scotland. In the Cambrian conglomerates near Llanfaelog there is a remarkable assemblage of fragments which gives indisputable evidence of the pre-Cambrian rocks which were in existence in that area when the conglomerates were deposited, and of their condition when the fragments were broken off.

In papers read before the Society in 1883, the fragments contained in these conglomerates were described by Prof. Bonney and myself, and we then showed that large masses of the granite, gneiss, volcanic rocks, and schists, such as are now seen *in situ* in the neighbourhood, are abundant in them, and by microscopic examination it was found that no important change had taken place in these rocks since pre-Cambrian time. Hitherto no remains of organisms have been obtained from undoubted pre-Cambrian rocks in Anglesey, but recently Mr. Greenly (Quart. Journ. Geol. Soc. vol. lii. 1896, p. 618) has referred to some sponge-spicules which he found in a grit near Beaumaris as possibly of pre-Cambrian age. Upper Cambrian fossils were found by Prof. Hughes many years ago in rocks near the centre of the island, which until then had been classed as of Caradoc age (Quart. Journ. Geol. Soc. vol. xxxvi. 1880, p. 237).

Up to the present, Middle and Lower Cambrian fossils have not been discovered there, but I see no reason whatever why the flaggy sandstones which directly overlie the conglomerates near Llanfaelog and along the western border of the granite-and-gneiss axis should not yield Lower or Middle Cambrian fossils if properly searched, as they clearly are much older than the rocks containing the Upper Cambrian fossils farther north.

#### *Merionethshire.*

On the flanks of the Harlech Mountains Upper and Middle Cambrian fossils were found many years ago—the latter soon after we described the Menevian beds at St. David's. As there are in the Harlech Mountains considerable thicknesses of sediments underlying the beds containing the Menevian fossils, it is more than likely that there are zones also, which only require to be worked out, which would probably contain fossils representing the Solva and Caerfai groups of St. David's, as the lithological characters of the underlying beds are remarkably like those at St. David's.

I have expressed the opinion in previous papers that there are indications of a core of pre-Cambrian rocks in these mountains,

and have pointed out spots where there appear to be traces of an unconformity between typical Harlech rocks and some underlying beds.

*Western and Central England.*

In the years 1864 and 1865 Dr. Holl read papers before this Society in which he maintained that the rocks forming the axis of the Malvern Hills, then classed as syenite, were not intrusive in the Cambrian and Silurian rocks, but were a portion of an old pre-Cambrian land on which the newer rocks had been deposited. In the first-named year Mr. Salter and I announced (Brit. Assoc., Bath Meeting) that the so-called syenite of St. David's was also of pre-Cambrian age, and that it supported, but did not penetrate, the shallow-water accumulations of the surrounding Cambrian. These views were strongly controverted at the time, and in speaking of the Malvern rocks Sir R. Murchison in 1867 ('*Siluria*,' 4th ed. p. 93) said:—'I consider them to be a metamorphosed mass of the lower portion of the Cambrian deposits, and therefore equivalents of the crystalline (metamorphic) Cambrian rock of Anglesey and North Wales.' As is well known, the view here expressed by Sir R. Murchison was the one held by the chiefs of the Geological Survey in regard to the pre-Cambrian crystalline masses in Wales up to a very recent period.

Though the crystalline nucleus of the Malvern Hills was shown by Dr. Holl to be of pre-Cambrian age, it was not until the year 1879 that it was pointed out, chiefly through the labours of Dr. Callaway, that there was a newer group of pre-Cambrian rocks in the spurs running off from the eastern side of the Herefordshire Beacon, which he then correlated with the Pebidian group of St. David's. In that year I visited the district with Dr. Callaway, and was struck by the similarity of the rocks occurring there with those which we had previously described at St. David's and in North Wales.<sup>1</sup> Though typical Lower and Middle Cambrian fossils have not as yet been discovered on the flanks of the Malvern chain, it is more than probable that rocks of that age occur in the area. Upper Cambrian fossils, as is well known, were discovered there in beds overlying the Hollybush Sandstone many years ago. In the year 1877 Mr. S. Allport<sup>2</sup> made the important announcement that the Wrekin ridge and another area to the north-west, coloured as intrusive greenstone in the Geological Survey maps, consisted almost entirely of a 'series of ancient

<sup>1</sup> See Proc. Geol. Assoc. for 1879, vol. vi. p. 233.

<sup>2</sup> Quart. Journ. Geol. Soc. vol. xxxiii. p. 449.

vitreous and semivitreous lavas, with their associated agglomerates and ashes.' He did not, however, recognize that they were of pre-Cambrian age, but supposed them to belong to the 'older contemporaneous volcanic series so extensively developed in the Lower Silurian district of Salop and Radnor.'

In the same year Dr. Callaway published a paper in the Journal of this Society, vol. xxxiii. p. 652, in which he gave an account of the discovery by him some years before of Upper Cambrian fossils in the Shineton Shales which had previously been classed as of Caradoc age. He also mentioned the occurrence of underlying rocks which he correlated with the Hollybush Sandstone near Malvern.

As the result of these discoveries he was led soon afterwards to class the igneous rocks of the Wrekin and of neighbouring areas as of pre-Cambrian age.

On June 11th, 1879,<sup>1</sup> a paper on the pre-Cambrian rocks of Shropshire was read by Dr. Callaway before the Geological Society in which he grouped them geographically as follows:—

'A. *The Wrekin Group*.—Lilleshall Hill, Ercal, Lawrence Hill, the Wrekin, Primrose Hill.

'B. *Caer Caradoc Group*.—The Lawley, Caer Caradoc, the Ragleth, Hope Bowdler Hill.

'C. *Horderley Group*.

'D. *Kington Group*.'

He claimed that the granitoid rocks, as at Malvern and St. David's, were the oldest, and that they were overlain by the Volcanic Group.

In his 'Notes on the Microscopic Structure of some Shropshire Rocks,' read at the same meeting, Prof. Bonney says, p. 668:—'As the result of the investigations above described, I should conclude, from microscopic evidence alone, irrespective of that obtained in the field, that the granitoid series was much older than the other rocks, and that materials from it, together with fragments from the rhyolitic series, had been worked up into several of the later clastic rocks.'

Subsequently Dr. Callaway added fresh areas to those he had previously described, and lastly included the Longmynd rocks (Cambrian of Murchison) in the pre-Cambrian under the term Longmyndian. It is difficult at present to say whether all or only a part of the Longmynd rocks, as suggested by Mr. Blake, are of pre-Cambrian age, and it is most unfortunate that up to the present no important additions to the fauna of these rocks has been made since the discovery in them by Mr. Salter of a fragment of a trilobite (*Palæopyge Ramsayi*) and annelid-borings.

<sup>1</sup> Quart. Journ. Geol. Soc. vol. xxxv. p. 643.

These rocks are well stratified, but must have been deposited in shallow water, the materials being derived mainly from volcanic rocks, or possibly, in part, as dust and muds, directly from volcanoes.

The age of the volcanic rocks, now the Uriconian of Dr. Callaway (originally classed by him with the Pebidian of St. David's, which they greatly resemble), has been proved beyond doubt by the very important discoveries made by Dr. Callaway, Prof. Lapworth,<sup>1</sup> and Mr. S. Groom of Lower and Middle Cambrian fossils in the Comley Sandstone (originally called Hollybush Sandstone by Dr. Callaway) near Lilleshall Hill. This sandstone rests on a quartzite, and the latter lies unconformably on the volcanic rocks of Little Caradoc.

In the year 1882 Prof. Lapworth announced the discovery of Cambrian Rocks in the neighbourhood of Birmingham (Geol. Mag. 1882, p. 563). These rocks had previously been classed as of much newer age, not in any case older than Upper Silurian. The discovery appears to have been jointly made by Prof. Lapworth, Mr. T. S. Houghton, and Mr. W. J. Harrison. Several exposures are referred to, namely, the Lower Lickey Ridge, Nuneaton, Stockingford, and Dort Hill. In the shales of Stockingford Prof. Lapworth discovered many typical Upper Cambrian fossils.<sup>2</sup> The investigations showed 'that a range of country 10 or 12 miles in length by 2 miles in width is occupied by rocks of Upper Cambrian age.' There are two main divisions, the lower being a thickly bedded quartzite which at its base is a 'coarse breccia made up of fragments of red and green felspathic rocks, slaty shales, and various quartz-porphyrines'; these 'have apparently been derived from an older series of igneous and altered strata' which may occasionally be seen rising out from below them. The rocks of Charnwood Forest in Leicestershire, which were formerly supposed to be of Cambrian age, have in recent years been most carefully described by the Rev. E. Hill and Prof. Bonney, who have shown that they resemble much more closely the volcanic rocks of pre-Cambrian age than any which have been classed elsewhere on satisfactory evidence as Cambrian. Though there are no beds containing Cambrian fossils reposing upon these rocks, it is worthy of note that the fossiliferous Upper Cambrian in the neighbouring area of Nuneaton previously mentioned rests on some volcanic rocks, which greatly resemble in their condition some of the Charnwood

<sup>1</sup> Geol. Mag. 1888, p. 484; *ibid.* 1891, p. 529.

<sup>2</sup> More recently Prof. Lapworth discovered fossils in the quartzite series which are very probably of Lower Cambrian age.

series. It seems to me that there is strong evidence to show that the Charnwood Forest rocks are of pre-Cambrian age, and this is the view generally adopted by the majority of those who have been working among the older rocks.

The pre-Cambrian rocks in various areas in England and Wales to which I have referred have been defined as such only within comparatively recent years, the first announcements having been made in 1864, when Dr. Holl referred to the crystalline axis of the Malvern Hills as older than the surrounding rocks, in a paper read before the Society in June of that year 'On the Geological Structure of the Malvern Hills and Adjacent District;' and Mr. Salter, at the meeting of the British Association of the same year, gave an account of our discovery of a 'Pre-Cambrian Island at St. David's, Pembrokeshire.'

Before the year 1862, when Mr. Salter discovered *Paradoxides* in the Lower *Lingula*-Flags of St. David's, the only fossils that had been obtained from the Lower or Middle Cambrian rocks in England or Wales were the fragment of trilobite and the traces of annelids, already referred to, from the Longmynd rocks; and it is since then that all the other fossils which are now known to mark so many zones in the Middle and Lower Cambrian of Britain have been discovered, and the life-history of those periods made out.

#### *Scotland.*

In the year 1878 I read a paper before the Society which reopened the controversy concerning the so-called metamorphic rocks of the Highlands, which had then been dormant for many years. In that paper I maintained that the views held by Prof. Nicol were more in accordance with the facts which I had obtained than were those of Sir R. Murchison and the members of the Geological Survey. Since that date numerous papers have been written on these rocks, especially on those of the North-western Highlands, and much new and important information concerning them and the overlying rocks has been obtained. The gradual and important additions to our knowledge which have been made will be understood by reference to the following papers:—Hicks, *Quart. Journ. Geol. Soc.* vol. xxxiv. 1878; Hudleston, *Proc. Geol. Assoc.* 1879, vol. vi.; Bonney, *Q. J. G. S.* vol. xxxvi. 1880; Hicks & Davies, *Geol. Mag.* 1880; Hicks, *Proc. Geol. Assoc.* 1880, vol. vi.; Hicks & Bonney, *Q. J. G. S.* vol. xxxix. 1883; Callaway, *Q. J. G. S.* vol. xxxvii. 1881, and vol. xxxix. 1883; Hudleston, *Geol. Mag.* 1882; Lapworth, *Geol. Mag.* 1883, and *Proc. Geol. Assoc.* 1884, vol. viii.; Blake, *ibid.*; Geikie, Peach, & Horne, 'Nature,' 1884;

Peach & Horne, Q. J. G. S. vol. xlv. 1888; and the Reports of the Geological Survey.

In the papers by Mr. T. Davies, Prof. Bonney, Dr. Callaway, and myself petrological descriptions of the characteristic rocks found in the neighbourhoods of Gairloch, Loch Maree, Central and Southern Ross-shire, and a portion of the Central Highlands were given. Prof. Bonney showed that the so-called 'syenite' in Glen Logan was not an intrusive mass, but a portion of the old gneiss floor which had been brought into that position by faults, and I pointed out that the older gneisses cropped up in several areas east of Loch Maree, where previously they had been unsuspected, and also that the schistose series in the neighbourhood of Gairloch was unlike any which had previously been described from the western areas. It was further shown that at the base of the Torridon sandstone large masses of these schists occurred in association with fragments derived from the so-called Lewisian gneiss and numerous other fragments which could not then be located in the district. Attention was also called to the highly-faulted condition of the rocks in the several areas examined, and the newer rocks were stated to occur in broken synclinal folds.

In the year 1883 Prof. Lapworth, when describing the Durness and Eriboll areas, pointed to evidences in that area of an old mountain system accompanied by great dislocations. He also divided the Palæozoic rocks of those areas into numerous fossil zones. Moreover, Dr. Callaway, in the same year, showed that there were evidences of great dislocations and of foldings of the limestone- and quartzite-beds, not only at Durness but also in the neighbourhood of Assynt. He had previously, in a paper communicated to the Geological Society in 1881, stated that he had arrived at the conclusion that the sections in those areas 'were broken, and therefore untrustworthy, but that the relations of the several rock-groups were inconsistent with the supposition that the limestone passed below any part of the newer metamorphic series.'<sup>1</sup>

In the year 1884 the Director-General of the Geological Survey (Sir A. Geikie) and Messrs. Peach & Horne, in a paper in 'Nature,' November 13th (vol. xxxi. p. 32), stated that the results recently obtained by them when re-surveying the Durness and Eriboll areas went to show that 'the Silurian strata in the Durness area are arranged in the form of a basin truncated on the east side by a fault that brings them against the Archæan gneiss.' They also refer to the flexures and great dislocations of the strata in the Eriboll area, previously pointed out by Prof. Lapworth, and Sir A. Geikie

<sup>1</sup> Quart. Journ. Geol. Soc. vol. xxxvii. p. 239.

concludes by saying: 'With every desire to follow the interpretation of my late chief, I criticized minutely each detail of the work upon the ground; but I found the evidence altogether overwhelming against the upward succession which Murchison believed to exist in Eriboll from the base of the Silurian strata into an upper conformable series of schists and gneisses,' (p. 30). Since that time the districts about Loch Maree, Gairloch, Auchnasheen, and Loch Carron have been surveyed by the officers of the Geological Survey, and in their report for 1895 (p. 19) it is stated that 'in the area mapped between Auchnasheen and Loch Alsh, evidence has been obtained of the alternations of strips of recognizable Lewisian Gneiss with schists of the true Moine type . . . Some of the cores and lenticles of gneiss, almost certainly Lewisian, attain a considerable size. Thus, to the south of Auchnasheen, a tract of hornblendic gneiss covers an area of perhaps more than 50 square miles.' It is but right to state that Prof. Bonney and I called particular attention to what we considered the re-appearance of the older gneisses in these areas in 1883, and therefore far to the east of any areas in which they had previously been described, and the following passage occurs in my paper of 1883:—'The presence of a group of gneisses of so old-looking a character, and with a crystalline condition, as shown in microscopical sections, not to be distinguished from the oldest gneisses of the Loch Maree type, reaching to the crest of a mountain of over 2300 feet in height, in an area regarded as containing the so-called newer Silurian metamorphic rocks only, and east of the limestone series, is a fact of enormous importance, especially as we are told by Murchison and Geikie that the rocks found in this area are newer than the limestone series of Loch Kishorn, and that they repose conformably upon the latter.'<sup>1</sup> Since the rocks of these areas were described by us in 1883, views as to the origin of the gneisses and of some of the crystalline schists have undergone a considerable change, and it is now generally admitted that the massive gneisses are in the main igneous rocks which had been crumpled, crushed, and deformed in pre-Cambrian times. Facts bearing on these questions have been worked out with great care by the officers of the Geological Survey in several areas in Scotland.

At the Meeting of the British Association in 1891 an important announcement was made by Sir A. Geikie of the discovery of Lower Cambrian fossils by the officers of the Geological Survey in rocks overlying unconformably the Torridon Sandstone in the North-west Highlands. The Torridon Sandstone, which attains a thickness

<sup>1</sup> Quart. Journ. Geol. Soc. vol. xxxix. p. 151.

of several thousand feet in the neighbourhood of Loch Maree and Loch Torridon in Ross-shire, was until then generally classed as of Cambrian age; therefore this discovery of the *Olenellus*-zone in the overlying rocks at once made it clear that the Torridon Sandstone would in future have to be classed as of pre-Cambrian age. It had been known for a long period that the Torridon Sandstone rested on a strongly-eroded surface of Archæan gneiss and schists, fragments of which occurred in it, and in the year 1878 (Quart. Journ. Geol. Soc. vol. xxxiv. p. 813) I particularly called attention to the fact that in addition to these local fragments there were others, especially in the basal breccias at Gairloch, which did not seem 'to have come from the immediate neighbourhood,' but were 'similar in many respects to those found in the Cambrian conglomerates in Wales, and which were there undoubtedly derived from the underlying Pebidian beds.'<sup>1</sup> In the more recent descriptions given by the Geological Surveyors of the Torridon Sandstone in the different areas attention is also pointedly called to these facts, and it seems highly probable that at one time a volcanic group of rocks similar to the Pebidian of Wales must have existed either in the area or at no great distance from it. In that case the volcanic group would have to be classed as older than the Torridonian and newer than the gneiss and crystalline schists, as in Wales. The Longmyndian and Torridonian rocks seem therefore to be nearly on the same horizon, and intermediate in position between the Pebidian and the Cambrian. In referring to the Torridonian rocks in the 'Annual Report of the Geological Survey' for 1895, p. 20, Sir A. Geikie says:—'During the progress of the mapping of the Torridonian rocks in the west of Sutherland and Ross-shire, the attention of the surveyors has been continually directed to the nature of the sediments composing these rocks, and to the interesting problems connected with their origin. While the sandstones, shales, and conglomerates of this system may be reasonably supposed to have been mainly derived from the denudation of the Lewisian Gneiss, they yet contain materials which have not been found in the gneiss itself, and the source of which it would be important, if possible, to discover. The contents of the conglomerates seem to prove the existence of some series of sedimentary and volcanic rocks older than the Torridonian formations. It seemed desirable that a detailed study should be made of the Torridonian petrography.

<sup>1</sup> In 1880, Proc. Geol. Assoc., I mentioned the following as occurring as fragments, namely, gneiss, granite, quartz-felsite, quartz-quartzite, jasper, talcose, chloritic and micaceous schistose rocks, etc. See also 'Pre-Cambrian Rocks in Cambrian Conglomerates,' Geol. Mag. 1890, p. 516.

Accordingly I requested Mr. Teall to undertake this task. He has already made considerable progress in the investigation, directing special attention to those pebbles in the conglomerates which were evidently not derived from the immediately underlying gneiss. The specimens collected in the field and submitted to him comprise vein-quartz, quartzites, cherts, jasper, felsites, quartzschists, and mica-schist, including green aventurine.' And at page 21 (Notes by Mr. Teall):—'The felsites are exceptionally interesting, and have been described in detail. They are dark-purplish compact rocks, usually less red in colour than the jaspers, but not always easily distinguishable from them. They consist of porphyritic crystals, and crystal-groups of felspar, often oligoclase, in a spherulitic, micropegmatitic, micropoikilitic, or microcrystalline groundmass. The spherulitic felsites occasionally show traces of perlitic structure in the matter which fills up the spaces between the spherulites. These felsites bear the most striking resemblance to those of Uriconian age which occur in Shropshire, and which have furnished pebbles to some portions of the Longmyndian rocks.' It is also stated that 'the tracts of Torridonian rocks mapped last year have lain entirely to the east of the line of great complication, and are all moved masses.' In my paper, *Quart. Journ. Geol. Soc.* vol. xxxix. (1883), I called attention to the fact that we had found these rocks in several localities east of the limit usually assigned to them, including most of the areas referred to in the report, and said, p. 148 :—'That these are true Torridon Sandstones, and not subordinate bands in the quartzite series, is perfectly clear to any one who has seen the succession on the Torridon shores.'

Recent researches by the Geological Surveyors and others have tended strongly to confirm the view that the gneisses and crystalline schists in the central areas in Ross and Sutherland, as also in the Central Highlands, are of pre-Cambrian age, but the exact age of some newer rocks which overlie or are entangled amongst them has not as yet been made out. It is probable that in time some of these will be shown to be of Cambrian age.

#### *South of England and Channel Islands.*

Having thus referred to the areas in Wales, the centre of England, and North Britain, where the facts are clear, it may now be well to enquire into the evidence which has been brought forward to show the presence of pre-Cambrian rocks in more southerly districts. In my paper 'On some Recent Researches among Pre-Cambrian Rocks in the British Isles' (*Proc. Geol.*

Assoc. vol. vii. 1881, p. 73), I spoke with some doubt as to the evidence then available to show the occurrence of pre-Cambrian rocks in Cornwall, but said:—‘At present, however, it would be unsafe to theorize upon the evidence available, but no harm can arise from referring briefly to the facts. It is well known that the Eddystone lighthouse is built upon rocks of a gneissose type, some massive, others more schistose. These gneisses appear to be of the true type of the older or granitoid kind, hence rendering it probable that in the Channel, at least, a ridge of these older rocks occurs.’

Prof. Bonney, from the result of careful researches in the Lizard district, has arrived at the conclusion that at any rate the gneisses, hornblende-, and other schists may probably be of pre-Cambrian age, and the researches of Mr. J. H. Collins, Mr. Howard Fox, and Mr. J. J. H. Teall have also shown that rocks of Ordovician age are faulted against the gneissose rocks at several points in that district. The finding of radiolarian cherts in these Ordovician rocks by Messrs. Fox & Teall is of interest as indicating that at least moderately deep-water deposits were being thrown down in this area early in Palæozoic time. In *Quart. Journ. Geol. Soc.* vol. xxxi. 1875, I published a map of the European area, showing the comparative thickness and depth of deposition of the Cambrian and Lower Silurian rocks in different areas, and one of the lines of greatest depression was shown to run in a direction from S.W. to N.E. south of the English Channel. In that paper also I said that the evidence seemed to show that moderately deep water covered many of the western areas in Europe at that time. Prof. Bonney has suggested that the micaceous and chloritic schists at Start Point which are faulted against slaty rocks, probably of Devonian age, are pre-Cambrian. These schists, he says, are almost identical with some of the members of the great upper group of schists in the Alps. Those who know the amount of faulting and crushing which has taken place in the rocks of South Devon can readily realize why, if these be pre-Cambrian rocks, there is no actual evidence showing Lower Palæozoic rocks in contact with them.

The researches of the Rev. E. Hill, Prof. Bonney, Dr. Barrois, M. Bigot, and Prof. de Lapparent in the Channel Islands and neighbouring areas in Normandy and Brittany show clearly that there both Upper and Lower Cambrian rocks repose unconformably upon pre-Cambrian gneiss-rocks and felstones, the latter resembling closely those which occur in the volcanic series of Wales and Shropshire. I am told by Prof. Bonney that in Jersey felstones and coarser crystalline igneous rocks underlie a conglomerate accepted now as basal Cambrian, and some of the crystallines are

older than the Schistes de St. Lô. In Alderney granitic rocks underlie Grès Felspathique. The crystallines of Guernsey and of Sark cannot be dated, but it is reasonable to suppose that they are of about the same age as those in the other islands, while the hornblende-schists of Sark are precisely the same as those of the Lizard, and there are moreover old-looking gneisses. The occurrence of undoubted Cambrian rocks in the areas last referred to, and unconformable to the volcanic and gneiss-rocks, shows clearly that the physical changes which affected the British Isles also extended over wide areas in Western Europe.

These discoveries, moreover, add confirmatory evidence in support of the contention in my paper read before the Society in 1875, p. 558, where I maintain that, wherever in the European areas the rocks 'belonging to the old pre-Cambrian continent are now found exposed, they show every indication of having been old land-surfaces before the overlying rocks had been deposited, and almost invariably the lowest beds in contact with them are either sandstones or conglomerates, whether they belong to the Cambrian or the Silurian.' (Quart. Journ. Geol. Soc. vol. xxxi.)

#### *Ireland.*

Though it is now fully admitted that pre-Cambrian rocks occur in several areas in Ireland, some doubt still exists as to the exact position of the rocks which have been classed as Cambrian in that island. They are known to occur only at Howth, about Bray, and in Wexford.

Mr. A. McHenry and Mr. W. W. Watts, in their 'Guide to the Collections of Rocks and Fossils belonging to the Geological Survey of Ireland' (1895), say that the only fossils hitherto obtained from these rocks are *Oldhamia*, which is of 'doubtful but probably of organic origin,' and tracks and burrows of worms, and the microscopic bodies from the slates of Howth, stated by Prof. Sollas 'to have the appearance of being relics of minute animals (radiolaria).'

Prof. Sollas has also more recently described an obscure 'but probably organic structure under the name *Pucksia McHenryi*' from these rocks. The strata are pierced by dykes of igneous rocks, but 'no contemporaneous volcanic rocks are known' in them.

As it would occupy far more space than it would be reasonable to ask you to grant me for this address, if I were to attempt to review all the work which has been done among these rocks during the past 30 or 35 years, I have thought it advisable to

confine my remarks, with one or two exceptions, to the researches which have been carried on in the British Isles, and in areas with which I am more or less familiar. It will, of course, be understood that important advances have also been made during the same time in many other countries in Europe and in America; and, as bearing on the biological history, the discoveries made by the Scandinavian, Russian, and American geologists have been of the highest value.

### Summary.

From the scattered details which I have thus imperfectly laid before you, it may be well to sum up the main results which have been obtained. It has been seen that very different views are now held in regard to the origin of many of the pre-Cambrian rocks from those which prevailed from 20 to 30 years ago. Then all the crystalline schists and gneisses, and many also of the granitic rocks, were looked upon as metamorphosed sediments. Gradually, and mainly owing to the careful microscopical work which has been carried on by so many eminent petrologists in this and other countries, we have been led to recognize that a very large proportion of the crystalline rocks previously supposed to have been sediments are igneous rocks which have been crushed, cleaved, and have suffered other changes from chemical and mechanical influences. It has been shown also that very large and unexpected proportions of the pre-Cambrian rocks were built up from materials derived from volcanic outbursts, and that this was particularly the case in the British areas. As a consequence, few of the sediments are such as could have been deposited in marine areas favourable to organic life, or such as would be likely to retain very definite evidence of its existence. Still the very earliest of the Cambrian rocks, or those sediments which were deposited in a fairly tranquil sea, following the great physical changes which took place at the close of the pre-Cambrian era, contain ample evidence that the sea which was gradually encroaching on the pre-Cambrian land on both sides of the Atlantic teemed with life, in which probably all the orders of the Invertebrata were represented.

These discoveries have undoubtedly added most important evidence in support of the theory of the gradual evolution of organic life, and lead us to speak very hopefully of finding yet earlier traces of the life-history of our globe. The readiness with which suitable forms tenanted all the areas as they were covered by the sea shows that there was abundance of life near at hand in the adjoining submerged areas, and that the changes then taking

place were only such as had been going on more or less continuously on the surface of the globe from the moment when the waters began to collect or, at any rate, became suitable for the existence of life. The earliest records may have been completely blotted out by the repeated changes which had previously taken place, or may be entirely buried beneath and hidden from our view in the great oceanic areas. Still the results obtained within comparatively recent years lead us to hope that there is yet room to discover much in those areas which hitherto have been but imperfectly examined or not at all explored.

In conclusion, I may, I think, venture to say that as geologists we feel quite certain that from the earliest Cambrian to the present time, we are dealing only with a comparatively recent period in the world's history; and, as biologists, that we are convinced that innumerable successions of organic beings must have lived and passed away in the pre-Cambrian era before such an advance could have been attained as is manifest in those forms which tenanted the earliest Cambrian seas. We may also, I think, venture to congratulate ourselves that recent researches have enabled geologists to take up a far more satisfactory position in regard to the theory of evolution than when Darwin felt constrained to pen the following words in referring to the imperfection of the geological record ('Origin of Species,' p. 310):—'The several difficulties here discussed, namely, our not finding in the successive formations infinitely numerous transitional links between the many species which now exist or have existed; the sudden manner in which whole groups of species appear in our European formations; the almost entire absence, as at present known, of fossiliferous formations beneath the Silurian strata, are all undoubtedly of the gravest nature. We see this in the plainest manner by the fact that all the most eminent palæontologists, namely, Cuvier, Owen, Agassiz, Barrande, Falconer, E. Forbes, etc., and all our greatest geologists, as Lyell, Murchison, Sedgwick, etc., have unanimously, often vehemently, maintained the immutability of species.'

No one could now venture to blame our predecessors for the cautious attitude which they assumed in consequence of the evidence then available to them; but I think that we may take a lesson from the results since then obtained, and not be too ready to condemn or cast a doubt on new discoveries which may not quite fit in with our preconceived ideas.

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February 24th, 1897.

Dr. HENRY HICKS, F.R.S., President, in the Chair.

Capt. Arthur Richard Dwerryhouse, 65 Louis Street, Leeds; Percy Emary, Esq., 12 Alwyne Square, Canonbury, N.; William Douglas Ferguson, Esq., 7 Great Winchester Street, E.C.; Charles Olden, Esq., Whitby Lodge, St. George's Terrace, Perth, Western Australia; and George de Wolf, Esq., Vancouver, British Columbia, were elected Fellows of the Society.

The List of Donations to the Library was read.

The following communications were read:—

1. 'On the Nature and Origin of the Rauenthal Serpentine.' By Miss Catherine A. Raisin, B.Sc. (Communicated by Prof. T. G. Bonney, D.Sc., LL.D., F.R.S., V.P.G.S.)

2. 'On Two Boulders of Granite from the Middle Chalk of Betchworth (Surrey).' By W. P. D. Stebbing, Esq., F.G.S.

3. 'Coal: a new Explanation of its Formation; or the Phenomena of a New Fossil Plant considered with reference to the Origin, Composition, and Formation of Coal-beds.' By W. S. Gresley, Esq., F.G.S.

The following specimens and maps were exhibited:—

Hand-specimens and microscope-sections of Rauenthal rocks, exhibited by Prof. T. G. Bonney, D.Sc., F.R.S., V.P.G.S., in illustration of Miss Raisin's paper.

Specimens, photographs, and microscope-sections of Granite Boulders from the Chalk of Betchworth, exhibited by W. P. D. Stebbing, Esq., F.G.S., in illustration of his paper.

Specimens of Boulders from the Chalk of Norfolk, exhibited by the Director-General of H.M. Geological Survey.

Specimen of the Granite Boulder from Purley, near Croydon, from the Society's collection; and a smaller portion of the same, exhibited by Prof. J. W. Judd, C.B., LL.D., F.R.S. Also a microscope-section of the same, exhibited by Prof. T. G. Bonney, D.Sc., F.R.S., V.P.G.S.

Sheets 3, 6, 9, and 15 of the new Index Map of H.M. Geological Survey (Scale: 4 miles to 1 inch); Sheet 299—Winchester of the 1-inch Map, New Series, and Sheet 81, Monmouthshire and Glamorganshire, of Vertical Sections, presented by the Director-General of that Survey.

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March 10th, 1897.

Dr. HENRY HICKS, F.R.S., President, in the Chair.

Conyers Kirby, Esq., Preswylfa, Bryngwyn Road, Newport (Mon.); Joseph Coventry P'Anson, Esq., 25 Palace Chambers, 9 Bridge Street, Westminster, S.W.; and Alfred James Hodgkinson-Carrington, Esq., Assoc.M.Inst.C.E., 34 Queen Street, Melbourne (Victoria), were elected Fellows of the Society.

The List of Donations to the Library was read.

The following communications were read:—

1. 'Volcanic Activity in Central America in relation to British Earthquakes.' By A. Gosling, Esq., H.M. Minister & Consul-General in Central America. Communicated (through H.M. Foreign Office) by the President.

2. 'The Red Rocks near Bunmahon on the Coast of Co. Waterford.' By F. R. Cowper Reed, Esq., M.A., F.G.S.

3. 'On the Depth of the Source of Lava.' By J. Logan Lobley, Esq., F.G.S.

Rock-specimens and Photographs were exhibited by F. R. Cowper Reed, Esq., M.A., F.G.S., in illustration of his paper.

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March 24th, 1897.

Dr. HENRY HICKS, F.R.S., President, in the Chair.

James Negus, Esq., The Mining School, Camborne; and John Francis Cleverton Snell, Esq., Assoc.M.Inst.C.E., 6 Thornhill Crescent, Sunderland, were elected Fellows of the Society.

The List of Donations to the Library was read.

The following communications were read:—

1. 'Notes on some Volcanic and other Rocks which occur near the Baluchistan-Afghan Frontier, between Chaman and Persia.' By Lieut.-Gen. C. A. McMahon, V.P.G.S., and Capt. A. H. McMahon, C.I.E.

2. 'On the Association of *Glossopteris* and *Sigillaria* in South Africa.' By A. C. Seward, Esq., M.A., F.G.S.

3. 'Notes on the Occurrence of *Sigillaria*, *Glossopteris*, and other Plant-remains in the Triassic Rocks of South Africa.' By David Draper, Esq., F.G.S.

The following specimens were exhibited :—

Rock-specimens, Microscope-sections, and Lantern-slides, exhibited by Lieut.-Gen. C. A. McMahon, V.P.G.S., & Capt. A. H. McMahon, C.S.I., C.I.E., in illustration of their paper.

Plant-remains from the South African Republic (from comparatively short distances from Johannesburg), exhibited by A. C. Seward, Esq., M.A., F.G.S., in illustration of the papers by himself and David Draper, Esq., F.G.S.

Rock-specimens from Mexico and Nevada, exhibited by O. H. Howarth, Esq., F.G.S.

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April 7th, 1897.

Dr. HENRY HICKS, F.R.S., President, in the Chair.

Capt. John Hamilton Anderson, Mandora Barracks, Aldershot; and Capt. Arthur Henry McMahon, C.S.I., C.I.E., 87 Cadogan Gardens, S.W., were elected Fellows; and Dr. Anton Koch, of Budapest; Prof. A. Lacroix, of Paris; and Prof. Count H. zu Solms-Laubach, of Strassburg, were elected Foreign Correspondents of the Society.

The List of Donations to the Library was read.

The PRESIDENT then left the Chair, which was taken by Prof. T. G. BONNEY, D.Sc., F.R.S., V.P.G.S.

The following communications were read :—

1. 'On the Morte Slates and Associated Beds in North Devon and West Somerset.—Part II.' By Henry Hicks, M.D., F.R.S., P.G.S. With Descriptions of the Fossils by the Rev. G. F. Whidborne, M.A., F.G.S.

(The PRESIDENT resumed the Chair after the Discussion of the above paper.)

2. 'The Glacio-Marine Drift of the Vale of Clwyd.' By T. Mellard Reade, Esq., C.E., F.G.S.

The following specimens were exhibited :—

Fossils, exhibited by the President in illustration of his paper.  
Boulder Clay Foraminifera and Rock-specimens, exhibited by T. Mellard Reade, Esq., C.E., F.G.S., in illustration of his paper.

April 28th, 1897.

Dr. HENRY HICKS, F.R.S., President, in the Chair.

H. F. Bulman, Esq., Byermoor, Burnopfield, R.S.O., Co. Durham; and Christian Adolph Heussler, Esq., Kalgoorlie, Western Australia, were elected Fellows of the Society.

The List of Donations to the Library was read.

The PRESIDENT, referring to the exhibits of models of the dorsal and ventral aspect of *Triarthrus*, said that these had been prepared and sent to him by Mr. Charles E. Beecher, of Yale University Museum. He was sure that they would prove of great interest to the Fellows, who were well acquainted with the extremely careful work which Mr. Beecher had done in connexion with *Triarthrus*.

The following communications were read :—

1. 'Note on a Portion of the Nubian Desert South-east of Korosko.' By Capt. H. G. Lyons, R.E., F.G.S. With Notes on the Petrology by Miss C. A. Raisin, B.Sc. (Communicated by Prof. Bonney, D.Sc., F.R.S., V.P.G.S.) And Water-Analyses by Miss E. Aston, B.Sc. (*Idem.*)

2. 'On the Origin of some of the Gneisses of Anglesey.' By Charles Callaway, M.A., D.Sc., F.G.S.

The following specimens were exhibited, in addition to those mentioned above :—

Rock-specimens and Microscope-sections, exhibited by Capt. H. G. Lyons, R.E., F.G.S., in illustration of his paper.

A series of Microscope-sections, exhibited by Dr. C. Callaway, M.A., F.G.S., in illustration of his paper.

Specimens of Flint-implements from the Test Valley, Hampshire, and Thornton Heath, near Croydon, exhibited by A. E. Salter, Esq., B.Sc., F.G.S.

A specimen of Arborescent Carboniferous Limestone from Bentry Hill, near Henbury, Bristol, obtained by Spencer G. Perceval, Esq., and exhibited by the Director-General of H.M. Geological Survey.

Sheet 20 (Killean) and Sheet 103 (Golspie) of the Geological Survey of Scotland, 1-inch map, presented by the Director-General of H.M. Geological Survey.

Sheets Zwingenberg and Bensheim of the  $\frac{1}{25,000}$  Geological Survey Map of the Grand Duchy of Hesse, presented by the Director of that Survey.

May 12th, 1897.

Dr. HENRY HICKS, F.R.S., President, in the Chair.

William Robert Coleridge Beadon, Esq., Queen Anne Cottage, Keswick Road, East Putney; Gerald Noël Brown, Esq., 8 The Esplanade, Plymouth; and William Earl Hidden, Esq., 25 Orleans Street, Newark, New Jersey, U.S.A., were elected Fellows of the Society.

The List of Donations to the Library was read.

The following communications were read :—

1. 'On the Gravels and Associated Deposits at Newbury (Berks).' By E. Percy Richards, Esq., F.G.S.
2. 'The Mollusca of the Chalk Rock: Part II.' By Henry Woods, Esq., M.A., F.G.S.

The following specimens, etc. were exhibited :—

Fossil Teeth, Bones, etc., exhibited by E. P. Richards, Esq., F.G.S., in illustration of his paper.

Flint from Halling, near Rochester, exhibited by G. E. Dibley, Esq., F.G.S.

Vertical Sections, Sheet 82, by C. E. De Rance, Esq., F.G.S., presented by the Director-General of H.M. Geological Survey.

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May 26th, 1897.

Dr. HENRY HICKS, F.R.S., President, in the Chair.

John T. Smith, Esq., Green Lane, Padiham, was elected a Fellow of the Society.

The List of Donations to the Library was read.

The following communications were read :—

1. 'On Augite-Diorites with Micropegmatite in Southern India.' By Thomas H. Holland, Esq., A.R.C.S., F.G.S., Officiating Superintendent, Geological Survey of India.
2. 'The Laccolites of Cutch and their Relations to the other Igneous Masses of the District.' By the Rev. J. F. Blake, M.A., F.G.S.

The following specimens were exhibited :—

Augite-diorites with Micropegmatite, from Southern India, exhibited by T. H. Holland, Esq., A.R.C.S., F.G.S., in illustration of his paper.

Igneous Rocks from Cutch, exhibited by the Rev. J. F. Blake, M.A., F.G.S., in illustration of his paper.

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June 9th, 1897.

Dr. HENRY HICKS, F.R.S., President, in the Chair.

John Ball, Ph.D., A.R.S.M., 18 Redshaw Street, Derby; and John Isaac Lowles, Esq., Leverington Chambers, Coolgardie, Western Australia, were elected Fellows of the Society.

The Names of certain Fellows were read out for the first time, in conformity with the Bye-Laws, Section VI. Art. 5, in consequence of the non-payment of Arrears of Contributions.

The List of Donations to the Library was read.

The following communications were read :—

1. 'The Cretaceous Strata of County Antrim.' By W. Fraser Hume, D.Sc., F.G.S.

2. 'An Account of the Portraine Inlier (Co. Dublin).' By C. I. Gardiner, Esq., M.A., F.G.S., & S. H. Reynolds, Esq., M.A., F.G.S.

3. 'Some Igneous Rocks in North Pembrokeshire.' By J. Parkinson, Esq., F.G.S.

The following specimens were exhibited :—

Fossils, Rock-specimens, Microscope-sections, and Photographs, exhibited by W. F. Hume, D.Sc., F.G.S., in illustration of his paper.

Fossils, Rock-specimens, Microscope-sections, and Photographs, exhibited by Messrs. C. I. Gardiner, M.A., F.G.S., & S. H. Reynolds, M.A., F.G.S., in illustration of their paper.

Rock-specimens, Microscope-sections, and Lantern-slides, exhibited by J. Parkinson, Esq., F.G.S., in illustration of his paper.

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June 23rd, 1897.

Dr. HENRY HICKS, F.R.S., President, in the Chair.

A. Vivian Moore, Esq., The Club, Kidderminster; and David Woolacott, Esq., M.Sc., 156 Roker Avenue, Sunderland, were elected Fellows of the Society.

The following Names of Fellows of the Society were read out for the second time, in conformity with the Bye-Laws, Sect. VI. Art. 5, in consequence of the non-payment of Arrears of Contributions:—  
J. F. BRAGA, Esq.; Dr. J. C. S. BURKITT; A. JOHNSTONE, Esq.; E. M. JONES, Esq.; T. R. MADDISON, Esq.; Rev. H. E. MADDOCK; P. J. OGLE, Esq.; J. F. PAGEN, Esq.; J. POPE, Esq.; H. K. SPARK, Esq.; and the Rev. B. WILKINSON.

The List of Donations to the Library was read.

The following communications were read:—

1. 'Notes on a Collection of Rocks and Fossils from Franz Josef Land, made by the Jackson-Harmsworth Expedition during 1894-96.' By E. T. Newton, Esq., F.R.S., F.G.S., & J. J. H. Teall, Esq., M.A., F.R.S., V.P.G.S.

2. 'Deposits of the Bajocian Age in the North Cotteswolds.—I. The Cleve Hill Plateau.' By S. S. Buckman, Esq., F.G.S.

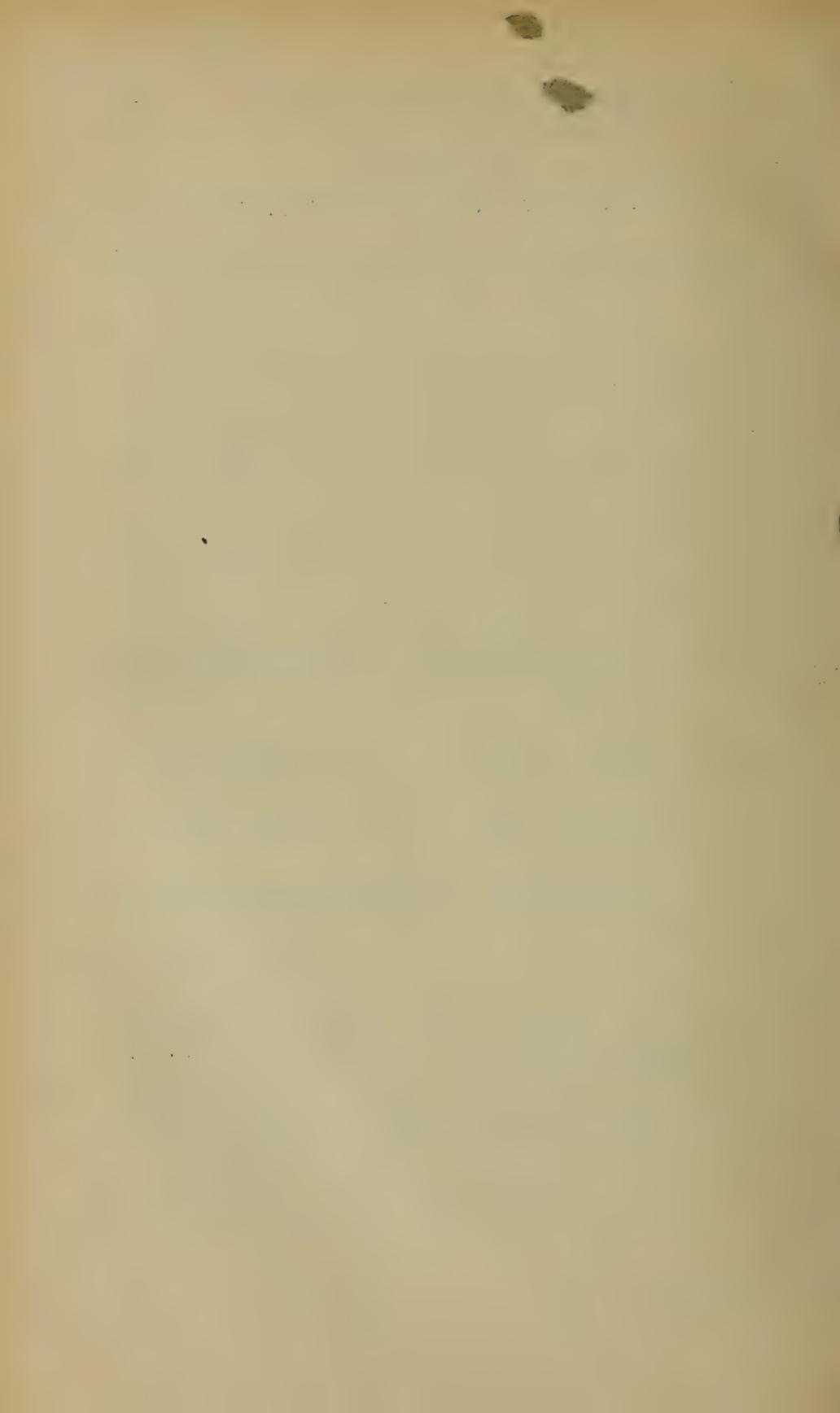
3. 'Pleistocene Plants from Casewick, Shacklewell, and Grays.' By Clement Reid, Esq., F.L.S., F.G.S.

4. 'An Explanation of the Claxheugh Section (Co. Durham).' By D. Woolacott, Esq., M.Sc. (Communicated by Prof. G. A. Lebour, M.A., F.G.S.)

The following specimens and maps were exhibited:—

Rocks, Microscope-sections, Fossils, Photographs, and Water-colour Sketches, exhibited by Messrs. E. T. Newton & J. J. H. Teall in illustration of their paper.

Messrs. W. & A. K. Johnston's Geological Map of the British Isles, presented by them; and 4 sheets of the Geological Survey Map of Roumania, presented by the Director of that Survey.



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OF

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The Fellows are entitled to receive gratuitously all the volumes or parts of volumes of the Quarterly Journal of the Society that may be published after their election, so long as their Annual Contributions are paid; and they may purchase any of the publications of the Society at a reduction of 25 per cent. under the selling prices.

The Library is open daily to the Fellows between the hours of 10 and 5 (except during the first two weeks of September), and on Meeting days until 8 P.M.: see also next page. Under certain restrictions Fellows are allowed to borrow books from the Library.

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[No. 213 will be published next February.]

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[The Editor of the Quarterly Journal is directed to make it known to the Public, that the Authors alone are responsible for the facts and opinions contained in their respective Papers.]

\* \* \* The Council request that all communications intended for publication by the Society shall be clearly and legibly written on one side of the paper only, with proper references, and in all respects in fit condition for being at once placed in the Printer's hands. Unless this is done, it will be in the discretion of the Officers to return the communication to the Author for revision.

The Library and Museum at the Apartments of the Society are open every Weekday from Ten o'clock until Five, except during the first two weeks in the month of September, when the Library will be closed for the purpose of cleaning; the Library is also closed on Saturdays at One P.M. during the months of August and September. It is open until Eight P.M. on the Days of Meeting for the loan of books, and from Eight P.M. until the close of each Meeting for conversational purposes only.

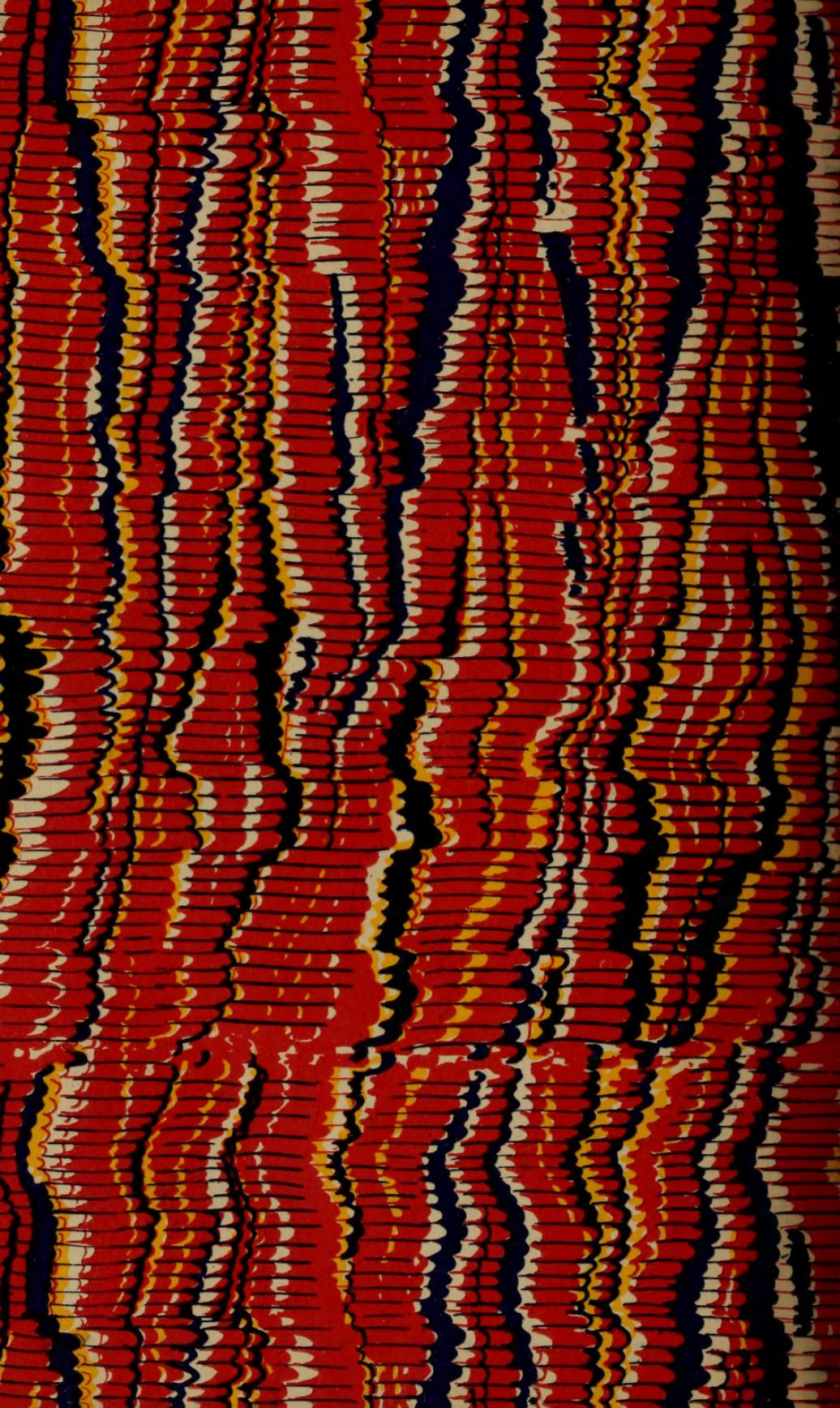














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