GEOLOGICAL SURVEY,
SCOTLAND.

THE MESOZOIC ROCKS

OF

APPLECROSS, RAASAY, AND NORTH-EAST SKYE,

BY

G. W. LEE, D.Sc.,

WITH CONTRIBUTIONS AND AN APPENDIX BY

S. S. BUCKMAN, F.G.S.

PUBLISHED BY ORDER OF THE LORDS COMMISSIONERS OF HIS MAJESTY'S TREASURY.

EDINBURGH:
PRINTED UNDER THE AUTHORITY OF HIS MAJESTY'S
STATIONERY OFFICE
BY MORRISON & GIBB, LIMITED, TANFIELD.

And to be purchased from
E. STANFORD, 12, 13 and 14 LONG ACRE, LONDON;
W. & A. K. JOHNSTON, LIMITED, 2 ST. ANDREW SQUARE, EDINBURGH;
HODGES, FIGGIS & CO., LIMITED, 104 GRAFTON STREET, DUBLIN.
From any Agent for the sale of Ordnance Survey Maps;
Or through any Bookseller, or from the Director General, Ordnance Survey Office, Southampton.

1920.

Price Six Shillings Net.

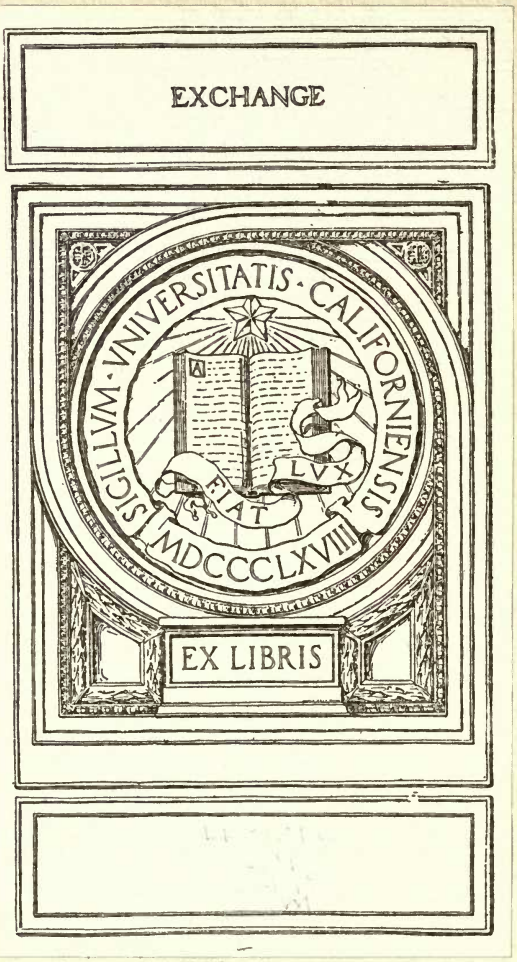


PLATE I.—(*Frontispiece*)

1. *Great Estuarine Series.*
2. *Ledge at position of OIL SHALE.*
3. *Inferior Oolite Sandstone.*
4. *Slope of Aalenian Shales.*
5. *Middle Lias Sandstone.*

General View of Jurassic Rocks below Dun Caan, Island of Raasay.

MEMOIRS OF THE GEOLOGICAL SURVEY, SCOTLAND.

THE MESOZOIC ROCKS OF APPLECROSS, RAASAY, AND NORTH-EAST SKYE,

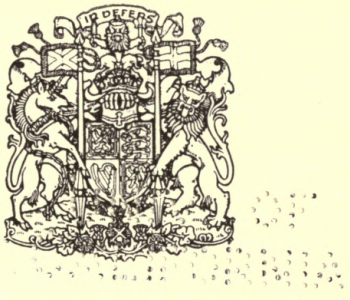
BY

G. W. LEE, D.Sc.,

WITH CONTRIBUTIONS AND AN APPENDIX BY

S. S. BUCKMAN, F.G.S.

PUBLISHED BY ORDER OF THE LORDS COMMISSIONERS OF HIS MAJESTY'S TREASURY.



EDINBURGH:
PRINTED UNDER THE AUTHORITY OF HIS MAJESTY'S STATIONERY OFFICE
BY MORRISON & GIBB, LIMITED, TANFIELD.

And to be purchased from
E. STANFORD, 12, 13 and 14 LONG ACRE, LONDON;
W. & A. K. JOHNSTON, LIMITED, 2 ST. ANDREW SQUARE, EDINBURGH;
HODGES, FIGGIS & CO., LIMITED, 104 GRAFTON STREET, DUBLIN.
From any Agent for the sale of Ordnance Survey Maps;
Or through any Bookseller, or from the Director General, Ordnance Survey Office, Southampton.

1920.

Price Six Shillings Net.

PREFACE.

THE Jurassic rocks which form the southern end of the island of Raasay and the neighbouring coasts of Skye have long been known to geologists for the rich variety and abundance of their fossils, but they acquired a new interest when the late H. B. Woodward pointed out in 1893, while surveying the island of Raasay on behalf of the Geological Survey, that they contained a workable bed of ironstone. After some further examination a part of the island was taken up by Messrs. William Baird & Co., and preparations were made for the opening of mines. Raasay is expected soon to furnish almost one-half of the iron-ore annually raised in Scotland, and though the ore is not of high quality it is self-fluxing and well adapted for admixture with other ores. Only the southern part of the ironstone-field has as yet been explored by bores, but in that part upwards of 10,000,000 tons of ore are regarded as having been proved, and in other parts nearly 12,000,000 tons more are considered likely to exist.

As the stratigraphical sequence of the Jurassic rocks is largely dependent upon the palæontology for its correct determination, Dr. G. W. Lee was instructed to examine the strata with special attention to the contained fossils for the purpose of fixing precisely the geological horizon of the ironstone.

In preparing this account of his researches, Dr. Lee has had the benefit of the co-operation of Mr. S. S. Buckman, whose intimate knowledge of the Jurassic brachiopods and ammonites and of their zonal significance has rendered his assistance in the determination of the sequence in these islands of special value. The result of their joint work has been to delineate the life-zones of the Jurassic rocks of this part of the west of Scotland in the fullest manner, and in accordance with the most recent researches on succession and phylogeny.

The map which forms Plate II. in this Memoir is based on the accurate six-inch mapping carried out by the late H. B. Woodward, but a different interpretation placed upon some of the lines drawn by him has led to modification of the boundaries of the Great and Inferior Oolites, the Upper Lias and the basement-beds of the Lower Lias. A small patch also of Cornbrash has been added, but traces of Upper Greensand, which have been observed on Dun Caan, are too small to be shown. An addition to the ironstone-field, in the form of a faulted tract on its southern margin,

M & G Ltd Wt 8881/84 4-20 500 G. 2

is based on the prospecting work of Mr. W. Thorneycroft and Mr. C. B. Wedd.

We are indebted to Messrs. Baird & Co., and to their Manager, Mr. D. Munro, for facilities for gathering the available information respecting this important field of iron-ore.

A. STRAHAN,
Director.

Geological Survey Office,
28 Jermyn Street, London, S.W. 1,
17*th September* 1919.

CONTENTS.

CHAPTER I.

CHAPTER II.

CHAPTER III.

CHAPTER IV.

CHAPTER V.

CHAPTER VI.

CHAPTER VII.

CHAPTER VIII.

CHAPTER IX.

CHAPTER X.

CHAPTER XI.

CHAPTER XII.

APPENDIX.

PALÆONTOLOGICAL CLASSIFICATION AND COMPARISON OF CERTAIN JURASSIC ROCKS OF RAASAY AND SKYE. By S. S. Buckman.

CHAPTER I.

CHAPTER II.

CHAPTER III.

CHAPTER IV.

CHAPTER V.

BIBLIOGRAPHY.

FIGURE IN TEXT.

PLATES.

THE MESOZOIC ROCKS OF APPLECROSS, RAASAY AND NORTH-EAST SKYE.

CHAPTER I.

INTRODUCTION.

Physical Features and Geological Structure.

The Mesozoic rocks to be described are the remnants of once widespread formations the greater part of which has been removed by denudation. What is left owes its preservation to the protecting covering of hard igneous rocks on areas which in many cases were brought by the action of faulting into favourable positions for escaping denudation. The region dealt with—1-inch Map 81—includes the N.E. coast of Skye, the greater part of the isle of Raasay, and part of the mainland of Ross-shire. It is a district deeply cut by sea lochs and narrow sea arms, the land area being hardly larger than that of the sea. The mainland consists principally of old gneiss, Torridon Sandstone and Cambrian; the Torridon Sandstone being by far the most widespread. The ground is hilly, rather bare and of typically glaciated aspect. Rona and the northern extremity of Raasay consist of old gneiss. Torridon Sandstone forms the middle part of the island, while the southern half—which is separated from the Torridonian area by an important fault—consists of Mesozoic rocks partly hidden under Tertiary igneous rocks. The portion of the Isle of Skye which comes within the scope of the present Memoir forms a long narrow coastal strip defined by the western margin of the map. It consists of Jurassic strata and Tertiary igneous rocks, with conspicuous cliff scenery.

The "solid" rocks of the region are as a rule fairly well exposed, except on the higher ground, where peat and boulder-clay often obscure them. There are few deep streams, and in consequence stream sections are not as favourable as the coast sections, though these are sometimes difficult of access.

The geological structure is simple: there are no folds, the Mesozoic rocks forming a sort of plateau with a low prevailing dip to the N.W. There are, on the other hand, numerous ordinary faults which play an important part. Landslips and fissuring of the ground are very common and striking in certain areas.

Types of Rocks.

The Trias consists mainly of conglomerates passing up into marly beds with subordinate siliceous limestone or "cornstone."

The Lias contains a variety of types: limestones of several kinds, shales and sandstones. The now well-known Raasay iron-ore belongs to the top of the formation, as represented here.

The Inferior Oolite is essentially a sandstone formation, with a thin calcareous horizon resting on a base of shales. The Great Oolite is characterised by bituminous shales with beds of sandstones, shelly limestones and argillaceous limestones.

These various types of rocks react naturally on the scenery; the limestones of the lower part of the Lower Lias, the sandstones of the Middle Lias and Inferior Oolite, form great cliffs which rank among the highest in the Western Islands, while the shales of the upper part of the Lower Lias and of the Great Oolite form soft, moorland features.

Jurassic Fossils.

Fossils occur plentifully through great parts of the Jurassic Series. With the exception of the Great Oolite, which is of estuarine origin, the fossils are throughout typical marine forms. In some cases they are so crowded that they form the bulk of certain strata, as, for instance, the limestones of the basal Lower Lias full of a small *Ostrea*, and the limestones of the Great Oolite Estuarine Series, practically made up of *Cyrena* shells.

If lamellibranchs are the most abundantly represented as regards individual numbers, on the other hand ammonites have yielded the greatest variety of species. Other groups are rather restricted or sporadic in their occurrence: corals, for instance, occur only at Applecross, and are not found at the corresponding horizon in Raasay nor at other horizons higher up in the sequence.

In many of the exposures of the strata at the base of the sea cliffs and on the foreshores, the fossils are often beautifully freed from their matrix and are in consequence specially conspicuous. The fossiliferous character of this region therefore attracted the notice of the early observers, who collected materials which are the types of well-known species.

The state of preservation varies with local conditions of deposition and with the degree of induration due to neighbouring igneous rocks, though the latter phenomenon has not perceptibly spoilt the area under consideration from the point of view of fossil collecting, as is unfortunately so often the case in the Hebrides. On the whole the state of preservation leaves little to be desired: the shells of *Ostrea liassica* found in the limekiln quarry at Applecross could not be rivalled for their freshness and perfect preservation of details, and it is much the same with some of the Inferior Oolite ammonites.

The zonal distribution of the fossils in this region is now made out with a fair degree of completeness, and the recent investigations of the Survey with the collaboration of Mr. S. S. Buckman have shown that the sequence is as full and of as great interest to the stratigrapher as in any of the classical English districts. In fact one of the zones at

least attains a development which exceeds anything yet known in England.

The fauna as a whole is of the usual English type, and there are few species that could be said to be peculiar to the district. The zones established are based on known zonal forms readily recognised, and the faunal assemblages are often remarkably like those known elsewhere.

Tabular Statement of Formations.

Although the following list is primarily designed to show the sequence of the Jurassic Rocks, the other formations are also indicated in order to show their relations to the series which is the special object of this Memoir.

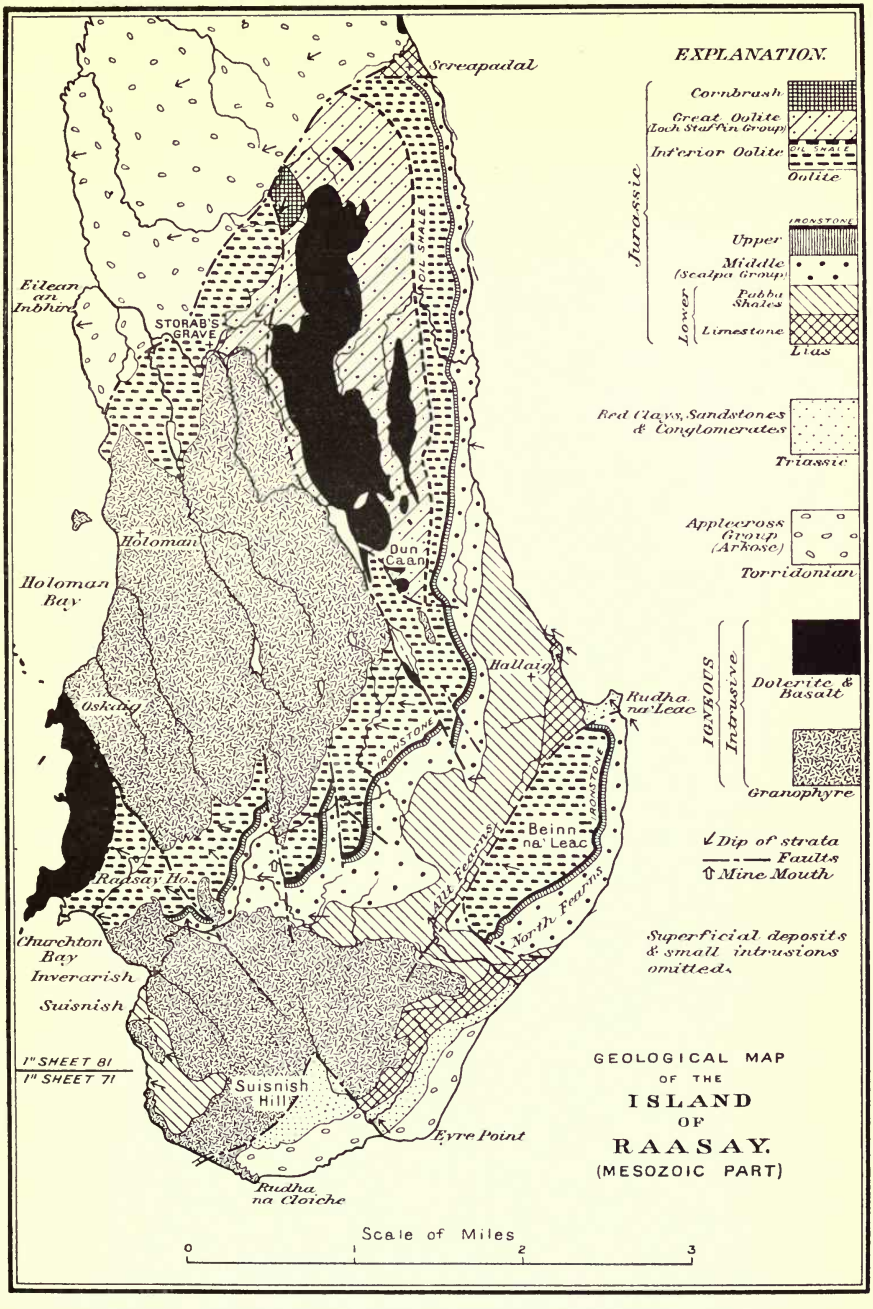
Recent and Pleistocene.	Peat.	
	River alluvia.	
	Raised beaches.	
	Drift.	
Tertiary Igneous Rocks.	Minor intrusions—basalt dykes and sills.	
	Acid sills—granophyre.	
	Volcanic rocks—basalt lavas.	
	Unconformability.	
Cretaceous.	Upper Cretaceous (? Cenomanian)—Glauconitic Sandstone.	
	Unconformability.	
Cornbrash (Great Oolite ?) Fuller's Earth.	Cornbrash, calcareous grit.	
	Great Estuarine Series, bituminous shales with shelly sandstones and limestones.	
Inferior Oolite.	Zones from Aalensis to Garantiana.	Mainly sandstone, calcareous at base and resting on shale. Clay at the top. Thickness up to 700 feet.
	Stratigraphical Break (Non-sequence).	
Upper Lias.	Zones from Tenuicostatum to Subcarinatum.	Oolitic ironstone or limestone resting on shale, and top of Scalpa Sandstone. Thickness up to 70 feet in Skye.
Middle Lias.	Margaritatus, Laevis and Spinatum Zones.	Sandstone — "Scalpa Sandstone." Thickness up to 240 feet.
Lower Lias.	Pabba Shales; Zones from Raricostatum to Valdani.	Shales, about 600 feet thick.
	Broadford Beds; Lower Lias zones up to Turneri Zone.	Chiefly limestones passing up into sandstone 240 feet thick.
Trias.	Conglomerates, with red and green marls at top.	
	Unconformability.	
Upper Cambrian.	Durness limestone.	
Lower Cambrian.	Serpulite grit, Fucoid Beds and "Pipe Rock."	
Precambrian.	Torridonian. Arkoses and shales.	
Metamorphic Schists.	"Moine Series."	
Lewisian,	Gneiss.	

Previous Geological Literature.

The Jurassic rocks of Raasay and neighbouring districts of Skye, Scalpa and Pabba have long attracted attention. In 1819 Macculloch gave a general account of Raasay and ascertained the sequence of the main rock-divisions.

Murchison in 1827 published two papers in which fossil-evidence is used with great skill, enabling him to recognise the existence of several members of the Lower Oolite, though he fell into error concerning the true position of the Middle Lias Sandstone. Bryce's and Tate's accounts of the stratigraphy and palæontology of Skye and Raasay are valuable contributions to our knowledge of the district, published in 1873. Prof. Judd's Memoir on the Secondary Rocks of Scotland, published in 1878, remains a classic of Hebridean geology, remarkable for its accurate and modern treatment of the subject, and especially for a masterly handling of zonal subdivisions, which marks a great advance on the work of British contemporaries.

To the late H. B. Woodward we owe a most accurate map, on the scale of 6 inches to a mile, of the district dealt with in this Memoir, with several short notes and contributions which appeared between 1893 and 1897, and also a general account of the geology of Raasay, published posthumously by the Edinburgh Geological Society in 1914. All readers interested in our supplies of iron-ore are probably aware that the now well-known ironstone deposit of Raasay was discovered by Woodward during his survey of the ground in 1893. The possibility of finding this ironstone in adjacent areas was considered by Messrs. W. Thorneycroft and C. B. Wedd, and the results of their investigations were read before the Edinburgh Geological Society in 1914. The writer of the present Memoir spent part of 1913 and 1914 in establishing the sequence of the Jurassic life-zones of Applecross, Raasay and N.E. Skye, and preliminary results which benefited largely from help kindly given by Mr. S. S. Buckman have appeared in the " Summary of Progress " of the Geological Survey for the years 1913, 1914 and 1915. A paper of great importance, on account of the general principles involved, and the method of work, was read by Mr. Buckman before the Geological Society of London in June 1917. The discoveries made, chiefly in the Pabba Shales of Raasay, furnished the chief suggestions for this paper, and Raasay material is used in illustration. It is published under the title "Jurassic Chronology: I, Lias" in the *Quarterly Journal of the Geological Society*, vol. lxxiii., 1919, p. 257. It was written some time after the contribution given in this Memoir, and contains a more detailed arrangement of zones.



GEOLOGICAL MAP OF THE ISLAND OF RAASAY.

CHAPTER II.

TRIAS.

Applecross.

Sediments of the usual West Highland type referable to the Trias are well developed in the Applecross district, but they are considerably obscured by drift and are not exposed in clear sections. The succession as a whole can, however, be estimated by piecing together the evidence offered in various exposures. Beds which, if they do not actually belong to the base of the formation, are at least very near to it, are seen south of Loch a' Mhuilinn. They are a very coarse conglomerate composed of a sandy pebbly matrix derived from Torridon Sandstone, and containing large elements, up to one foot in diameter: quartzose schist, quartzite and Durness Limestone, the latter plentiful. The thickness of this conglomerate cannot be estimated. The next higher exposure, at a level of perhaps 100 feet above this, occurs on the eastern slope of the hillock which rises half a mile S.E. of Loch a' Mhuilinn. This exposure is interesting on account of its close resemblance to beds which form a conspicuous feature near the top of the Trias in Morvern, namely, a rock allied to "cornstone." Here, it is an eight-foot crag of pebbly grit with calcareo-siliceous matrix, which in the lower half shows a tendency to forming vertical veins, but in the top part the matrix is uniformly distributed. Thin, short layers of silex occur here and there. The silica assumes also the form of thin patches consisting of hemispherical opalescent globules.

The topmost portion of the formation is exposed on the banks of the two streams which flow south of Applecross House. Here some 50 feet of strata are visible, consisting mainly of red sandy marl with intercalations of pebbly sandstone and a conglomeratic band with calcareous matrix, passing up into greenish, reddish and purplish sandy marls, which immediately underlie the basement beds of the Lower Lias.

Raasay.

The New Red rocks of the southern end of the island have been described by Mr. Woodward in a previous Memoir,* and require no further description, except in reference to derived fossils to be mentioned later on. The only exposure besides this is that which forms the promontory of Rudha na' Leac. The junction with the Torridonian is below sea-level, but probably at no great depth, as shown by comparison with the sequence at the southern end of the island.

* "The Geology of Glenelg, Lochalsh and South-East Part of Skye," *Mem. Geol. Survey*, 1910, p. 91.

The sequence of the strata at Rudha na' Leac is as follows, in descending order :—

	Ft.
Gap	
Grey marl	6
Red sandy marl with sandstone bands . . .	20
Pebbly grit	10
Alternations of conglomerate and pebbly grits in bands 2–3 feet thick, with red, sandy marl . . .	50
Conglomerate and grit with a band of red sandy marl .	15
Tough sandy marl or marly sandstone, red, with ill-defined calcareous nodules. The upper half is conglomeratic	12
Conglomerate with thin gritty layers . . .	20

The elements which make up the lowest conglomerate are mostly rounded and vary in size up to a diameter of one foot. They include—in order of abundance—quartzite, vein quartz, green schist, aplite, salmon-coloured felsite and a few fragments of Durness Limestone.

The nodules of the overlying marly band have neither a regular shape nor a definite orientation, and show no tendency towards the vertical arrangement often displayed by cornstones.

The second conglomerate band is made up of Moine Schist, green schist, quartzite, together with abundant fragments of Durness Limestone, on the surfaces of which fossils can occasionally be detected. Of the specimens collected here two are referable to *Dalmanella* ? while two other specimens of the same genus were also obtained at the south end of the island. Considering that the total number of fossils found is very small, it is interesting to note the relative abundance of brachiopod remains, which are extremely rare in the typical Durness Limestone localities. Other fossils are : cf. *Hormotoma subangulata* Ulrich and Scofield, *Maclurea*, *Ophileta*, and a rod-like organism.

The highest bed of sandy marl is seen forming a small crop among a mass of débris, in close proximity to the limestones of the Lower Lias basement beds. The gap in the sequence cannot be estimated accurately, but it does not exceed 20 feet.

CHAPTER III.

LOWER LIAS.

HETTANGIAN AND SINEMURIAN.

Broadford Beds.

Applecross.

The base of the strata to be described is tentatively referred to the Rhætic in the colour-scheme of 1-inch Map, Sheet 81. This attribution was not based on palæontological evidence, but Mr. Woodward, who was aware of the doubt necessarily attached to it, may have estimated that the stratigraphical position of the beds could, for the sake of convenience, justify their tentative allocation to the Rhætic. But the fuller knowledge we have at present of the Liassic basement-beds in this region favours the view that neither at Applecross nor in Raasay is there any recognisable development of the Rhaetic. The non-marine strata referred to the Trias are directly overlain by a marine formation which grades insensibly into typical Lower Lias strata, from which it could not be separated conveniently. These strata can evidently be referred to the basal portion of the "Broadford Beds," a division of the Lower Lias of Skye thus named by Mr. Woodward, which includes the Lower Lias zones from that of *Psiloceras planorbis* to that of *Asteroceras obtusum*.

A clear junction of the Trias with the overlying beds is shown ¾ mile S.E. of Applecross House, on the right bank of the stream which flows close to the limekiln, some 50 yards above the bridge over the main road. Higher beds are seen below the bridge and in the quarry where the limekiln stands. The following section is in descending order :—

		Ft.	In.
10.	Oolitic limestone with *Ostrea*, seen in quarry	10	0
9.	Hard calcareous sandstone, not well seen	5	0
8.	Blue soft clayey shale with *Cardinia*, *Ostrea*, *Pecten*	10	0
7.	Calcareous sandstone with *Ostrea* band	1	0
6.	Soft sandstone	0	6
5.	Fine-grained calcareous sandstone	0	9
4.	Calcareous conglomeratic sandstone, pyritous, with obscure fossils	0	9
3.	White fine-grained knobby limestone with irregular fracture lines	1	0
2.	Grey sandy limestone with obscure traces of lamellibranchs	1	0
1.	White fine-grained knobby limestone with irregular fracture lines	1	0
	Triassic sandy marls		

Beds Nos. 1 and 3 appear to be devoid of fossils. The obscure remains seen in bed No. 2 may perhaps be referred to *Ostrea*, the same doubtful form occurring in bed No. 4, together with gasteropod

shells. The *Ostreas* of bed No. 7 are too firmly embedded to be extracted. As seen in section they are rather flat and average about one inch in length. The overlying shale is rich in fossils, but owing to its soft, crumbling nature, good specimens are difficult to get. Limestone-lenticles occur near the top of the shale : they yielded *Modiola sp.* and *Ostrea liassica.* Obscure remains of some lamellibranch resembling *Lima* are all that could be observed in the calcareous sandstone which comes next.

The limestone which constitutes the highest member in this particular section is well displayed in the quarry, where it is wrought for lime-burning. Owing to its markedly oolitic structure it is easily recognised at the various points where it crops out, and is thus a useful index-bed.

The limestone is generally grey or pale blue, with a yellowish weathering. It occurs in bands mostly less than one foot thick, which are not separated by clayey partings, except one near the base.

The top layer, which is overlain by turf, is regularly channelled by the corrosive action of the humic acids of the surface water, this mode of weathering simulating on a small scale that of the Alpine " lapiaz " and of certain tracts of Carboniferous Limestone. The limestone is homogeneous and free from detrital matter, and is easily polished. A stone of this description could perhaps be used for ornamental purposes, provided it were not exposed to weathering.

In the bulk of the limestone the ooliths lie close together, the interspaces being filled by small granular bodies which look like incipient ooliths. The ooliths average a little less than 1 mm. in diameter. The concentric structure is well shown, and a centre of aggregation can be detected in most cases. This nucleus might perhaps be referred to comminuted shell fragments. As a rule, the ooliths are spherical, but elongate ones are not uncommon, and in those cases the shape is evidently dependent on that of the nucleus. Under certain conditions of weathering the ooliths drop out and gather as a millet-seed like sand, while the rock assumes a characteristically pitted surface. In those portions of the limestone where ooliths are less abundant, the interspaces are occupied by comminuted shell fragments, foraminifera, small gasteropods and echinodermic remains.

Fossils—other than the submicroscopic ones referred to—are restricted to very few species. Indifferently preserved gasteropods occur here and there, and a cidariform Echinid was observed in the lowest bed, but the species of which individuals are particularly abundant is *Ostrea liassica* Strickl., which can be obtained in great numbers and in a perfect state of preservation. It occurs sporadically throughout, and is plentiful in a layer at the top of the second bed, but specimens cannot be collected easily unless the surface of the rock be exposed to weathering for some time. Although individual specimens exhibit a certain amount of variation, the bulk tends towards a Gryphæid type falling into two groups. The predominant group is characterised by the small extent of the base of attachment—the shell becoming free early in life—while in the other group the attachment is well marked. In both cases the surface is very rugose, and the shell evinces a strong tendency towards thickening. One or two specimens

assume an evenly rounded shape simulating that of *Gryphæa cymbium* Lam., while in a few there is a slight lateral twisting of the umbo. The length averages one inch, but may reach one and a half.

Higher beds are not preserved in this section, but the oolitic limestone with *Ostrea* is well shown in another stream-section, where higher beds are exposed. It is the locality referred to by Prof. Judd.*

This stream—Allt Breugaireadch—is not indicated by name on the 1-inch Map, but intending visitors could easily recognise it from the fact that its right bank forms a conspicuous scarp a little over half a mile south-east of the Post Office. Owing to coincidence of dip and slope the lowest member of the sequence, namely, the oolitic limestone, occupies the bed of the stream for about a hundred yards upstream from the corner of the wood, and the next bed—shales and limestones—is seen on the right bank, under an overhanging ledge. For convenience of description the following table of the strata, in descending order, may be given here :—

	Ft.	In.
26. Sandstone, soft, yellow fracture	10	0
25. Conglomeratic band, rounded quartz, pink or white, up to	1	0
24. Sandstone, grey at base, pinkish above, rather soft, slightly pebbly, with occasional crinoid ossicles	12	0
23. Sandy shale with coal streak	1	0
22. Hard solid calcareous sandstone	1	6
21. Sandy shale	1	0
Sill		
20. Sandy shale alternating with bands of calcareous sandstone. *Ostrea*, obscure gasteropods and crinoid remains	7	0
19. Calcareous sandstone	3	0
18. Sandy shale	1	6
17. Calcareous sandstone	1	0
16. Sandy shale	1	0
15. Grey sandy crinoidal limestone	1	6
14. Soft sandstone	1	0
13. Coral limestone	3	0
12. Fossiliferous limestone	4	0
11. Obscure ground, probably sandy shale	10	0
10. Calcareous sandstone	2	0
9. Sandy shale	1	0
8. Pale grey sandy limestone with small red ooliths, weathering dark with carious surface	4	0
7. Sandy shale	1	0
6. Hard dark calcareous sandstone	5	0
5. Light grey sandy shale	4	0
4. Earthy limestone with *Ostrea*	3	0
3. Hard limestone, slightly oolitic, with gasteropods and occasional corals	4	0
2. Hard sandy limestone, slightly oolitic, with *Ostrea*	4	0
1. Alternations of soft dark grey sandy shale with bands of hydraulic concretionary limestone containing *Ostrea*, *Modiola*, gasteropods, etc.	6	0
Oolitic limestone (already described)	12	0

The sedimentation of bed No. 1 is rather peculiar and does not occur at other levels. The limestone concretions assume the shape of dichotomising elongate bodies of elliptic section. Fossils are fairly abundant in the limestone and rare in the shale. Of the following list *Ostrea liassica* and *Modiola* are the most abundantly repre-

* "The Secondary Rocks of Scotland," *Quart. Jour. Geol. Soc.*, 1878, p. 698.

sented as regards individuals. The *Ostrea* is smaller than in the underlying oolitic limestone, and seems to belong mainly to the type with well marked base of attachment. The most interesting feature of this bed is the fact that it yielded an ammonite. No ammonites had so far been found in Scotland anywhere below the Rotiformis Zone, with the exception of a derived specimen from the Arran volcanic vent, hence the importance of this find which greatly strengthens the correlations previously based on considerations mainly stratigraphical. The specimen is very poorly preserved—the periphery being hidden and no suture line visible—but Mr. Buckman sees no reason to doubt that it is a *Schlotheimia*, reminiscent of *S. montana* Wähner, a species of the Marmorea Zone, which is the highest zone of the Hettangian stage, next below the Rotiformis Zone. This means that the greater part of the Applecross Lower Lias is to be referred to the upper part of the Hettangian, and base of the Sinemurian, leaving but a small thickness of sediments to include the rest of the stage, and opens the question of the possibility of a non-sequence. The fossils are :

Cardinia sp.
Homomya ?
Modiola hillana *J. Sow.*
Modiola scalprum *J. Sow.*
Mytilus sp.
Ostrea liassica *Strickl.*
Turritella deshaysea *Terq.*
Euomphalus-like gasteropod
Schlotheimia *cf.* montana *Wähner*

Fossils cannot be extracted from the limestones 2 and 3. The coral is not readily seen except when the rock has been polished by the action of running water. The higher beds, up to No. 12, do not show any points of palæontological interest. Geologists visiting this section should notice that when reaching band No. 7 they will meet some of the lower beds, brought up by a fault, and that the up-throw side offers the better facilities for investigation. Beds 12 and 13 form together a crag whose conspicuous whiteness is a good landmark. Both beds contain several bands separated by thin clayey layers. The lower one shows rapid lateral variation: hard and compact and relatively unfossiliferous at one place, it becomes, a few yards away, softer and earthy and richly fossiliferous. The most abundant fossil is a species of *Gryphœa*, which is much larger than the *Ostrea* of bed No. 1. It is a convex shell with corrugated surface, showing some slight resemblance to *G. arcuata* Lam., but it is probably not related to it as the umbones taper more rapidly and evince a marked tendency towards an Exogyriform twisting. The other fossils are :

Thecosmilia martini (*de From.*)
Rhynchonella calcicosta *Dav.* (non *Quenst.*)
"Zeilleria" *cf.* darwini *Desl.*
Mytilus sp.
Syncyclonema sp.
Euomphalus-like gasteropod

The *Mytilus*, which may possibly be new, is a subtriangular form of the type of *M. aviothensis* Buv., but more expanding.

The coral occurs only sporadically, while the *Rhynchonella* is found throughout, but is specially common in a layer either at the top of this bed or at the bottom of the upper one. *Ostrea münsteri* Bronn [= *O. multicostata* Münster] was also found in this *Rhynchonella* layer.

The top bed of the crag differs from the lower one in that at certain points it is practically made up of *Thecosmilia martini* and looks like a coral reef. It is, however, variable in character, passing laterally to a sandy limestone without corals. *Rhynchonella calcicosta* and a cidariform plate were also found there.

Loose blocks in the bed of the stream, which probably belonged to the coral-limestone, have yielded an interesting fauna, unfortunately in a poor state of preservation. The fossils obtained are :

Anomia ?
Astarte ?
Cardinia *cf.* listeri *J. Sow.* [rather transverse]
Gervillia sp.
Lima sp.
Pholadomya sp.
Pinna sp.
Cryptænia sp.
Euomphalus-like gasteropod (new ?)
Large spirally-striated gasteropod, shaped like Bourguetia
Littorina ? clathrata *Deshayes*
Neritiform shell
Patella *cf.* schmidti *Dunker*
Turritella deshayesea *Terq.*

In the rest of the section the fossils are imperfectly preserved and difficult to extract. A single ammonite, obtained by Mr. Tait after considerable toil, proves of great zonal value. It was not found *in situ*, but its position where lying and the lithological characters of the matrix seem to show that in all probability it was derived from the hard calcareous sandstone bed No. 22. The specimen, which is imperfect, is part of a large example of *Coroniceras coronaries* (Quenst.). This gives us palæontological evidence of the presence of the Rotiformis Zone, but to what extent it should include the strata above and below cannot be determined, on account of the scarcity of zonal fossils. The presence of a fairly thick series of sandstone belonging either to the Rotiformis Zone or to the zone above is an interesting fact worthy of special notice when comparing the sequence here with that of other areas.

The above description of the Allt Breugaireadch section agrees with that given by Prof. Judd, p. 698, *loc. cit.* But, without specifying the locality where his observation was made, he indicates a thick series —more than 50 ft.—of limestones as coming above the highest sediments of the Allt Breugaireadch section. With this, the recent examination of the Applecross district is not in agreement. The mapping of Mr. Woodward does not show the presence of higher beds *in situ*, nor could they be detected by the present writer—excepting, of course, the *Gryphæa*-limestone to be mentioned further on. Owing to the presence of small subsidiary dislocations the structure of the ground is not always quite clear, and it is possible that Prof. Judd may have been deceived by some such cause, and taken the basal limestones to be the higher groups (Nos.1 and 2) of his section.

The shore section is very striking owing to the lateral extent of the bare dip-slope of limestone, so regular as to look like an artificial pavement. Between Milton Pier and the Post Office there is an ascending sequence from the S.W. to N.E. The lower bed, which forms the sloping pavement, is a slightly oolitic limestone, presumably Nos. 2 and 3 of the Allt Breugaireadch section. After a horizontal gap of 50 feet it is succeeded by higher beds, including a coral limestone which also matches with the stream section. A thin calcareous sandstone with a pebbly band is succeeded by an horizontal gap of 20 feet, after which there is a sudden and strong increase of dip and a change of strike in the strata met with. These are seen quite close to the Post Office, and evidently belong to the margin of a faulted patch. They consist of four bands of sandy limestone with *Gryphæa arcuata* Lam., and possibly *Lima gigantea*. The fault runs probably along the high-water mark, since the foundations of the Post Office rest on beds which, judging from their dip and strike, lie probably a short distance above the coral-limestone. This small exposure of *Gryphæa*-beds is the only one in the Applecross district. Further N.E. they are covered by drift or raised beach materials. Prof. Judd states that he noted them in 1872 in an excavation then being made near Applecross House, and quotes a number of fossils he obtained there.

Higher members of the Liassic sequence are not known at Applecross, and it is not likely that any lie hidden under superficial deposits.

Raasay.

In Raasay the Lower Lias strata belong to two main lithological divisions. The basal portion consists mainly of limestones or of calcareous sandstones forming scarps which contrast greatly with the smooth features due to the soft, shaly nature of the overlying division known as " Pabba Shales." A somewhat similar sequence obtains in the Isle of Skye, and it has been proposed that the name Broadford Beds be applied to the lower division. Palæontologically the Broadford Beds of Skye range from the basement beds, which probably include the Planorbis Zone, to the Obtusus Zone.

In Raasay no fossils of zonal value were found below the beds of Rotiformis age. The beds lying below those which show the first indication of a Rotiformis fauna are of considerable thickness, and are presumably Hettangian as in the Applecross district.

These lower beds are best seen on the west side of the bay that lies to the west of Rudha na' Leac. The basal portion shows only on the shore, while the rest of the section forms the base of the scarps which stretch from the Hallaig path down to the sea. The sequence consists of limestones alternating with bands of shale. Arenaceous or coarsely detrital sediments are not represented. The examination of the fossils does not show any striking feature regarding the distribution of the fauna within the various bands. Consequently there is no call for describing each band separately, while the following tabular statement will suffice to show the relations between the fossils and the beds they come from :—

		Ft.	In.
44.	Brown hard sandy limestone	4	0
43.	Brown sandy carbonaceous limestone forming ledge	4	0
42.	Shale	0	2
	Sill	3	0
41.	Shale	0	2
40.	Hard brown sandy limestone, obscure fossils	2	0
39.	Dark shale	2	0
38.	Limestone	2	0
37.	Gap, grassy slope	about 15	0
36.	Sandy limestone	2	0
35.	Lumpy limestone, grey and fœtid	2	0
34.	Coarse grey sandy limestone	1	6
33.	Grey lumpy limestone	4	0
32.	Grey sandy limestone, weathering pinkish	6	0
31.	Lumpy limestone, abundant *Gryphæa*, also *Pleuromya*	10	0
30.	Limestone and partings, both full of small *Gryphæa*	2	0
29.	Shale and limestone bands	2	0
28.	Pale limestone	4 to 7	0
	Sill	3	0
27.	Grey limestone with siliceous films, obscure fossils	5	0
	Sill with columnar jointing	10	0
26.	Knobby brown limestone with obscure fossils	?	
25.	Pale brown limestone	1	6
24.	Brown limestone with *Ostrea*	2	0
23.	Hard blue limestone with *Ostrea*	3	0
22.	Shaly limestone passing to tough calcareous shale	3	0
	Sill	2	0
21.	Blue limestone	1	0
20.	Tough calcareous shale or shaly limestone with crushed lamellibranchs	3	0
19.	Limestone with small *Ostrea*	0	6
18.	Fissile shale	0	6
	Sill	6	0
17.	Black shale	0	1
16.	Black shaly limestone made up of a crushed shell	0	6
15.	Brown sandy limestone	0	6
14.	Shale	0	3
13.	Brown limestone full of an obscure small bivale	0	6
12.	Gap	1	0
11.	Blue limestone with obscure sections of fossils	0	6
10.	Shale with *Ostrea*	0	6
9.	Earthy limestone	1	0
8.	Shaly limestone with *Ostrea*	0	6
7.	Gap, partly occupied by sill	10	0
6.	Brown earthy limestone with *Pecten* and also *Ostrea*	1	0
5.	Gap	1	0
4.	Hard blue limestone with a few irregular shaly partings. Occasional sections of gasteropods	2	0
3.	Gap	6	0
2.	Blue limestone with irregular shaly partings containing a large *Lima*	3	0
1.	Brown limestone with abundant *Ostrea* ?	0	6
	Gap	about 20	0

The fossils are generally in a poor state of preservation, which renders identification difficult. It is therefore possible that the fauna may contain forms which may be new, although they are here referred to, or compared with well-known species.

From beds No. 1 and 2 Mr. Tait obtained :

? Eopecten tuberculosus (*Gold.*)
Lima (Plagiostoma) *cf.* gigantea (*J. Sow.*)
Modiola *aff.* morrisi *Oppel*

Mytilus sp.
Ostrea *cf.* liassica *Strickl.*
Pinna sp.
Pleuromya ? sp.

Bed No. 4 yielded a *Modiola* allied to *M. morrisi*, *Ostrea irregularis* Münster, with broad attachment, and a convex form of *Ostrea*.

Ostrea liassica Strickl., and a rather convex form allied to it, occur in bed No. 6, together with a *Cardinia* and a *Pecten* resembling *P. valoniensis* Defr. The fossils from beds Nos. 19 to 24 are *Cardinia listeri* J. Sow., *Modiola* aff. *morrisi*, differing from Oppel's species in being narrower anteriorly, *Modiola sp.* resembling *M. scalprum* of Dumortier (*non* Sow.), *Ostrea liassica* Strickl., a small arcuate *Ostrea*, and another with a base of attachment.

Bed No. 30 forms a recess in the third scarp, which consists of limestone and partings characterised by the abundance of a small *Gryphæa*. Other fossils are rather sparingly represented, as the following list shows :—

Cardinia sp.
Gryphæa, 2 spp.
Lima sp.
Mytilus sp.
Pleuromya sp.

Neither of the two forms of *Gryphæa* appears to belong to described species. Both are small and arcuate, the more common form being straight, while the other is characterised by the *Exogyra*-like twist of the umbo. It is like the form from the coral-limestone of Applecross, but is smaller. The higher beds of this section have not yielded any determinable fossils.

From the above account of the distribution of life in these rocks it will be seen that, although their place in the zonal scheme cannot be fixed on incontrovertible palæontological evidence, the facies of the fauna as a whole is reminiscent of that of the Hettangian strata of England, and there can be little doubt as to the correctness of this correlation, made by earlier observers.

Through insensible gradation the topmost band of the above described section passes into a set of sediments characterised by the first appearance of the *arcuata* group of *Gryphæa*. Higher up these sediments become more or less arenaceous, as shown on the following section in which the strata are indicated in descending order : the lowest band being directly superposed to the highest of the section just considered.

	Ft.	In.
56. Muddy micaceous sandstone, calcareous, with *Gryphæa arcuata* and large ammonites of *bucklandi* type half-way up, and *Vermiceras* cf. *conybeari* 10 feet from base	50	0
55. Calcareous sandstone and sandy shale with *Gryphæa arcuata* with corrugated shell.	15	0
54. Calcareous sandstone and sandy shale with *Gryphæa arcuata*	5	0
53. Calcareous sandstone, with a band of very large *Lima gigantea*	1	0
52. Micaceous shale with twelve bands of calcareous sandstone	20	0
Gap	10	0

	Ft.	In.
51. Hard sandy shale with a few *Gryphæas* . . .	10	0
50. Sandy micaceous shale	10	0
49. Brown sandy limestone with band of *Gryphæas* at base	10	0
48. Sandy shale	0	6
47. Brown sandy limestone	3	0
46. Sandy shale	0	6
45. Hard brown sandy limestone. *Gryphæa* cf. *arcuata* makes its first appearance here in a band at base .	4	0

Until we reach the *Lima*-bed, *Gryphæa* is the only fossil present in the section. In the lower band, No. 45, it is represented by a small narrow form, less arcuate than *G. arcuata*, and devoid of sulcus. The same type still occurs in bed No. 49. In band 51 the *Gryphæa* is almost typical *G. arcuata*, only the sulcus is rather faint.

The *G. arcuata* of bed 54 is quite typical, and in the higher beds it shows a marked wrinkling or corrugation of the shell.

The top of this section forms the line of crags down which the Hallaig burn tumbles into the sea as a conspicuous waterfall. A few fossils were obtained at this point, besides the *Gryphæa* just referred to. They are :

Rhynchonella *cf.* parvirostris *Rau*
Spiriferina walcotti (*J. Sow.*)
Cardinia listeri (*J. Sow.*)
Grammatodon ?
Lima pectinoides (*J. Sow.*)
Lima sp.
Unicardium ?
Amberleya chapuisi (*Terq. and Piette*)
Turbo *aff.* licas *d'Orb.*
cf. Umbonium sordidum (*Tate and Blake*).

Ammonites obtained from the base of the cliff below the waterfall indicate the Gmuendense Zone. They are :

Agassiceras sauzeanum (*d'Orb.*)
,, *aff.* sauzeanum (*d'Orb.*)
,, halecis (*J. Buck.*)
,, *cf.* subtaurus (*Reynès*)

Vermiceras conybeari (d'Orb.) [*non* Sow.] indicating the underlying Rotiformis Zone, was found farther inland, below the path to Hallaig, 30 feet above the Lima Bed. Loose blocks yielded also the following species of the Gmuendense Zone :—

Coroniceras gmuendense (*Reynès*)
,, alcinoe ? (*Reynès*)
,, nodosaries ? (*Quenst.*)

Arnioceras sp., indicating the Semicostatum Zone, was obtained some 12 feet higher in the section, that is, several feet below the lip of the waterfall.

This bed is succeeded by another sandstone, 40 feet thick, forming the cliff north of the waterfall. It is flaggy and carbonaceous and weathers with a rusty colour. Objects resembling worm castings and fucoid markings are common, and also ferruginous nodules.

The fossils collected are :

Gryphæa arcuata *Lamarck*
Mytilus sp.
Ostrea irregularis *Münster*
Protocardia truncata (*J. de C. Sow.*)
Pseudomonotis *cf.* decussatus (*Münster*)
Unicardium subglobosum (*Tate*)
Arietites turneri ? (*J. de C. Sow.*)
,, brooki ? (*J. Sow.*)
,, plotti ? (*Reynès*)
Microderoceras birchi (*J. Sow.*)

Of the ammonites all but the last indicate the Turneri Zone. With so few specimens at hand it is not possible to estimate the thickness of sediments referable to the Birchi Zone. *Gryphæa* is very scarce and occurs only in a layer 6 feet below the top of the sandstone.

Before proceeding further, it may be mentioned that the basement beds with *Ostrea* and the *Gryphæa*-beds occur also in the south part of the island in the area of Ordnance 1-inch Sheet 71. They do not display good sections, and there is little to add to the account given by Mr. H. B. Woodward.* There is a lithological difference which ought to be mentioned ; the *Gryphæa*-beds are more calcareous and less arenaceous than at Hallaig, forming true limestones, but include also coarsely detrital sediments. A conglomeratic band underlying limestone with *Gryphæa* is seen on the shore a few hundred yards east of the new pier.

Calcareous sandstones with *Gryphæa* are also exposed near the mouth of the stream which flows between North Fearns and South Fearns. The section is not favourable for detailed examination, much of it being too steep, but there can be little doubt that in the main the beds exposed belong to the Semicostatum, Birchi and Turneri Zones.

The small triangular patch of Lower Lias shown at South Screapadal in the extreme N.E. corner of the Jurassic area of Raasay, between the main fault and a branch of it, consists of micaceous shale with numerous bands of calcareous sandstone. The lithological character, and also the presence of abundant *Gryphæa arcuata* of the typical shape shows that these beds belong to that division of the Hallaig section which comprises the *Lima gigantea* band—although this particular fossil was not detected here. In other words, in terms of the zonal nomenclature, the Lower Lias of South Screapadal belongs in a general way to the Rotiformis Zone. The above remarks apply to some 40 feet of strata forming the top of the section. Nearer the mouth of the stream the ground is obscured, and there comes a repetition of similar beds, pointing to the presence of a fault running probably from S.E. to N.W.

In Skye the calcareo-arenaceous lower half of the Lower Lias comprises sediments belonging to the Obtusum Zone. The equivalent lithological division in Raasay has not yielded any indications of the presence of that zone, which is therefore either absent or restricted to an inconsiderable thickness of strata in which—if present—fossils were not detected.

**Loc. cit.*, p. 97 and pp. 112-113.

Charmouthian.

Pabba Shales.

The thick series of shales which constitute the higher member of the Hebridean Lower Lias was named "Pabba Shales," after the name of the Island of Pabba. It should however be noted that in the type locality only part of the series is exposed, that is, the portion representing the Armatus and the Jamesoni Zones. At that time the great development of the underlying Zone of *Echioceras raricostatum*—which cannot be separated from the higher ones on lithological grounds—was not known. But as the term has since been used to denote the whole sequence of shales, it is more convenient to retain it, although, strictly speaking, it is somewhat a misnomer.

In Raasay the Pabba Shales cover a considerable tract of ground, and stretch obliquely across the island from Suisnish to the north-east beyond Hallaig. These strata, in the southern end of Raasay, have been briefly described by Mr. Woodward,* and since they are much hardened by the contact action of igneous rocks they are not a favourable field for fossil collection, so that there is nothing to add to Mr. Woodward's description. On the other hand, north of the sheet of granophyre which covers a large part of the southern end of Raasay, the Pabba Shales are unaltered and can be studied in detail. The thickness of the series amounts to about 600 feet, but exact measurements of the various zones included cannot be given, owing to the paucity of clear sections of sufficient length, as can be expected when dealing with such a soft, crumbling formation.

The base of the series is exposed for a short distance in the bed of the stream south of North Fearns, but no fossils were found at that point. It is near Hallaig that the basal beds are best shown: The Hallaig burn runs for about three-quarters of a mile along a dip-slope, its actual bed being on the sandstone of the Turneri Zone, while its left bank consists of black shale. This illustrates forcibly the sharp junction between the two divisions, the shale coming in abruptly without any transition whatever. Although no conglomerates or coarse detrital sediments occur at the base of the shale, its sudden incoming on strata of such different character points to a break in the sedimentation. Another feature which seems to point to a break is the apparent absence of the Stellare and Oxynotum Zones, besides that of the Obtusum Zone already referred to.

For a few feet upwards from the junction the strata are relatively unfossiliferous, yielding mainly obscure lamellibranchs. The lowest bed with zonal fossils was found in a small affluent which joins the main stream near the point where it crosses the path to Hallaig, and its horizon may be some 10 feet above the base. Here were obtained small gasteropods and ? *Echioceras spiratissimum* (Quenstedt). This bed passes up into more shales, with clay-ironstone nodules and a 6-inch band of sandy limestone. These strata yielded a number of fossils, including ammonites, the determination of which has introduced a puzzling element in the reading of the sequence. The succession appears quite simple and normal, up a gentle slope, and shows no signs of faulting or slipping. Yet Mr. Buckman thinks that the

**Loc. cit.*, p. 113.

ammonites: *Echioceras* cf. *aplanatum* (Hyatt), *E. microdiscus* ? (Qu.), *E. modestum* ? S. Buck [*Ar. spiratissimus* ? Hug *non* Qu.] indicate a position high up in the Raricostatus zone. It follows that the strata were either slipped from their true position in such a manner as to deceive the observer completely, or that these species may be deceptive homoeomorphs. This discrepancy is regrettable as there are no other favourable exposures of that level, so that our knowledge of the Pabba Shales life-zones is not so complete as it might have been. *Gryphæa arcuata* Lam., was found 20 feet up from the base in the first mapped affluent of the Hallaig burn, and *Echioceras* aff. *deciduum* (Hyatt) at the top of the second affluent, that is, some 150 feet from the base. That species was also obtained higher up in the bank of the main stream. Allt Fearns (not indicated by name on the 1-inch map), which has its source W. of Beinn na' Leac, and reaches the sea between North Fearns and South Fearns, offers a magnificent section through several hundred feet of the Pabba Shales, going upwards from the sharp bend of the stream, on the left-hand side of the road (Pl. III., 1). Down stream from that point the shales are obscured by drift, and are also presumably crossed by a fault which prevents a correct estimate of the vertical distance between the base of the series—seen half a mile below—and the first beds of the section above the bend.

The lithological characters of the shales are throughout remarkably constant. They are uniformly dark and micaceous, with argillaceous nodules and thin lenticular bands of calcareous sandstone and argillaceous limestones. On account of this lack of differentiation, a tabular statement of the section to show the relations between the fauna and the sediments would not be sufficiently illustrative, and another means of expressing the faunal sequence will be adopted here. The fossils were collected zonally with great care in successive lots, each designated by a reference number entered in the list-books. It must be noted that these numbered lots are not meant to express distinct assemblages or subzones; they are merely artificial landmarks to facilitate the interpretation of the faunal distribution. The numbers are in ascending sequence from the base upwards, and spread over a vertical distance of about 300 feet, from the bend of the stream to the point where it is crossed by the path leading to Dun Caan.

	Horizon numbers.
Pentacrinine ossicles	7
Rhynchonella *cf.* calcicosta (*Quenst.*)	11
„ „ gryphitica juvenis (*Quenst.*)	4, 5, 6
„ „ parvirostris *Rau*	13
Cardinia listeri *J. Sow.*	7, 11
Gryphæa *cf.* arcuata *Lam.* [sulcus indistinct]	10, 11
„ „ cymbium *Lam.* [small]	11
„ sp. (1)	7
„ sp. (2)	4
„ sp. (3)	13
Hippopodium ponderosum *J. Sow.*	10, 12, 13, 14
Homomya vetusta (*Phill.*)	13
Lima pectinoides *J. Sow.*	7, 13, 14
„ sp.	10
Modiola scalprum *J. Sow.*	10, 14
Ostrea sp.	7
Pecten *cf.* æquivalvis *J. Sow.* [small]	14

1. Upper Portion of Pabba Shales. Allt Fearns, Island of Raasay.

2. Scree detached from hill slope. South-west side of Beinn na' Leac, Island of Raasay.

	Horizon numbers.
Pecten calvus *Münster*	11
„ liasinus *Nyst*	7
„ *cf.* thiollieri *Mart.*	7, 8
„ *cf.* texturatus *Münster*	7
„ sp. [fine ribbing]	8
„ sp. [*cf.* valoniensis *Defr.*]	11
Perna sp.	7
Pinna folium *Phill.*	11
„ hartmanni *Ziet.*	14
cf. Plicatula oxynoti *Quenst.*	10
Pteria inæquivalvis (*J. Sow.*)	14
Cf. Pteria papyria (*Quenst.*)	10
Unicardium cardioides (*Phill.*)	14
Amberleya gaudryana (*d'Orb.*)	10
Gasteropods	8
? Bifericeras subplanicosta (*Oppel*)	7, 10
Deroceras anguiforme (*Simpson*)	5
„ *cf.* hastatum (*Y. and B.*)	13
„ *cf.* miles (*Simpson*)	12
„ *cf.* densinodus (*Quenst.*)	7
„ milleri (*Wright*)	9, 10
„ *cf.* obsoletum (*Blake*)	7, 10
Echioceras aplanatum ? (*Hyatt*)	13
„ aureolum (*Simpson*)	7
„ boehmi (*Hug*)	7, 11
„ boreale *S. Buck.*	10
„ cereum (*Simpson*)	10
„ edmundi (*Dum.*)	7
„ costidomus ? (*Quenst.*)	8
„ *cf.* deciduum (*Hyatt*)	10
„ *cf.* faivrei (*Hug*)	10, 11
„ gracile ? (*Quenst.*)	8, 10
„ lævidomus (*Quenst.*)	7
„ macdonnelli (*Portl.*)	10, 11
„ meigeni (*Hug*)	10
„ microdiscus (*Quenst.*)	8
„ modestum, *S. Buck.*	7, 10, 11
„ oosteri (*Dum.*)	10
„ *cf.* polygyratum *S. Buck.*	7
„ prorsum *S. Buck.*	7
„ pellati (*Reynès*) [non *Dum.*]	11
„ patti ? (*Reynès*)	7
„ ? pauli ? (*Dum.*)	8
„ raricostatoides (*Vadasz*)	10
„ robustum (*Quenst.*)	7, 8
„ *cf.* rhodanicum *S. Buck.*	7
„ scoticum *S. Buck.*	11
„ subquadratum *S. Buck.*	13
„ subobsoletum *S. Buck.*	10
„ zieteni ? (*Quenst.*)	7, 8, 10
Belemnites apicicurvatus *Phill.*	11, 13, 14
„ breviformis *Phill.*	14
„ oxyconus *Phill.*	7
Decapod crustacean	10

This rich fauna characterises the Raricostatus Zone. Mr. Buckman has already commented on the importance of this zone in Raasay as compared with its development in England.*

Here the Raricostatus Beds fill about 300 feet of strata, and this

* "Summary of Progress" for 1913 (*Mem. Geol. Surv.*), 1914, p. 87. Also "Yorkshire Type Ammonites," 1914, pp. 96c, 96d, and "Jurassic Chronology," *Quart. Jour. Geol. Soc.*, vol. lxxiii., part 4, 1917.

is not all, since the base of the section is obscured. In England—as remarked by Mr. Buckman—these beds are poorly developed and in many cases their fauna is found *remanié* in the Armatus Beds. *Echioceras* is remarkably prolific, not only as regards the number of species, but also as regards the abundance of individuals. Besides the better preserved specimens found in nodules, there are swarms lying crushed in certain layers of the shale. There is here an excellent opportunity to note the sequence of *Echioceras* species within the limits of the zone itself, and from data furnished by the Geological Survey Mr. Buckman constructed the following tabular statement, which is reproduced here from p. 96d of his "Yorkshire Type Ammonites."

"Sulcates and sub-sulcates.	*E.* cf. *oosteri*, *E.* cf. *aplanatum*. *E. subquadratum*.
Degenerates and subsulcates.	*E. macdonnelli*, *E. scoticum* and other subsulcates.
Crassicostate non-sulcates.	*E. robustum*, *zieteni*, *raricostatoides*, *cereum*.
Sub-sulcates and non-sulcates.	*E. boehmi*. *E. lævidomus*, *E. edmundi*.
Parvicostate non-sulcates.	*E. boreale*, *E. prorsum*, with Derocerates of the *densinodum* type.

"The above are some illustrative species. It will be seen that in a general way the geological and biological sequences are in accord."

The type-specimens of *E. boreale*, *E. subobsoletum* and *E. scoticum* are from this locality. That of *E. polygyratum* S. Buck. comes from near the source of the Hallaig burn, where it was found together with *E. boehmi* ? (Hug) and *E. ophioides* (d'Orb.).

The presence of species of *Deroceras* is one of the most interesting features of this series and opens the question of "faunal repetition" developed by Mr. Buckman in his paper already referred to.

This type of sediments is evidently unfavourable to gasteropod life, since only two were oberved. Of the numerous species of lamellibranchs few are abundantly represented. *Cardinia* is the most common form. *Hippopodium ponderosum* attains a large size and is represented by a few remarkably well-preserved specimens. *Gryphæa* occurs only sporadically, never in clusters. Some approach *G. arcuata* in the possession of an arcuate shape, but the sulcus is not defined. Perhaps it is the form to which the name *G. obliquata* (J. Sow.) has sometimes been applied ; but it is better not to use this name until we know more of the exact nature of Sowerby's species. Other forms tend towards *G. cymbium* in the broadening and flattening of the shell, but they are much smaller.

The nodules—from which several of the ammonites were obtained—are rather interesting. In the lower half of the section they are irregular flattened masses which may attain a length of one foot. Towards the middle of the section, some show a peculiar structure, consisting of a core of sandy limestone reeking of sulphuretted hydrogen, with a crystalline cortex. In the top half a large proportion of the nodules are small and tend towards uniformity of shape, mostly that of an elongate ellipsoid.

The highest beds of the Allt Fearns section are exposed in the steep

bank forming the western slope of the valley above the path leading to Dun Caan. Lithologically they are like the lower beds, with this difference that they are slightly more sandy. This bank, which is some 70 feet thick, has not yielded many zonal fossils. The few ammonites obtained *in situ* indicate the Jamesoni or the Valdani Zone. Indications of the Armatus Zone were found in a loose block, but there is not room here for the full development of the zone. It is possible part of it may be cut out by a fault or hidden by slipping, but the base of the scarp being obscured by talus the explanation cannot be arrived at here. Therefore, the description of the Armatus Beds seen on the Hallaig shore will be given here so as not to interrupt the stratigraphical order of this account. They are exposed between tidemarks E. and S.E. of the fishermen's hut three-eighths of a mile N.W. of the waterfall. The junction with the Raricostatus Beds is not seen, the latter being obscured by a large landslip and also presumably partly cut out by a fault, indications of which are shown by the disturbed state of the Armatus Beds, which dip up to 30° N.W. Like the Raricostatus Beds they consist of micaceous shale with ferruginous limestone nodules. Their thickness is perhaps about 100 feet. Fossils are not abundant, but they are well preserved and typical of the Armatus Zone.

Cardinia listeri (*J. Sow.*)
Gryphæa cymbium *Lam.*
Gryphæa sp. [of *arcuata* type]
Hippopodium ponderosum *J. Sow.*
Modiola scalprum *J. Sow.*
Pholadomya ambigua (*J. Sow.*)
Pleuromya costata (*Y. and B.*)
Pleurotomaria anglica (*J. Sow.*)
Deroceras *cf.* distans (*Quenst.*)
„ hamiltoni ? (*Simp.*) [Amm. nodogigas *Quenst.*]
„ marshallani ? (*Simp.*)
„ miles (*Simp.*)
„ *cf.* owenense (*Simp.*)
„ *cf.* submuticum (*Dum.*) [non *Oppel*]
„ unimacula ? (*Quenst.*)
Belemnites apicicurvatus ? *Phill.*

Transition to the overlying Jamesoni Zone begins approximately north of the hut. There is little lithological change, which is moreover very gradual. The shales become gradually harder and more sandy, with intercalations of lenticular calcareous sandstone bands. Fossils are also more abundant, but not so well preserved. In particular, some of the calcareous lenticles are full of comminuted shell débris, and in the shale, too, the state of the fossils sometimes strongly suggests that they are *remanié*. These Jamesoni Beds are about 50 feet thick. Besides the fossils of the following list, *Acanthopleuroceras solare* ? (Quenst.) and *Platypleuroceras sp.* were also obtained, but not abundantly enough to permit a separate description of the Valdani Zone which they indicate.

Rhynchonella *cf.* curviceps (*Quenst.*)
„ „ tetrahedra *Dum.* [non *Sow.*]
Cardita sp. nov. *aff.* multicostata (*Phill.*)
Gresslya intermedia (*Simp.*)
Gryphæa cymbium *Lam.*
Lima pectinoides (*J. Sow.*)
Modiola scalprum *J. Sow.*

Pholadomya ambigua (*J. Sow.*)
Pinna sp.
Pleuromya costata (*Y. and B.*)
Unicardium cardioides (*Phill.*)
Uptonia costosa ? (*Quenst.*)
,, lacunosa ? (*Quenst.*)
Belemnites acutus ? *Phill.*
,, apicicurvatus ? *Phill.*

The *Cardita* approaches *C. multicostata* in the possession of very fine ribbing, but it differs from Phillips' species in being much larger, with higher beaks. Tough shales with red spots, and calcareous sandstones weathering with a carious surface, some 20 feet thick, separate the highest strata in which indications of the Jamesoni-Valdani fauna were found, from the base of the Middle Lias sandstone. *Gryphæa cymbium*, *Pecten æquivalvis*, a huge *Pinna*, and Belemnites occur here, but no ammonites. But, inferring from evidence obtained at other points, it is probable that these beds belong to the Striatum and Capricornus Zones.

After the above account of the Hallaig shore section, which was necessary in order to show the extent of the Armatus Beds, the description of the higher beds in the Allt Fearns and tributary sections can now be resumed.

The highest western bank in Allt Fearns, and the section along the second stream west of it belong to the Jamesoni and Valdani Zones. The fauna is here slightly different from that of the shore section. For instance, *Gryphæa* which at Hallaig is sporadic, forms here a thick bed at a certain point, while, on the other hand, ammonites are few. Here again, owing to the scarcity of ammonites a well-defined line between the two zones cannot be recognised, yet the evidence shows that the greater thickness of strata belongs to the Jamesoni Zone.

The fossils obtained by the Geological Survey are :

Ditrupa circinata *Tate*
Rhynchonella *cf.* calcicosta (*Quenst.*)
,, ,, furcillata *Dav.*
,, ,, gryphitica juvenis (*Quenst.*)
,, sp. [of the *rimosa*-group]
,, sp. [of *variabilis*-type]
,, tetrahedra *Dum.* [non *Sow.*]
Spiriferina gamma ? (*Quenst.*)
,, pinguis ? (*Ziet.*) [non *Sow.*]
Zeilleria hispidula ? (*Simpson*)
Cucullæa ?
Gryphæa *cf.* arcuata *Lam.*
,, cymbium *Lam.*
Hippopodium ponderosum *J. Sow.*
Homomya vetusta (*Phill.*)
Lima hermanni *Voltz*
,, pectinoides (*J. Sow.*).
Lucina sp.
Modiola scalprum *J. Sow.*
,, sp.
Ostrea liassica *Strickl.*
,, sp.
Pecten *cf.* acutiradiatus *Münster*
Pecten æquivalvis *J. Sow.*
,, liasinus *Nyst*

Pecten priscus *Schloth.*
„ *cf.* valoniensis *Defr.*
Pholadomya ambigua (*J. Sow.*)
„ glabra ? *Ag.*
Pinna sp.
Pleuromya costata (*Y. and B.*)
Protocardia sp.
Unicardium cardioides (*Phill.*)
Pleurotomaria *cf.* sulcata *Desl.*
Acanthopleuroceras valdani ? (*d'Orb.*)
„ maugenesti ? (*d'Orb.*)
Deroceratid, new form
Platypleuroceras amplinatrix ? (*Quenst.*)
„ brevispina (*Quenst.*) [non *Sow.*]
„ aureum (*Simp.*)
„ rotundum ? (*Quenst.*)
Uptonia jamesoni ? (*J. de C. Sow.*)
„ regnardi ? (*d'Orb.*)
Belemnites apicicurvatus *Phill.*
„ breviformis *Phill.*
„ bucklandi ? *Phill.*
„ milleri ? *Phill.*
Ichthyosaurus.

Some of the fossils in this list are of special interest, and have been examined critically by Mr. Buckman. The *Rhynchonella* of the *rimosa* group is a remarkable form, being by far the largest of the group. At Radstock *R. rimosa* occurs in the Jamesoni Zone, and this related species occurs here at the same horizon.* *Gryphæa* cf. *arcuata* differs from Lamarck's species in having no sulcus, or only a faint indication of the presence of the sulcus. One specimen resembles the topotype of Sowerby's *G. obliquata* preserved in the Natural History Museum, that is, an arcuate *Gryphæa*, without sulcus, and somewhat expanding. These arcuate *Gryphæas* occur throughout the section, and co-exist with *G. cymbium* in a conspicuous *Gryphæa*-band at the waterfall above the road in the second stream west of Allt Fearns. There is also a form allied to *G. cymbium*, but more convex and lacking the sulcus. *Hippopodium ponderosum* is represented by large specimens in a perfect state of preservation. The *Lima* referred to *L. hermanni* Voltz, is a rather narrow form bearing a closer resemblance to the delineation of Chapuis and Dewalque than to the original figure. The species entered in the list as *Modiola sp.* is a large, high form, devoid of ridge. *Unicardium cardioides* is rare at this locality, and is represented by a specimen which is rather more transverse than the type.

Several short exposures along the path leading from Beinn na' Leac to Dun Caan have yielded a few ammonite-fragments indicating the Jamesoni and Valdani Zones.

The topmost portion of the Pabba Shales is much more arenaceous than the strata below, consisting of thin-bedded sandstones difficult to separate lithologically from the overlying Scalpa Sandstone. These strata, which on palæontological grounds must be assigned to the top of the Lower Lias, are of inconsiderable thickness, and are well exposed at two points only. Low water flats on the shore one

* It is figured and described as *Rimirhynchia tardata gen. et sp. nov.* by Mr. Buckman in Brach. Namyau Beds, Burma; *Pal. Ind.*, N. S., III. (2) xiii. 7, 8, p. 229, 1917.

mile south of Rudha na' Leac consist of black micaceous thin-bedded sandstone with abundant belemnites, where a large specimen of *Lytoceras salebrosum* ? Pompeckj, was found. This ammonite indicates either the Striatum or the Capricornus Zone.

At high-water mark, $\frac{7}{8}$ mile N.E. of Dun Caan the presence of the Striatum or of the Capricornus Zone is indicated by *Androgynoceras* cf. *maculatum* (Y. and B.). Four examples of this ammonite were found in close juxtaposition with one of ? *Seguenziceras sp.*, pointing to the Algovianum Zone, which is taken here as the lowest zone of the Middle Lias (Domerian). Other fossils obtained here are : *Gryphæa cymbium* Lam., *Modiola scalprum* J. Sow., *Plicatula spinosa* d'Orb. and *Pleuromya costata* (Y. and B.). As already mentioned, this horizon is also exposed further south, some 200 yards north of Hallaig hut, but no ammonites were found at that point. Low-water flats at the foot of Druim an' Aonaich, one mile south of Screapadal, may possibly also belong to the Capricornus Zone, but palæontological evidence is lacking.

CHAPTER IV.

MIDDLE LIAS.

DOMERIAN.

Raasay.

THE Middle Lias of the present classification represents the upper part of the Middle Lias of most authors, who include under that name lower zones referred here to the Lower Lias.

This division of the Lias is extensively developed in the Hebrides and plays an important part in the structure and scenery of the Jurassic areas in Raasay, Skye and Mull. It consists chiefly of white, yellowish or greyish sandstone, and as it constitutes the main mass of the Liassic rocks on the island of Scalpa it has been called the "Scalpa Series." The series contains also intercalated bands of sandy micaeous shale, especially in the middle part. The sandstone is fine-grained and generally calcareous; it is distinctly bedded towards the base, while the top part tends to be massive. A constant and striking feature is the presence of numerous very large calcareous doggers. These doggers usually assume the shape of flattened ellipsoids, up to 6 feet in diameter. Their surface is often regularly honeycombed by shallow pits due to the removal by weathering of the more easily soluble portions of the mass.

The following section measured in the cliff N.E. of Dun Caan may be taken to be representative of the sequence in Raasay :—

	Ft.
Upper Lias shale and ironstone.	
Muddy greenish sandstone with *Dactylioceras* 6 feet from top [wholly or partly Upper Lias] . . .	12
Hard calcareous sandstone	2
Muddy sandstone with large doggers	65
Pecten æquivalvis band	1
Muddy sandstone forming scarp	45
Sandstone with alternation of sandy shale. *Gryphæa gigantea* 30 feet from top	100
Sandstone with carbonaceous markings. *Pecten æquivalvis, Gryphæa cymbium*	20

As can be expected from the prevailing uniformity of the type of sedimentation, the faunal facies shows few differences in the vertical distribution of the fossils. Most belong to shallow-water genera such as *Gryphæa*, *Pecten*, *Plicatula*, etc. Ammonites are sporadic, and brachiopods occur principally as clusters in the doggers and other calcareous portions of the sandstone. As the various life-zones are not defined by lithological features they cannot be mapped separately, and moreover the sporadic character of the ammonites on which they are based makes it impossible to estimate the respective thicknesses of the various zones with anything like accuracy. However, it seems that the Algovianum, Margaritatus and Lævis Zones constitute the lower half of the series, while the

top belongs to the Spinatum Zone, which means about a hundred feet of sediments for the three lower zones combined, and approximately as much for the highest zone. Direct measurements made in the cliffs N.E. of Dun Caan, and along the path south of that hill gave a total thickness of about 240 feet, which is considerably less than the apparent thickness in the slopes and cliffs east of Beinn na' Leac, where the series appears to be some 300 feet thick. As it is highly improbable that the amount of sediments could have varied to that extent within the short distance of one mile, a likely explanation may be found in assuming the apparent increase to be due to slipping on a large scale along the strike. Owing to the considerable covering of scree-material there is here no clear section actually showing the presence of slipping, but since this feature occurs extensively elsewhere, as, for instance, north of Hallaig, it is not impossible for it to have played here the part suggested.

Exposures of the Middle Lias sandstones are very numerous, and therefore need not be described separately—especially since there is no appreciable change in the sequence within the island. The cliffs and slopes which form the eastern boundary of Beinn na' Leac are Middle Lias. The bed of the Inverarish burn follows that formation for the greater part of its course, while the path leading from Beinn na' Leac to Dun Caan traverses the series from base to top at a point where the strata are moderately inclined, thus affording a section easy of access. Further north the series forms the base of the imposing cliff which stretch in a straight line from Hallaig to Screapadal. Many fine exposures are shown along these cliffs, but, as is the case east of Beinn na' Leac they are not often of easy access.

As already stated, the various life-zones based on the distribution of ammonites cannot be mapped separately, nor could they be readily recognised in the field were one to restrict the zoning on the presence of the index-fossils only. Fortunately the index ammonites are accompanied by other groups of fossils, more abundantly represented, which are often sufficiently reliable to serve as zone-fossils. By this it must not be assumed that these fossils are actually zonal, but they are here of value owing to their definite distribution in this particular district. *Gryphœa cymbium* is abundant in the Margaritatus zone; *Gryphœa gigantea* occurs constantly in a band towards the base of the Spinatum Zone, and has not been found at other levels in Raasay. *Pecten æquivalvis* occurs throughout, but is of larger size in the Spinatum Zone than lower down: an example of $7\frac{1}{2}$ inches across has been noted. Most of the other fossils in the list below occur throughout. Those which in other districts are known from definite horizons only, are here too sporadic to afford ready means for the identification of any particular zone.

Of the several zones represented in the Middle Lias rocks of Raasay, the Spinatum Zone is the most readily recognisable one in the field. The ammonites of the zones below are so sporadic that it is difficult to establish clear zonal demarcations. Of the species of *Amaltheus* in the following list the greater number are referred by Mr. Buckman to his Lævis Zone, but they occur in especially rich clusters, and it does not follow that they characterise a thicker set of strata than the forms referred to the Margaritatus Zone. As already noted a ? *Seguenziceras* found at the base of the series suggest

a thin development of the Algovianum Zone. From the above remarks it will be seen that separate lists illustrating the fauna of each of the zones would be extremely difficult to procure, and it has consequently been deemed advisable to give a single list for the whole of the Middle Lias, which will serve the purpose once the zonal forms have been pointed out.

Aulacothyris florella (*Dav.*)
Aulacothyris ?
Lingula sacculus *Dav.*
Rhynchonella acuta (*J. Sow.*)
,, *cf.* acuta [very flat]
,, *cf.* amalthei (*Quenst.*)
,, capitulata *Tate*
,, *cf.* buchardi (*Quenst.*) [non *Dav.*]
,, compressa (*Y. and B.*)
,, delmensis ? *Haas*
,, *cf.* fodinalis *Tate*
,, media (*J. Sow.*)
,, rosenbuschi *Haas*
,, scalpellum (*Quenst.*)
,, scalpellum latum ? (*Quenst.*)
,, steinmanni ? *Haas*
,, *cf.* subdecussata (*Münster*)
,, tetrahedra (*J. Sow.*)
,, *cf.* triplicata bidens (*Quenst.*)
,, sp. [between *R. amalthei* and *R. northamptonensis* Walker]
Rhynchonella sp. nov.
Spiriferina oxyptera *Dav.*
,, rostrata *auct.* [*cf.* S. pinguis *Ziet.* non *Sow.*]
,, signiensis *Blake*
Zeilleria subnumismalis (*Dav.*)
,, *cf.* subnumismalis
,, *cf.* scalprata (*Quenst.*)
Anomia pellucida *Chap.* and *Dew.*
Cardinia antiqua (*Phill.*)
Ceromya petricosa (*Simpson*)
Cucullæa sp.
Goniomya hybrida (*Münster*)
Gresslya sp.
? Gresslya intermedia (*Simpson*)
Gryphæa cymbium *Lam.*
,, gigantea *J. Sow.*
Inoceramus substriatus *Münster*
Lima hausmanni *Dunker*
,, pectinoides *J. Sow.*
,, punctata *J. Sow.*
,, succincta (*Schloth.*)
,, sp. [very broad ribbing]
Modiola numismalis *Oppel*
? Nuculana sp.
Pecten æquivalvis *J. Sow.*
,, calvus *Goldf.* [large form]
,, humberti *Dum.*
,, *cf.* humberti *Dum.*
,, liasinus *Nyst*
,, substriatus *Roemer*
Pholadomya ambigua *J. Sow.*
,, sp.
Pleuromya costata (*Y. and B.*)
Plicatula spinosa *J. Sow.*
Protocardia truncata (*J. de C. Sow.*)

Protocardia *cf.* truncata [umbones more central]
„ sp. nov. ?
Pteria calva (*Schloth.*)
„ cygnipes (*Y. and B.*)
„ inæquivalvis (*J. Sow.*)
Trapezium sp.
? Actæonina ilminsterensis (*Moore*)
Amberleya imbricata (*J. Sow.*)
Amberleya ?
Chemnitzia *cf.* semitecta *Tate*
Cf. Chemnitzia complicata *T. and B*
Cryptænia expansa (*J. Sow.*)
„ rotelliformis *Dunker*
Nerita alternans *Tate*
Turbo cyclostoma ? (*Zieten*)
? Turbo lineatus *Moore*
Amaltheus amaltheus ? (*Qieten*)
„ acutus ? (*J. Sow.*)
„ calcar ? (*Brown*)
„ clevelandicus (*Y. and B.*)
„ *cf.* coronatus (*Qu.*)
„ depressus ? (*Simpson*)
„ lævis (*Quenst.*)
„ *cf.* nodifer *S. Buck*
„ nudus (*Quenst.*)
Amauroceras *aff.* ferrugineum (*Simpson*)
Lytoceras gigas (*Quenst.*)
Paltopleuroceras elaboratum (*Simpson*)
„ *cf.* hawskerense (*Y. and B.*)
„ pseudocostatum (*Hyatt*)
„ pseudospinatum (*Hyatt*)
„ *cf.* pseudospinatum (*Hyatt*)
„ spinatum (*d'Orb.*)
Seguenziceras ?
Belemnites ilminsterensis ? *Phill*
„ paxillosus *Phill*
„ paxillosus amalthei *Quenst.*

Field-observation shows that the brachiopods are more numerous in the Spinatum Zone than below. Of these some are well-known Spinatum Zone forms, such as *Rh. compressa*, *Rh. media* and *Rh. tetrahedra*. It is from the upper part of the zone that a new form apparently connecting the *tetrahedra* group and the *lineata* group was obtained. It is larger than anything yet found in the British Domerian, and Mr. S. S. Buckman has taken it as the type of one of the genera into which he proposes to subdivide *Rhynchonella*. This new form falls into Mr. Buckman's new genus *Grandirhynchia* (*Records, Geol. Surv. India*, vol. xlv. Part I., 1915, p. 76), and is represented here by two species, namely, *G. grandis*, and *G. lævigata*, described by Mr. Buckman in his Memoir on brachiopods from Burma referred to above. *G. grandis*, which is genotype, is figured in Plate XIII., Fig. 5, while a specimen of *G. lævigata*, a somewhat primitive form, is figured in Plate XIII., Fig. 6. The distribution of *Gryphæa cymbium*, *G. gigantea* and *Pecten æquivalvis* has already been indicated. Of the other lamellibranchs the most abundant are *Lima pectinoides*, *Pecten humberti*, *Pleuromya costata*, *Plicatula spinosa*, *Protocardia truncata* and *Unicardium subglobosum*. These occur throughout, but *P. spinosa* is specially noticeable in the Spinatum Zone at the horizon of *Gryphæa gigantea*. *Pteria inæquivalvis* is widespread, and *P. cygnipes* seems restricted to the Spinatum Zone. *Protocardia sp. nov.* ?

is comparable with specimens in the Museum of Practical Geology from the Middle Lias Marlstone of Chideock, labelled *Protocardia dayi* Etheridge MSS. The gastropods are sporadic and occur mostly in the calcareous doggers.

The species of *Amaltheus* are not confined to the Margaritatus Zone: Mr. Buckman proposes a zone of *A. lævis* coming just above, in which *A.* aff. *depressus*, *A.* cf. *acutus*, *A. amaltheus* ? *A.* cf. *coronatus* and *Amauroceras* occur together with the index form. *A.* cf. *nodifer* and *A.* cf. *subnodosus* were also obtained from the excavated materials of the gallery to the Main Mine, which appears to pass through the upper part of the Spinatum Zone.* *Lytoceras gigas* is referred to the Margaritatus Zone. The species of *Paltopleuroceras* are all from the Spinatum Zone.

North-East Skye.

The Middle Lias of the Portree district was first detected by Murchison. A fuller account of its sequence and fauna is given by Bryce † and the outcrops were mapped by H. B. Woodward in 1896. The series of Middle Lias sandstone with doggers forms the substructure of the Jurassic rocks for some three miles south of Holm, and from the entrance of Portree Bay to Tianavaig Bay. It is almost everywhere of difficult access, and is quite unsuitable for the study of the distribution of its fauna along zonal lines. Consequently the recent examination of the Jurassic Rocks of north-east Skye has not added to previous knowledge.

South of Portree Bryce noted an upper part of yellow calciferous sandstones with *Ammonites spinatus* beds, overlying blue micaceous sandstones with large blue calcareous nodules and septaria with *Ammonites margaritatus*, *Pecten æquivalvis*, *P. liasinus*, *Limea acuticosta*, *Pentacrinus amalthei*, etc., resting on hard micaceous sandy and calcareous shales with rows of spherical nodules.

Mr. Woodward's mapping and recent observation are in accord with this succession established by Bryce, but there is some doubt whether Tate's correlation of the basal member is correct. In the palæontological appendix to Bryce's paper (*loc cit.* p. 343) he correlates this horizon with the zone of *Ammonites capricornu*, and cites from it *A. Davoei*. The ground is so badly broken by slips and faults that it is, of course, possible, but no exposure of the top of the Pabba Series is at present visible.

Mr. Woodward noted both Spinate and Annulate ammonites in the top layers. This shows the persistence of the arenaceous facies up into the Upper Lias as it does in Raasay.

Along the coast south of Holm the Middle Lias forms a vertical cliff some 100 feet high. This includes probably the upper half of the series only, the base emerges nowhere. The top portion is here often crinoidal and contains nests of *Rhynchonella*. Prince Charles' cave is along a dyke in the Middle Lias sandstone, as are other caves both here and south of Portree Bay.

* See footnote by Mr. Buckman, Appendix, p. 67.

† "On the Jurassic Rocks of Skye and Raasay." By James Bryce. *Quart. Jour. Geol. Soc.*, 1873, p. 317.

CHAPTER V.

UPPER LIAS.

WHITBIAN.

Raasay.

THE Upper Lias, the presence of which was first detected by Prof. Judd, was mapped on the 6-inch scale by H. B. Woodward during the geological survey of the district, and subsequently in greater detail by Messrs. Wedd and Thorneycroft in order to ascertain the economic value of the iron ore discovered by Woodward.

Prof. Judd reckoned its thickness to be from 80 to 100 feet, but the greater portion of the strata referred by him, and later by Woodward, to the Upper Lias, belong to the Aalenian stage which in the modern English classification is allocated to the base of the Inferior Oolite. An important non-sequence separates the Aalenian from the Upper Lias which, as understood here, probably does not exceed 30 feet in thickness.

It is interesting to note that the incoming of the Upper Lias fauna preceded the change of lithological facies which characterises the bulk of the series. A *Dactylioceras* fauna represented by *D.* cf. *commune* (J. Sow.), *D. anguinum* ? (Reinecke) and *Dactylioceras sp.* occurs in the upper portion of the Scalpa Sandstone as far down as at least 6 feet from the top, that is, in the same sediment which a few feet lower down contains *Paltopleuroceras* of the Spinatum Zone. These *Dactylioceras* species Mr. Buckman refers to the *Tenuicostatum* Zone. Easily accessible outcrops of this horizon can be examined on the roadside above the sheepfold south of Rudha na' Leac and on the path to Dun Caan, north of Beinn na' Leac. It is well exposed, but less accessible, in the cliffs between Hallaig and Screapadal. With a sudden transition a dark shale facies succeeds the sandstone. This shale is calcareous and feruginous, sometimes oolitic. Its thickness varies from about 3 to about 9 ft. Natural exposures of this shale—with the overlying ironstone—are very few : it is seen in the banks of a small affluent of the Inverarish Burn, ½ mile N.E. of the outcrop mine, below the road at Rudha na' Leac and in the cliff N.E. of Dun Caan. Fossils are extremely abundant in this shale. They are almost exclusively represented by ammonites and belemnites. Collections were made at the entrance of the branch mine near the church, at the outcrop mine, at Rudha na' Leac and N.E. of Dun Caan. The species are the same at these various localities, and therefore can be shown in one single list :—

Dactylioceras *cf.* angulatum (*J. Sow.*)
„ *cf.* athleticum (*Simp.*)
„ crassifactum (*Simp.*)
„ *cf.* commune (*J. Sow.*)
„ delicatum (*Simp.*)
„ *cf.* holandrei (*d'Orb.*)

1. Exposure of Oil Shale, south of Holm, Skye.

2. Outcrop of Ironstone, east of Main Mine, Island of Raasay.

Dactylioceras raristriatum (*Quenst.*)
,, *cf.* tenuicostatum (*Y. and B.*)
,, vermis (*Simp.*)
,, spp. [several]
Peronoceras attenuatum (*Simp.*)
Harpoceras mulgravium ? (*Y. and B.*)
Harpoceras ? meneghinii *Bonarelli*
Belemnites (Megateuthis) *cf.* ilminsterensis *Phill.*
,, ,, nodotianus *d'Orb.*
,, (Dactyloteuthis) stimulus *Dum.*

Of these, *D. delicatum* is the most abundantly represented. The unnamed species of the list are also common ; according to Mr. Buckman they appear to be new. *Peronoceras* is also fairly abundant, but *Harpoceras* is not so common. These species indicate the Exaratum and the Falcifer Zones, the former being predominant.

Raasay Ironstone.

The oolitic ironstone of Raasay immediately follows on the shale just described. The transition is often marked by oolitic structure in the upper part of the shale itself. Natural outcrops are very few and quite restricted in extent, and might easily be overlooked : their discovery is a proof of great patience and acumen on the part of the late H. B. Woodward. One outcrop can be seen on the right bank of the Inverarish burn, at the pronounced bend of the path to Dun Caan, 1 mile S.S.W. of Loch na' Mna, and another about $\frac{1}{3}$ mile S.W. of this point, in an affluent of the same burn. It can also be seen at one or two points in the cliff N.E. of Dun Caan. At the time of writing there are artificial exposures at the entrance of the branch mine near the church, at the outcrop mine, and at Rudha na' Leac (Pl. IV., Fig. 2).

The average thickness of the ironstone along the southern margin of the field between Churchton Bay and Hallaig is about 8 ft. A thickness of 17 feet recorded in one bore may be ascribed to the action of faulting. Along the eastern margin of the field, running due north from Hallaig, the thickness of the ironstone is much reduced, and the ironstone disappears altogether N.E. of Dun Caan. The stone is in layers a few inches thick, separated by partings. The base consists of dark shaly compact layers with numerous fossils : *Amussium sp.*, belemnites and *Dactylioceras*. The bulk of the seam is markedly oolitic. Microscopic examination shows it to be composed of echinodermic limestone serving as matrix to the ooliths. These generally occur crowded together in thin irregular bands. Of these bands some are—on fresh surfaces—dark glossy green, while others are pale, lustreless green. Short exposure to atmospheric action brings rapid decomposition : the rock becomes brown and spongy, and the ooliths drop out of their sockets. Fossils are chiefly belemnites, with a few ammonites, and are not transformed into iron ore. Some were observed which suggest a *remanié* condition, appearing rounded, corroded and broken. The typical iron ore has also sometimes a slightly breccia-like appearance due to the presence of dark angular fragments similar in composition to the dark compact shale at the bottom of the seam.

Although the deposit as a whole is fossiliferous, it has yielded but few determinable forms. These were obtained from the upper part of the seam in the main mine gallery, at the outcrop mine, and from

the core of one of the bores. The very interesting fact brought to light by Mr. Buckman's determination of the ammonites is that several zones are represented in that upper part of the seam.

Dactylioceras delicatum ? (Simp.) from the top foot of the ironstone in one of the bores indicates the Falciferum Zone or lower. *Dact.* cf. *crassiusculosum* (Simp.) and *Dact.* cf. *gracile*—the latter found 2 feet from the top—are species indicating the Exaratum Zone. *Cœloceras dayi* ? (Reynès) belongs to the "Bifrons Zone" of Reynès, and *Hildoceras bifrons* (d'Orb.) [non Brug.] determines the highest zone represented here: the Subcarinatum Zone. From these examples the conclusion follows that the Raasay Ironstone was formed about the time of the Subcarinatum Zone, or a little later, and that the fossils of earlier zones which are included in it are derived. Other fossils, which have no zonal significance, may be mentioned here: *Belemnites* (*Dactyloteuthis*) *irregularis* Phill., *Protocardia* ?, *Inoceramus?*, *Anomia* and ostracods, besides abundant echinodermic fragments. An ammonite: *Pseudolioceras*, not indicated above because its position is not known, was also found among loose materials from a trial excavation at Rudha na' Leac.

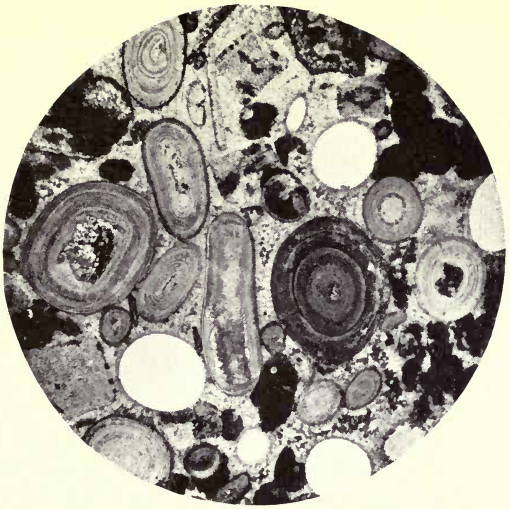
When the late H. B. Woodward announced * his discovery of iron ore in Raasay he was not in possession of palæontological evidence regarding the age of the deposit, but he assumed it to be the equivalent of the well-known Cleveland Ironstone of Yorkshire, which is a deposit of Spinatum age, as is fully proved by the labours of Tate and Blake. As just shown, this Raasay ore is several zones higher in the sequence. There are not sufficient data to say whether the Raasay ore represents merely a repetition, at a subsequent date, of the particular physical conditions leading to the deposition of the Cleveland ore, or whether it was due to a slow, northerly migration of these conditions, which did not reach Raasay till Subcarinatum time.

Structure and Composition.

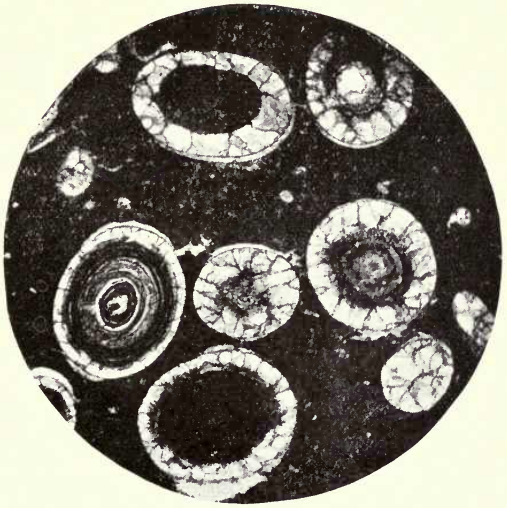
The structure of the ore varies within short distances: the markedly oolitic portions characterised by crowded layers of ooliths in a limestone matrix, pass into portions with few ooliths embedded in a dark ferruginous matrix. These two types can be recognised with the naked eye, but it needs the microscope to show the differences clearly. The following descriptions of representative thin sections may prove of interest.

Dark green rock. The matrix consists of calcite, obviously detrital, of echinodermic origin. It is traversed by occasional strings of opaque spots, but is otherwise quite clean looking. Relatively to the space occupied by the ooliths, it covers less than half the area of the slide. The ooliths have generally a depressed ellipsoid shape, and their average size is 1 mm. Their colour is green or brownish green, without noticeable concentric structure in half the number of examples observed. The rest show a concentric arrangement of the green and brown colours, the order of which varies as follows, from the centre outwards: brown, green, brown, green; green, brown, green; and brown, green. In a few cases a colourless mineral—presumably siderite with granular structure—is seen to replace part of the green material. The inclusion of

* *Geol. Mag.*, Dec., iii., vol. x., p. 493, 1893.



1. Typical example of Raasay green ore from Main Mine, Raasay.
(Ordinary light, magnified 11 diameters.)



2. Siderite facies of Raasay Ironstone, from Holm, Skye.
(Ordinary light, magnified 11 diameters.)

Microphotographs by G. V. Wilson.]

patches and the irregular junction points to alteration from the green into the clear material, and not to addition. Several contain minute black spots, sometimes arranged concentrically. A nucleus occurs, though not frequently. The examples observed appear to be calcite fragments. One oolith appears to have begun as two ooliths side by side, subsequently imprisoned in one common envelope. Between crossed nicols the ooliths show typical aggregate polarisation, with black cross in parallel light. Were it not for the clue afforded by the chemical composition of the stone—which contains no potash—anyone relying merely on microscopical examination would probably refer these green ooliths to the mineral glauconite, with which, as shown below, it has little in common beyond its aspect (Pl. VIII., Fig. 1).

Pale green stone. The matrix is of echinodermic fragments cemented by granular calcite. Some of the echinodermic fragments are impregnated with black iron oxide. Patches of the same black oxide occur here and there, but without showing any remains of possibly pre-existing echinodermic structure. Of the ooliths some are uniformly green with the same optic properties as the preceding. Others are arranged in concentric layers, being from the centre outwards: dark brown, green, black, colourless, green; or green, colourless, green, colourless. The colourless layers—which represent only a small portion of the whole—appear, as in the previous case, to be derived from the green mineral: their structure is granular, their boundaries are irregular, and they include patches of the green mineral. Quartz, felspar or other detrital minerals were not observed in these particular slides.

Dark stone with grey ooliths. The matrix is black, opaque, and isotropic in parts of the slides, and passes into green areas which show aggregate polarisation. Fragments of organic calcite are few, but remarkable in that they are epigenetised by the green mineral, the echinodermic structure still showing. Ooliths are much less abundant than in the type described above; they are of two kinds. The first kind is dull grey, opaque, isotropic and nearly structureless, mostly without nucleus. One example has a large nucleus of the black material; in another the nucleus is an aggregate of black and brown spots. The other kind of oolith is greyish, slightly green, showing faint indications of birefringence, with a brown cortical zone of high relief and birefringence. A nucleus is generally absent; when present it may consist of epigenetised calcite or of brown amorphous matter. Minute black specks are scattered through some of the ooliths.

From the above account it seems fairly evident that the principal iron-bearing element of the ore from the mine is, in some parts of the seam, the green mineral, while in other parts it is a mixture of some iron oxide and of the green mineral. Siderite forms only a small proportion of the ore in the area under discussion.

From the aspect of the stone as seen in thin sections it would seem that the green ooliths in a clear matrix represent the ore in its fresh unaltered stage, and that the formation of the black oxides and siderite is to be regarded as a process of alteration.

The composition of the green mineral and of the rock in bulk is shown in the following analyses by Mr. E. G. Radley :—

	Ooliths hand picked from the rock.	Rock in bulk.
SiO_2	20·62	8·58
TiO_2	·72	·28
Al_2O_3	11·96	4·24
F_2O_3	5·11	1·24
Cr_2O_3	not fd.	not fd.
FeO	25·98	11·79
MnO	·30	·65
(CoNi)O	·06	·04
BaO	not fd.	not fd.
CaO	11·50	35·43
MgO	3·07	1·71
K_2O	not fd.	·02
Na_2O	·09	·08
Li_2O	not fd.	not fd.
H_2O at 105 C.	2·56	1·37
H_2O above	8·36	4·44
P_2O_5	5·11	1·68
FeS_2	·71	·72
Fe_7S_8	not fd.	·15
SO_3	not fd.	·15
C	·25	·26
CO_2	3·94	37·54
Total	100·35	100·37

This is the first analysis made of the ooliths hand picked from the Raasay Ironstone. The results are most interesting, and call for the following remarks—bearing in mind the physical constitution of the ooliths as seen in thin sections. Hitherto the Raasay ore had been taken to be iron in the form of carbonate. From inspection of the bulk analysis it is not possible to disprove this statement, but the analysis of the green oolitic portion shows that most of the iron is concentrated in the ooliths, and, further, that there is not more CO_2 than would satisfy one-fourth of the FeO, which must accordingly be mostly in the form of silicate, in combination with the alumina and water. This silicate would probably represent the green mineral portion of the ooliths as seen in thin section. The ferric iron may be assumed to be the decomposition product of originally ferrous iron. The high percentage of phosphorus is fully accounted for by the available lime after deduction of lime possibly present as carbonate. Its place as calcium phosphate within the oolith structure would be indicated by some of the dark opaque spots noted under the microscope.

From purely analytical considerations it is difficult to decide to which of the acids the magnesium oxide should be allocated. There is no evidence to show why it should not be present as carbonate, but, on the other hand, it is well known that this base commonly accompanies ferrous iron in numerous silicates of the chlorite group. Reasoning therefore from analogy there is thus a strong presumption that the magnesium oxide is here one of the constituents of the silicate.

The absence of appreciable amounts of alkalies is to be noted, as it has an important bearing on the classification of the mineral.

From the above remarks, and after neglecting the obviously unimportant components, the conclusion is that the ooliths are made up of a hydrous silicate of ferrous iron, alumina and magnesia, plus carbonates and phosphates. Therefore to get to a nearer approxima-

tion of the true composition of the silicate the percentages of carbonates, phosphates, etc., should be deducted from the total and the percentages of the silicate constituents raised in proportion. The corrected and expurgated analysis would then become—

SiO_2	26·73	
Al_2O_3	15·50	
FeO	33·67	39·63
FeO in Fe_2O_3	5·96	
MgO	3·98	
H_2O above 105°	10·83	
H_2O at 105	3·32	

The relations between the composition of the ooliths and that of the matrix, as deducted from the comparison of the two analyses given above, are expressed graphically in the diagram on p. 36, constructed by Mr. C. H. Dinham.

It is now possible to estimate how far the foregoing facts and considerations furnish sufficient data for the identification of the green mineral.

Silicates of iron, as the original source of iron ore, are more widespread than is apparent from geological text books. Several varieties are known and have received special designations. They are generally placed in the chlorite group of minerals, and are all fairly alike in their appearance and physical characteristics. Many of them have a cryptocrystalline structure, so that the usual optical methods of determination are not available, the chemical composition being the only safe criterion, and even that shows considerable variation. Some of these silicates have also strikingly similar modes of occurrence as ooliths or granules in sedimentary strata. *Glauconite*, which looks exactly like the Raasay mineral, differs widely in its composition : the iron is mostly in the ferric state, and there is a high percentage of potash. *Greenalite*, which is the source of one of the greatest iron ore deposits of the world—the Mesabi deposit—resembles the less concretionary variety of the Raasay mineral, but it differs from it in being non-aluminous.

Allowing for the necessary margin of variation in these minerals of somewhat uncertain composition, the conclusion arrived at is that the green silicate of the Raasay iron ore is the mineral known as *chamosite*, of composition H_6 (Fe, Mg)$_3$ Al_2 Si_2 O_{13}. Chamosite was discovered in 1820 in the Upper Jurassic rocks of the Chamoson, in Switzerland, and has since then been found in various geological formations.* A similar chloritic mineral forming ooliths was named *bavalite*, and occurs extensively in the Palæozoic oolitic ironstones of France.†

From the descriptions of the modes of occurrence of chamosite and bavalite it is shown that the ooliths they form frequently include siderite ; as stated in a previous page some of the Raasay ooliths contain subordinate layers of a colourless mineral which the evidence

* *Cf.* "Untersuchungen über Thuringit und Chamosit aus Thüringen und Umgebung.," von E. R. Zalinski. *Neues Jahrbuch*, xix., Beilage-Band, 1904, p. 40.

† *Cf.* "Etudes des Gites Minéraux de la France. Les Minerais de Fer Oolitique de France," par L. Cayeux, Paris, 1909.

at hand could not conclusively prove to be siderite, but analogy renders the presumption that it is siderite more likely.

As already stated, an important part of the iron in the ore at and

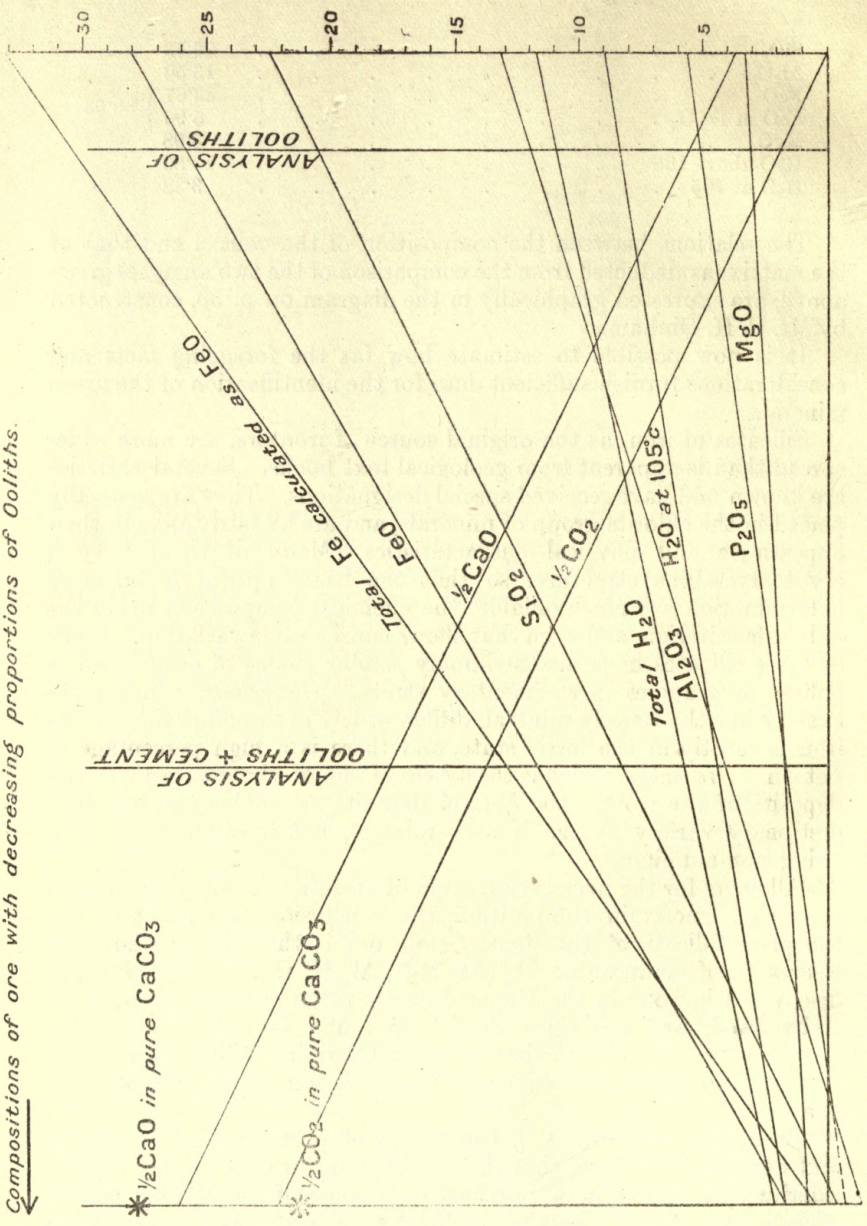


FIG. 1.—Diagram illustrating relations between matrix and ooliths. (Note: only half CaO and CO_2 are plotted to keep diagram within convenient size.)

near the workings—*i.e.* at the southern end of the field—is in the form of silicate. At the north-eastern edge of the outcrop, that is N.E. of Dun Caan, the seam is seen to thin out to an unworkable thickness. Likewise in Skye the seam is much poorer and considerably thinner. Samples collected at these two extreme localities from what is un-

doubtedly the same continuous seam, show a most radical difference: both in Skye and in N.E. Raasay the ooliths are almost entirely of *carbonate*, and the green silicate is practically absent. (Pl. VII., Fig. 2). The carbonate is predominantly siderite; calcite also occurs sparsely here and there, generally as an external cortex round the siderite. Owing to the difficulty of distinguishing between siderite and calcite in thin sections without the aid of chemical tests the proportion of calcite was erroneously exaggerated in the writers description of the plate accompanying Mr. Thorneycroft's paper (*op. cit.*).

The ooliths are of two kinds: some are plain spherical or ovoid grains without concentric arrangement, while others have the typical zonal arrangement. Those of the first kind have a granular structure, and sometimes contains small dark black specks which suggest magnetite, but otherwise look fresh and undecomposed. The concentrically built ooliths consist of more or less transparent siderite or of siderite alternating with a brownish semi-opaque substance, in which faint remnants of the green chamosite can occasionally be detected. The ooliths—which in the case of the green silicate rock are easily extracted, thus permitting a separate analysis—are firmly embedded in the matrix, and it would be a difficult matter to analyse them as thoroughly as was done with the sample discussed in the preceding pages. Still, the main fact is established that while in the workable field much of the ore is in the form of the silicate chamosite, the seam passes laterally into a carbonate deposit, with traces of pre-existing silicate.

How the alteration was brought about is not explained, though it seems clear that we are dealing here with a process different from that usually observed, in which a carbonate is the first stage in the evolution of the ore. As regards its date, the only inference that can at present be drawn rests on the fact that the shaly strata which overlie the seam are lithologically uniform whether the ore is chamosite or carbonate. It can then be surmised that the change took place before the deposition of these shaly beds. The process would not necessarily imply a short period of time, because, as Mr. Buckman found from the fauna, there is a great stratigraphical break between the top of the ironstone and the shales that immediately succeed. In other words, the change may have taken place between the middle of the Whitbian and the end of the Yeovilian, which represent the extent of the stratigraphical gap.

From what precedes it will have been seen that definite conclusions regarding the genesis of the ore are not yet established on all points, but it is hoped that more may come to light as the workings extend further into the field, thus affording means of following possible variations in the constitution of the seam. Should, for instance, the galleries reach a point where the green ore were to be seen passing into carbonate, special investigation at the junction of the two might yield much of the evidence which is so far lacking for a proper understanding of the problem.

Specimens from the working face, obtained by Dr. J. S. Flett in June 1917, representing the average type of the ore as then extracted, still belong to the green oolitic ore. The only difference from the ore at the outcrop is that the proportion of echinodermic calcite appears higher, the calcite being in large, glossy fragments.

The Iron-Ore Field.—The extent of the Upper Lias as known to Woodward is represented on the Geological Map on the scale of 1-inch to the mile, published by the Geological Survey in 1896. The detailed investigations undertaken by Mr. W. Thorneycroft, with the assistance of Mr. C. B. Wedd, have necessitated certain modifications in the mapping of the outcrop, and these are shown in the new edition of the map. An account of the results of their investigations was placed before the Geological Society of Edinburgh by Mr. Thorneycroft,* together with useful information on the Upper Lias of the Hebrides generally.

Several bores and trial excavations were put down by Mr. Thorneycroft and also by Messrs. Baird along the southern edge of the field, the configuration of which is therefore now accurately known. These bores and excavations have shown that the seam is of workable thickness along the southern edge of the main field, that is from Churchton Bay towards the path to Dun Caan above Hallaig. It is also presumably of workable thickness in the faulted outlier of Beinn na' Leac, but this area has not yet been investigated, with the exception of one excavation made at Rudha na' Leac. Exposures and trenches dug east and north-east of Dun Caan show that the seam thins out and disappears northwards along the east coast. Actual exposures do not occur in the two miles of cliff south of Screapadal, but from the complete absence of loose blocks of ironstone it may be safely inferred that the seam is absent, as noted further south. To sum up, we know that at, and near, the southern edge of the main Upper Lias area the ironstone is workable, while it is too thin or absent along its eastern margin. The central portions of the area have not been tested by borings: consequently we are in entire ignorance of the extent and value of the concealed field lying north of the southern margin. The proving of the north-western portion of the area would necessitate bores of considerable depth. Assuming the thicknesses measured on the east cliffs to hold good, the Upper Lias would lie some 670 feet below the surface at Storav's Grave (the small patch coloured as Upper Lias near Storav's Grave on the first edition of the map belongs to the base of the Great Estuarine Series).

The structure of the proved portion of the field permits at present, and for a considerable time to come, of a relatively simple mode of exploitation. Starting from a low level, galleries are driven up the dip, which thus creates a natural outflow for the water without pumping. Likewise the ore is carried direct from the working faces to the pier down the incline. Carriage is effected by a light tramway, the motive power being transmitted to the hutches by an endless cable.

North-East Skye.

The fullest visible development of the Upper Lias in N.E. Skye is towards the base of the cliffs and slopes between the entrance of Portree Bay and the islet of Holm. The soft shaly materials of the Upper Lias, occurring at the base of great superincumbent masses of rock, are mostly talus covered, and there are no clear natural sections.

* "Note on the Upper Lias of the Western Islands in reference to the Iron Ore Deposit therein." By Wallace Thorneycroft. *Trans. Edin. Geol. Soc.*, vol. x., Part ii., p. 196, 1914.

Here and there a bare patch occurs, and a general estimate of the thickness can be made by calculating the distance from the top of the Scalpa Sandstone to the base of the Inferior Oolite. Most of the evidence used here is based on the information from boring operations supplied by Messrs. Baird & Co., and from excavations made by Mr. D. Tait in the course of his collecting work for the Survey. The thickness varies considerably: in a bore put down near the mouth of the river Bearreraig there are 78 feet of strata between the top of the ironstone and the top of the Scalpa Sandstone. As measured by Mr. Tait along a trench he made three-quarters of a mile south of Holm the corresponding thickness is 48 feet, and it does not appear to be less than that anywhere north of Portree Bay. This does not include any portion of the top of the Scalpa Sandstone which might conceivably prove to be of Upper Lias date as is the case in Raasay. This great thickness, compared with the development in Raasay, is a striking feature, when one considers the short distance between the two areas and the fact that the same zones are involved: hence Mr. Buckman proposed the name "Portree Shales" for these Upper Lias shales.* The strata consist of dark micaceous shale, generally soft and friable, with occasional harder bands and limestone nodules. The basal portion of the shale is so covered by débris or inaccessible that the details of its fauna could not be ascertained, although its lithological characters are known from the boring records of Messrs. Baird & Co. The lowest point from which detailed search was made is 14 feet above the top of the Scalpa Sandstone. At this level, three-quarters of a mile south of Holm, Mr. Tait made the interesting discovery of a thin band of jet in close proximity to which ammonites were found: *Harpoceras* aff. *exaratum* (Y. and B.) and ? *Elegantuliceras elegantulum* (Y. and B.) which indicate the Exaratum Zone. The well-known Jet Rock horizon of Yorkshire is in the Exaratum Zone, and the similarity of conditions in widely separated areas like Yorkshire and N.E. Skye is truly remarkable.

In the unexplored portion below the Jet band there is ample room for deposits of the Tenuicostatum Zone.

The Exaratum fauna continues for some 2 feet above the jet; apart from the ammonites just mentioned the only other fossil found is a lamellibranch resembling *Astarte subtrigona* Goldfuss. The rest of the series, about 30 feet thick at the point specially searched, belongs to the Falciferum Zone. Here, the fauna of the Falciferum Zone consists for some 10 feet of ammonites mainly: *Dactylioceras* cf. *anguinum* (Rein.), *D.* cf. *crassiusculum* (Simp.), *D.* cf. *holandrei* (d'Orb.) and *Harpoceras* aff. *mulgravium* (Y. and B.). A line of limestone-nodules which follows has yielded *D.* cf. *gracile* (Simp.), *D.* cf. *holandrei*, *Coeloceras* cf. *foveatum* (Simp.), *Harpoceras* of the *mulgravium*- and *falciferum*-type, and *Harpoceratoides*; two gasteropods were also obtained: *Natica adducta* (Phill.) and a depressed form of *Pleurotomaria* with the shape of *P. actinomphala* (Desl.). In the shale in which the nodules are embedded *Phylloceras* and *D. gracile* ? were also found, accompanied by *Astarte*, *Lucina* and *Inoceramus*. Nodules 3 feet higher up are rich in *Dactylioceras*, especially *D.* cf. *vermis* (Simp.). Rusty, decalcified nodules occurring at two intervals a few feet higher up, are characterised by the same species. *D.* cf. *holandrei*

* See Appendix.

recurs in abundance higher up, accompanied by ? *Pseudolioceras* and cf. *Harpoceras*. *D.* cf. *athleticum* was found 2 feet above this.

No records are at hand regarding the fauna—if any—of the shale between the last-mentioned point and the representative of the Raasay Ironstone, which at the locality under consideration occurs 8 feet above. Here it is 2 feet thick; in the boring put down by Messrs. Baird near the mouth of the Bearreraig river its thickness was found to be 5 feet 9 inches. It is a greenish ferruginous oolitic limestone or low grade ironstone, different in composition from the green stone of Raasay. The iron in the Raasay workings occurs in the form of a silicate, while here it is as carbonate—at least as regards its main mode of occurrence, viz., ooliths. In a sample analysed by Messrs. Baird the average iron-percentage was 11·96 per cent., which is obviously too low for economic purposes. It is not so richly fossiliferous as the ironstone in Raasay; the only fossils observed are belemnites belonging to *Dactyloteuthis digitalis* (Phill.). Several examples are obviously worn and rounded, pointing to a *remanié* condition which would support Mr. Buckman's suggestion that the Raasay ironstone is a *remanié* deposit.

Above the ironstone the shale becomes harder and less argillaceous, and its fauna is that of the Aalenian stage, showing that, as in Raasay, there is a considerable gap cutting out the Yeovilian and part of the Whitbian.

Upper Lias strata occur at several places along the coast south of Portree Bay. They were noted and described long ago by Bryce (*op. cit.*, p. 322). They appear everywhere much thinner than in the district near Holm, but there can be no doubt that here all the sections are incomplete. The soft Upper Lias shales have been practically "squeezed" between the massive Scalpa Sandstone and the heavy superincumbent masses of Inferior Oolite which have slipped along low hade planes or lines of dislocation which are so common in Ben Tianavaig. What there is of the Upper Lias is very fossiliferous: small *Dactylioceras* and large *Harpoceras* are abundant. Lenticular masses of limestone, sometimes pyritous, occur here and there. H. B. Woodward noted the presence of "annulate ammonites" in the top layers of the Scalpa Sandstone, which would mean that the Upper Lias fauna begins to appear in that sandstone as it does in Raasay. No representative of the Raasay Ironstone was observed.

Comparisons with other Scottish Districts.—Owing to the importance of the Raasay Ironstone deposit it may not be out of place to give here a brief account of the Upper Lias in the other Jurassic areas of Scotland. Inquiries are sometimes made as to whether the ironstone is represented in these Upper Lias strata; and it can be asserted that there is no ready supply of the ironstone outside Raasay. Mr. Thorneycroft has dealt with the subject in his paper already quoted, and his views are in harmony with those of the present writer.

At Carsaig, in the south of the Island of Mull, there is a small tract of Upper Lias, with no indications of ironstone. Beyond quite thin ribs and nodules of clay ironstone there is likewise no deposit in the Upper Lias of the south-east part of Mull, namely, between Loch Buie and Loch Spelve, and in the Loch Don district.

The Kilchoan district of Ardnamurchan was visited in the company of Messrs. Thorneycroft and Wedd, also without results.

In Eigg the position of the Upper Lias must be at a considerable depth below sea-level.

In the south-east of Skye the ironstone condition is represented by a ferruginous limestone seen in a section north of Dun Liath. The unpromising nature of the ironstone outcrop in north-east Skye has already been indicated, and there remains to consider the possibilities of the concealed portions of the field. There is no reason to suppose that the Upper Lias does not extend under the whole of the north of Skye, and ironstone formation, as in Raasay, may conceivably have recurred at various points within that vast tract. Unfortunately the depth to be expected is everywhere—except in the vicinity of the outcrops—so great that the proving of the field by boring operations would be an expensive matter, and the probability of the development of any ironstone found would be most unlikely under present economic conditions. Taking into consideration only those points where borings could be started in Jurassic rocks beneath the covering of basalt, the least unpromising would probably be the Ollach coast, as it is the nearest to the Raasay field, but in order to reach the Upper Lias the whole thickness of the Inferior Oolite would have to be passed through : a matter of perhaps one hundred fathoms. Going northwards beyond the Holm district —which has been tested—the depth of the Upper Lias would gradually increase from a few fathoms at Bearreraig to the full thickness of the Inferior Oolite at Inver Tote, beyond which, in the direction of Staffin, an increasing thickness of Great Estuarine Series sediments would have to be added. The Upper Lias would thus be some 150 fathoms below sea-level at Staffin. A similar estimate applies to the other exposed Jurassic tracts of North Skye, namely, Monkstadt, Uig and Loch Bay, which were examined by the writer and all found to be high up in the Estuarine Series.

The Upper Lias is nowhere exposed in the Jurassic areas of the East of Scotland, and there is hardly any hope it might be reached by borings of moderate depth. At the most favourable points—namely, in the Brora district—the position is concealed through the action of faulting under the whole of the Inferior Oolite and part of the Great Oolite. It is true that we are in ignorance of the nature of the greater part of the sediments of the Inferior Oolite in the East of Scotland, little of which is exposed, but since in that region the Jurassic rocks as a whole evince distinct littoral and estuarine conditions of deposit of considerable thickness it seems unlikely that the Inferior Oolite could be less thick here than in Raasay and Skye. Thus depths of over a hundred fathoms would have to be expected in order to reach the position of the Upper Lias.

[Addendum to p. 37 :—

In "Die Versteinerungen der Eisenerzformation von Deutsch-Lothringen und Luxemburg," *Abhandl. z. geol. Specialkarte von Elsass-Lothringen, N.F., Heft* vi, 1905, p. 20, E. W. Benecke considers that the Lorraine ore was originally deposited as a Leptochlorite (Thuringite, Chamosite, etc.), as appears to be the case here.]

CHAPTER VI.

INFERIOR OOLITE.

AALENIAN TO VESULIAN.

Raasay.

THE Raasay Ironstone of Upper Lias date is succeeded by some 70 feet of micaceous shale which former observers, namely, Prof. Judd and H. B. Woodward, had attributed to the Upper Lias. Recent survey work has shown to Mr. Buckman that there is a stratigraphical gap above the ironstone. This gap includes part of the Whitbian and the whole of the Yeovilian. Adopting the classification now in use in the stratigraphical scheme of the Jurassic Rocks of England, these micaceous shales of Raasay would belong to the base of the Inferior Oolite, that is, to the Aalenian stage. Woodward's "Basement Beds" come higher up in the sequence. Their allocation to a position corresponding to the "Midford Sands" was due to the faulty identification of some ammonites, since then identified anew as proper Inferior Oolite forms.

The materials excavated when driving the gallery to the Main Mine have yielded good evidence, showing the relations between the Upper Lias and the Inferior Oolite. From shale on top of the ironstone, and under a sill which produced induration, Mr. Tait obtained the ammonites *Pleydellia subcompta* (S. Buck.), *Walkericeras burtonense* (S. Buck.) and *Cotteswoldia* cf. *limatula* S. Buck. These belong to Aalenian forms, and they show that the Aalensis Zone rests non-sequentially on the ironstone, and that there is a big gap: all the Yeovilian and part of the Whitbian missing; as mentioned elsewhere the same succession occurs in N.E. Skye.

The Inferior Oolite of Raasay consists of two lithological divisions: a great mass of sandstone 600 feet thick, resting on a series of shale from 20 to 70 feet thick, which is the shale just referred to above. This shale of the Aalensis Zone offers few actual exposures, but it forms a well-defined sloping feature almost everywhere at the foot of the great sandstone. It attains its greatest thickness on the east side of the island, at the foot of Beinn na' Leac and at the foot of Dun Caan, while it is thinnest in the area near Inverarish. From the conspicuous feature it makes at the foot of Dun Caan, Mr. Buckman has proposed for it the designation "Dun Caan Shales," which may be usefully employed.

Although natural exposures are few and disconnected, the Survey is in possession of very satisfactory evidence regarding the fauna of the shale, thanks to the excavation work undertaken by Mr. Tait at the foot of Dun Caan, where over 70 feet of shale were examined in detail.

The fossils collected at this locality show that 49 feet of strata

belong to the Aalensis Zone proper, while in 16 feet of strata above Mr. Buckman recognises faunal changes which induce him to establish an "Upper Aalensis" or "Venustula" Zone. By far most of the fossils obtained from the Aalensis Zone are ammonites; belemnites come next in order of abundance, while other groups are only represented by a few lamellibranchs. Of the ammonites, specimens of *Cotteswoldia* are the most abundantly represented; they belong to *C. costulata* (Ziet.), *C. attrita* (S. Buck.), *C. particosta* S. Buck, *C. subcandida* S. Buck. and *C. superba* S. Buck., with doubtful representatives of *C. venustula* S. Buck., near the top. The zone-fossil *Pleydellia aalensis* (Ziet.) was found, though sparingly, accompanied by *P. leura* (S. Buck.) and ? *P. subcompta* (Branco), and an example of the distinctive *Pleurolytoceras leckenbyi* (Lyc.) was obtained from the top of the zone. Other ammonites are *Canavarina digna* S. Buck., *C. sp.*, *C. folleata* S. Buck., *Walkericeras delicatum* S. Buck., and *W. sp.*, prior to *W. burtonense*. Among the belemnites a form resembling *Dactyloteuthis irregularis* (Phill.), but much thinner, *Megateuthis tripartitus*? and *M.* cf. *tripartitus incurvatus* (Benecke) were found. Other groups of organisms are very scarcely represented: the only species observed are *Inoceramus* cf. *cinctus* Münster, and an *Astarte* of *excavata* type, with few, strong ridges.

The Upper-Aalensis Zone—which Mr. Buckman proposes to call the "Venustula" Zone—was examined both at the locality to which the foregoing remarks apply, and a few hundred yards further north, at Druim an' Aonaich. The stratal lithology differs only in the frequent presence of limestone-nodules, and the faunal facies is similar, except that most of the species are different. As lower down, ammonites predominate: *Canavarina digna* S. Buck., *C. venustula* S. Buck., an ammonite resembling *Cotteswoldia misera* S. Buck., and another like a form described on Plate XXXI., Fig. 7, of Mr. Buckman's Monograph on the Inferior Oolite Ammonites, *Pleurolytoceras leckenbyi* (Lycett) *P. hircinum* (Quenst.), *Walkericeras subglabrum* S. Buck., and doubtful examples of ? *Cypholioceras* cf. *opaliniforme* S. Buck., of *Pseudolioceras* cf. *beyrichi* (Schloenb.), and of *Pleydellia*. The lamellibranch *Posidonomya bronni* Voltz, was observed in different layers here as well as in the core of a bore midway between Dun Caan and Inverarish. *Inoceramus* and *Lucina* cf. *crassa* J. de C. Sow., occur sparingly, and also the belemnite *Pseudobelus subclavatus* (Voltz).

About five feet of shale with calcareous nodules and hard bands separate by gradual transition the shale of the Aalensis and Venustula Zones from the overlying great sandstone mass The fossils obtained from this horizon at Druim an' Aonaich were allocated by Mr. Buckman to the Opaliniformis Zone. The fossils obtained are:

? Lucina crassa *J. de C. Sow.*
Cypholioceras opaliniforme *S. Buck.*
Canavarella ? (or a new form ?)
Pleydellia *cf.* subcompta (*Branco*)
Pleydellia sp.
Pleurolytoceras hircinum (*Quenst.*)
Pseudolioceras beyrichi (*Schloenb.*)
Walkericeras subglabrum (*S. Buck.*)
Megateuthis tripartitus brevis (*Quenst.*)
„ „ oxyconus (*Quenst.*)

A large specimen of *Nautilus jurensis* ? Quenst., found loose, belongs probably to this horizon.

The above remarks exhaust the information collected from the Inferior Oolite shales, and the great sandstone will be considered next. The lower portion of the sandstone is more or less calcareous for some 50 feet, and the actual base is often marked by a thin limestone a few feet thick, sometimes ferruginous and rusty-looking. This basal limestone-horizon has been examined at several localities, of which the most fossiliferous is on the path one mile south of Dun Caan, where the following section is to be seen :—

	Ft.	In.
Calcareous sandstone		
Thin bedded limestone passing up into the above .	1	0
Limestone with fossiliferous lenticles full of ammonites	1	0
Shaly limestone	2	10
Limestone with belemnites	0	8
Thin bedded shaly limestone	3	0
Shaly limestone with belemnites and lamellibranchs	1	0
Talus, grassed over (Venustula Zone)		

These different beds are not clearly separated from each other, and the zones comprised within them are evidently very close together and not marked by lithological differences. The bulk of these beds, up to the limestone with lenticles, belong to the Scissum Zone. The limestone with belemnites, 8 inches thick, has yielded :

Pecten demissus *Phill.*
„ (Amussium) paradoxus *Goldf.*
Megateuthis conoideus (*Opp.*)
„ ventralis ? (*Phill.*)
„ voltzi ? (*Phill.*)
Pachyteuthis breviformis (*Phill.*)

The limestone with fossiliferous lenticles is very rich in small ammonites of the Scissum Zone, besides a few lamellibranchs. The following fossils were obtained : —

Rhynchonelloidea *cf.* krammi (*Ben.*)
Gresslya abducta (*Phill.*)
Pecten (Amussium) paradox s *Goldfuss*
Pteria sp.
Cf. Ancolioceras substriatum *S. Buck.*
Cf. Canavarella.
Lioceras costosum (*Quenst.*)
„ gracile *S. Buck.*
„ partitum *S. Buck.*
„ subcostosum *S. Buck.*
„ uncinatum *S. Buck.*
„ lineatum ? *S. Buck.*
„ *cf.* bifidatum *S. Buck.*
„ *cf.* comptum (*Rein.*).
„ *cf.* opalinum (*Rein.*).
„ *cf.* partitum *S. Buck.*
„ *cf.* plicatellum *S. Buck.*
„ *cf.* undulatum *S. Buck.*
„ sp., between uncum *and* gracile *S. Buck.*
Rhæboceras *cf.* tortum *S. Buck.*

This ammonite-fauna shows many points of resemblance to that from the Ardnadrochet Glen, Isle of Mull, which was examined for

the Geological Survey by Mr. Buckman. The small *Pecten paradoxus* occurs here in nests, as is the case in Mull, and many of the ammonite-species are identical. Owing, perhaps, to the lenticular nature of its fossiliferous portions the zone often escapes detection in Raasay. For instance, east of Dun Caan its position is clearly seen, but the rock is less calcareous and fossils scarce.

In his "Notes on the Upper Lias of the Western Islands," * Mr. W. Thorneycroft mentions the presence of a bed of ferruginous limestone at the top of the Upper Lias. What was known as "Upper Lias" at the time he made his observation is the shale just described as belonging to the Aalensis and Venustula Zones, and the ferruginous limestone found by him probably belongs to the Scissum or to the Murchisonæ Zone, more likely the latter than the former. This ferruginous facies † was noted at the foot of Dun Caan and in the bed of the Inverarish Burn near the ordnance datum point 533 on the 1-inch Map, where it contains many belemnites.

There are only faint suggestions of the Ancolioceras Zone. The presence of the Murchisonæ Zone was recorded at several localities in Raasay, the best from the point of view of collecting being the section along Dun Caan path just described. Here fossils of the Murchisonæ Zone were found 3 feet above the Scissum Zone. The relations of the Murchisonæ to the Scissum Zone are clear, but great difficulty was met in separating the Murchisonæ bed from those of the Bradfordensis, Concava and Discites Zones, which are very close to it and difficult to distinguish by field features. Small local dislocations, not easily detected, would increase the difficulty. That these zones are represented by very little sediment is shown by the fact that fossils representative of them were found in the same block. The fauna of the Murchisonæ Zone consists mainly of small ammonites.

Gresslya abducta (*Phill.*)
Cf. Isocardia cordata *J. Buck.*
Pecten sp.
Apedogyria subcornuta *S. Buck.*
,, sp. nov.
,, ? patellaria *S. Buck.*
Crickia reflua *S. Buck.*
Hyattia wilsoni *S. Buck.*
Hyattina brasili *S. Buck.*
Ludwigia murchisonæ (*J. de C. Sow.*)
,, lævigata ? *S. Buck.*
Cf. Ludwigina patula *S. Buck.*
,, umbilicata *S. Buck.*
Manselia subfalcata *S. Buck.*
New, *cf.* Paquieria.
? Pseudographoceras literatum *S. Buck.*
? Strophogyria pinax *S. Buck.*
Welschia extralævis (*Quenst.*)
,, obtusiformis *S. Buck.*
Belemnites (Megateuthis) tripartitus sulcatus *Quenst.*
,, (Pseudobelus) subclavatus *Voltz*

---

* *Trans. Edin. Geol. Soc.*, vol. x., part ii., 1914, p. 201.

† Hyphæ of a fossil fungus, *Palæomycès*, were found in microscope slides of a specimen collected in Raasay by Mr. W. Thorneycroft, either at this horizon or very close to it. See "Fossil Micro-organisms from the Jurassic and Cretaceous Rocks of Great Britain." By David Ellis, Ph.D., D.Sc., *Proc. Roy. Soc., Edin.*, vol. xxxv., 1915, p. 110.

Of ammonites indicating the Bradfordensis Zone few were obtained : —

Apedogyria platychora *S. Buck.*
Brasilia *cf.* decipiens *S. Buck.*
„ effricata *S. Buck.*
? „ bradfordensis *S. Buck.*
? Hyattia subcava *S. Buck.*

The Concava Zone is represented by a few ammonites : *Ludwigella attenuata* S. Buck., *L. cornu* (S. Buck.), *L.* cf. *micra* S. Buck., and ? *L. rudis* (S. Buck.) ; and, as already stated, it is unlikely that the zone occupies any considerable thickness in Raasay.

A comparatively large number of ammonites belonging to the Discites Zone were obtained from loose calcareous blocks near the main bed of Scissum Zone fossils on Dun Caan path. It has not been possible to estimate the extent of the bed *in situ*, which may very likely pass upwards into the more or less barren sandstones. This fossiliferous bed has not been found elsewhere in Raasay, which suggests a lenticular formation. The ammonites collected are all small specimens, but occasional large, indeterminable forms were observed at a position which may be in the Discites Zone, not far from sporadic layers of some large *Ostrea* occurring a few feet above the level from which the fossiliferous loose blocks presumably come. The following fossils were obtained :—

Gresslya abducta (*Phill.*)
Lima lycetti ? *Laube*
Pecten (Amussium) paradoxus *Goldf.*
„ personatus ? *Goldf.*
Pteria ?
Turreted gasteropod.
Braunsina subquadrata *S. Buck.*
„ *cf.* cornigera *S. Buck.*
„ *cf.* fastigata *S. Buck.*
Depaoceras fallax (*S. Buck.*).
„ formosum *S. Buck.*
„ hamatum *S. Buck.*
Lopadoceras arcuatum *S. Buck.*
Lucya sp.
Ludwigella sp. nov. *aff.* attenuata *S. Buck.*
„ *cf.* subobsoleta *S. Buck.*
Oedania *cf.* delicata *S. Buck.*
Cf. Platygraphoceras.
New, *cf.* Brasilina.
New, *cf.* Depaoceras.
Cf. Reynesella juncta *S. Buck.*

The preceding account still deals with the very base of the great Inferior Oolite sandstone. Above the position just considered fossils become scarce, consisting mainly of occasional belemnites. An indeterminable ammonite-cast, which may have belonged to some Stepheoceratid, was found 125 feet below the top. The strata consist of a rather soft sandstone, yellowish along fresh fractures, assuming a white surface with weathering. A thickness of a few feet at the top is gritty and contains layers of pectiniform lamellibranchs, sometimes in great abundance. These characters obtain all along the east side of the island, and also in the middle. At the north-western exposure of the Jurassic area, near Balachuirn, the Inferior Oolite sandstone partakes more of the Skye development,

that is, it contains calcareous nodules and doggers, which do not occur on the other side. These nodules and doggers contain fossils, lamellibranchs and brachiopods, but no ammonites were found.

The sandstone-facies stops abruptly and gives place to a plastic clay. The clay is nowhere exposed except in the right bank of the stream N.E. of Storav's Grave, but its position can easily be followed almost everywhere owing to the feature it marks at the top of the sandstone. At Storav's Grave the thickness is about 10 feet, which appears to be a maximum. There is a good deal of faulting at this locality, and the strata in question had originally been mapped by Woodward as Upper Lias, though later he felt disposed to group them with the upper part of the Inferior Oolite. That position was definitely established by the discovery of ammonites of the Garantiana Zone by Messrs. Wedd and Thorneycroft. With the exception of a ? *Corbis* and fish-tooth, the fossils collected during the last Survey are all ammonites :

Garantiana coronata *Wetzel*
„ pompeckji *Wetzel*
„ *cf.* garantiana (*d'Orb.*)
„ alticosta ? *Wetzel*
„ subgaranti ? *Wetzel*
Strenoceras bifurcatum (*Zieten*)
„ minimum *Wetzel*
„ subfurcatum (*Schloth.*)

These fossils indicate the Garantiana Zone, but Mr. Buckman states that there may also be indications of the Niortense Zone.

This clay with marine fossils forms the highest member of the Inferior Oolite, and it passes up insensibly into an estuarine oil-shale which, in this district, is the lowest member of the Great Estuarine Series—the Hebridean equivalent of the English Fuller's Earth and probably of the Great Oolite.

North-East Skye.

In N.E. Skye as in Raasay the Inferior Oolite attains a great development and contributes largely to the making of the rugged scenery of the coast, along which it forms bold features and precipitous cliffs from Camas Tianavaig S. of Portree to Upper Tote, 10 miles north of Portree. Its great development ought to have made it an ideal field for zonal stratigraphy, but unfortunately the precipitous nature of the ground puts difficulties in the way of detailed examination, especially as regards fossil-collecting. However, sufficient information has been obtained to give a fairly satisfactory notion of the sequence, which is one of the most remarkable in Britain.

Although so near to Raasay, there are some differences, both in sedimentation and in the distribution of the fauna. The Aalensis and Venustula Zones, which in Raasay occupy over 70 feet of shales, here occupy a comparatively small thickness of strata. The great sandstone, which in Raasay is practically unfossiliferous, is here very rich in fossils, mainly ammonites, which are often very well preserved, and the sandstone tends to be calcareous.

The following divisions can be observed in the cliff section south of Holm, from Fiurnean to sea-level. Formations above and below the

Inferior Oolite are included for the sake of completeness and to show the relations of the stratigraphy to the physical features.

		Ft.
Estuarine Series.	Sill forming uppermost crag	100
	Gap (shales)	25
	Sill	25
	Gap (shales)	10
	Massive white sandstone passing down to shaly dark sandstone, forming crag	100
	Bituminous sandy shale	3
	Oil-shale	7
Inferior Oolite.	Clay of *Garantiana* age, forming shelf, but passing northwards into black sandstone	5
	Calcareous grit	20
	Cliffs and scarps of yellow-weathering sandstone with calcareous bands and doggers. Stepheoceratids occur in upper half	150
	Cliffs of bluish shaly sandstone with calcareous bands and doggers with *Sonninia* and large belemnites	150
	Sandstone cliff	50
	Shaly fucoid sandstone (Aalensis Zone)	25
	Upper Lias shales	75
	Middle Lias sandstone, top of	100

The strata of the Aalensis Zone are shaly, but less micaceous than in Raasay. At the locality S. of Holm, which furnished most of the material for the description of the Upper Lias, the ammonites ? *Walkericeras* cf. *lotharingicum* (S. Buck.) was found 3 feet above the Ironstone position. Six feet higher up *Cotteswoldia costulata* (S. Buck.) [Zieten], ? *C. misera* (S. Buck.) and ? *C. superba* (S. Buck.) were obtained. In two feet of shale 3 feet higher up the following were got :—

Astarte ?
Lucina ?
Cotteswoldia costulata (*S. Buck.*)
„ superba ? *S. Buck.*
„ crinita (*S. Buck.*)

Whether there are fossiliferous layers of the zones which immediately succed, was not ascertained, but in any case the stratal development would be thin, since fossils of the Murchisonæ Zone were obtained at a position which appears not far above this one. As, however, it was at a different locality further north along the strike, there is room for error, and an estimate of the thickness of the intervening strata cannot be given.

The Murchisonæ Zone is represented in flaggy sandstone at the base of the great sandstone series, and fossils were obtained from an exposure accessible between tide-marks on the south side of the mouth of the River Bearreraig. Owing to circumstances Mr. Buckman was unable to name all the fossils collected here, but among others, may be mentioned *Apedogyria* cf. *subcornuta* S. Buck., and *Cosmogyria obtusa* (Quenst.). There are also lamellibranchs: *Cucullæa* or *Grammatodon* and a form resembling *Pleuromya compressiuscula* (Lyc.). The type-specimen of the zone-fossil *Ludwigia murchisonæ* (J. de C. Sow.), which is so frequently quoted in geological literature, was found by Lady Murchison near Holm, that is, at or near the locality under consideration. Yet, here the zone-fossil is by no means common: one

General View of Inferior Oolite, Bearreraig, Skye, showing sill at top. Murchisonae Zone in the foreground.

example only was obtained out of numerous species collected from loose blocks. This is not an isolated instance of a species being scarce at its type locality : to quote an example from the geological history of this region, the type of *Ammonites brevispina* came from the Island of Pabba, yet the species is scarce both there and in the neighbouring Liassic areas.

Loose blocks near the mouth of the River Bearreraig have yielded the following Murchisonæ Zone ammonites :—

Brasilina baylei (*S. Buck.*)
Crickia reflua *S. Buck.*
Hyattina brasili *S. Buck.*
Ludwigia murchisonæ (*J. de C. Sow.*)
,, *aff.* gradata *S. Buck.*
Ludwigina patula *S. Buck.*
,, umbilicata *S. Buck.*
Welschia extralævis (*Quenst.*)
,, obtusiformis *S. Buck.*
Strophogyria cosmia *S. Buck.*
,, pinax *S. Buck.*

The specimens on which this list is based are remarkably well preserved and abundant : Mr. Buckman has stated this to be the most ammonitiferous development of the Murchisonæ Zone discovered in the British Isles as yet. He points out that though the number of specimens is so great there are no examples of *Hammatoceras* or of *Erycites*, both of which are found in South England ; and the absence of these Hammatoceratidæ has an important bearing on the question of the geographical distribution of ammonite families. Some lamellibranchs were also collected at the same locality ; they may be mentioned here, though the evidence is lacking as to whether they belong to the Murchisonæ Zone or to zones above. They are :

Anatina ?
Cucullæa or Grammatodon
Gresslya abducta (*Phill.*)
Goniomya v-scripta (*J. Sow.*)
Inoceramus dubius (*J. de C. Sow.*)
? Lucina bellona *d'Orb.*

The zones which immediately follow the Murchisonæ Zone are poorly represented in the collection. The strata in which these zones are to be expected are fossiliferous, but difficult of access. They are best seen from 30–50 feet above sea-level between Holm and Bearreraig River ; they consist of bluish shaly sandstone with thin doggers. The fossils found are *Brasilia decipiens* (S. Buck.) of the Bradfordensis Zone, a form resembling *Lucya magna* S. Buck., and probably belonging to the Concava Zone, and a new form, an homœomorph of *Dissoroceras excavatum* S. Buck., with periphery narrower and less tabulate, which suggests the presence of the Discites Zone.

Higher strata, which cannot be examined closely owing to the steepness, are brought down to sea-level north of the River Bearreraig. Close to the fishermen's hut at Bearreraig there was found a loose, much weathered specimen of a gigantic ammonite, over 450 mm. in diameter. It may perhaps belong to *Shirburnia trigonalis* S. Buck.

This, and one or two other specimens of Sonninines would indicate the Shirburnia Zone.

Of the Witchellia Zone there is one example of *Witchellia* found in a loose block on the north side of Bearreraig Bay. Detached blocks from the calcareous doggers in the sandstone cliff north of Bearreraig Bay are very fossiliferous, some being crowded with well-preserved ammonites, mostly *Sonninia* of the Sauzei Zone. Carbonaceous markings are not uncommon here, and a fragment of fossilised wood was observed in direct juxtaposition with an ammonite. In this connection is may be stated that the whole formation is of marine origin, and that Prof. Judd's statement that part of it is estuarine was probably due to the deceptive abundance of these drifted plant-remains.

The following species have been identified by Mr. Buckman :—

Poecilomorphus macer *S. Buck.*
„ *aff.* macer
Sonninia carinodiscus (*Quenst.*)
„ mesacanthus (*Waag.*)
„ *aff.* mesacanthus
„ *aff.* sowerbyi (*Miller*)
Sonninia spp.

Of these *S.* aff. *sowerbyi* is the most abundantly represented.

A doubtful example of *Skirroceras nodosum* (Quenst.) was collected *in situ* in the bed of the stream ⅔ mile south-west of Holm, from a horizon which seems higher than that of the doggers with *Sonninia*.

The higher sandstone, that which weathers yellow, offers few opportunities for detailed examination, owing to the steepness of the outcrop, but there is no doubt that a considerable portion of it is characterised by the occurrence of ammonites formerly designated *A. humphriesianum*, which are plentiful in the loose blocks which cover the shore for one mile north of Bearreraig Bay. These ammonites, though abundant, do not form good collecting material, as they are mostly flattened, and in sandstone matrix, yet sufficient were obtained to show that the sandstone from which they were derived belongs to the Blagdeni Zone. They are represented in the collection by :

Stemmatoceras *cf.* subcoronatum (*Oppel*)
Stephanoceras cosmopoliticum ? (*Möricke*)
? Stepheoceras *cf.* pyritosum (*Quenst.*)
Teloceras *cf.* coronatum (*Quenst.*). [non *Schloth.*]

Half a mile south of Rigg, layers of a large, crushed Ostreid, a *Nautilus*, 19 inches in diameter, and large belemnites probably including *Megateuthis* cf. *aalensis* (Ziet.) were observed *in situ* at or slightly above the level from which the ammonites come from. Here the sandstone is darker than is the case near Holm, tending towards a brown colour.

The gritty sandstone which comes next has not yielded any recognisable fossils, but like the corresponding horizon in Raasay it is full of broken lamellibranch fragments.

Above the gritty sandstone—which forms the top of the Inferior Oolite cliff—there is a sudden change of sedimentation. Near Holm the succeeding strata consist of plastic clay—identical with the clay of Garantiana age in Raasay—while north of Bearreraig it is a soft

black sandstone. A specimen of *Garantiana* shows its age, but opportunities for making a representative collection of the fauna were lacking. The low dip to the north brings the top of the Inferior Oolite down to sea-level at Inver Tote Bay, and the formation does not reappear anywhere further north.

South of Portree Bay the Inferior Oolite Sandstone forms imposing cliffs in the fissured and dislocated mass of Ben Tianavaig, and can be followed at sea-level as far south as Ollach. Little need be said concerning this area, which is much less fossiliferous than the coast-sections of Holm and Bearreraig.

CHAPTER VII.

ESTUARINE SERIES.

Raasay.

In the Hebrides a series of strata of estuarine characters follows conformably upon the Inferior Oolite. They have been known for a long time: Macculloch first discovered them in the north of Skye, where they were named "Loch Staffin Beds" by Murchison. These beds at Loch Staffin were assigned to their position below the Oxford Clay by E. Forbes, who also described their fauna. To these beds, both in Skye and other Hebridean islands Prof. Judd gave the name "Great Estuarine Series." In a general way it may be said that this series consists essentially of alternations of black bituminous shale with sandstones and thin limestones. A small *Cyrena* is throughout the commonest fossil. Beds with gasteropods: *Viviparus scoticus* [= *Paludina*] mark the top of the series, while some distance below there are widespread beds with *Ostrea hebridica*. The strata show various peculiar features: there are frequent bands of fibrous carbonate of lime ("Beef"), oolitic limestones, compact cement-limestones, blue or cream-coloured, bituminous shales, and lenticles of impure coal.

Many of the characteristic features of the Estuarine Series can be observed in Raasay, but there is nowhere a single section showing the whole series from top to bottom. The ground is either obscured by landslips or it is heather- or peat-covered. The evidence has to be pieced together from isolated exposures, between which there are many gaps the nature of which can only be surmised.

The late H. B. Woodward has stated (*op. cit.*, p. 186) that probably of the divisions recognised in Skye only the lower—*i.e.*, up to the Ostrea Hebridica Beds—are represented in Raasay, and the recent Survey work seems to show that he was correct in making this statement.

The Estuarine Series in Raasay occupies an oblong area which caps the highest ground of the island from Dun Caan to the great boundary fault south of Beinn a' Chapuill. The general sequence appears to be as follows, but there is doubt regarding the position of the topmost members:

Ostrea hebridica Beds (not seen *in situ*).
Calcareous sandstones and limestones with *Cyrena* and *Viviparus* cf. *aurelianus*.
Shales and sandstones with *Cyrena*.
Thick sandstone.
Oil shale.

The total thickness is about 250 feet.

Oil-Shale.—The actual base of the series is marked by an oil-

shale, 8 to 10 feet thick, which follows conformably and gradually upon the clay of the Garantiana Zone. The outcrop of this shale is almost everywhere hidden by talus or by vegetation, but there is a good exposure at the top of the cliff due east of Dun Caan. But even where not actually seen, it can quite easily be recognised from the marked feature it forms between the Inferior Oolite below and the sandstone which comes above.

The shale of the exposure at Dun Caan is a true oil-shale, much like the Carboniferous shale worked for oil in the neighbourhood of Edinburgh, but at the time of writing it has not yet been ascertained whether it may possess any economic value. Any indication as to its oil-contents would require to rest on the analysis of fresh, unaltered shale obtained some distance from the weathered surface. It may, however, be of interest to quote here the results of an analysis of weathered samples kindly undertaken for the Survey by Mr. D. R. Steuart, of the Broxburn Oil Works. The results of his analysis, with suggestions based on its significance, were the subject of a short contribution to *Nature* for 9th Oct. 1913, from which the following abstract is taken :—

"The samples so far analysed were much weathered, so that we are not yet in possession of exact data concerning the yield and bye-products from the fresh shale. That the fresh shale might be expected to yield more than weathered portions seems probable, but to what extent is not known, and it is on that that the industrial possibilities of the find depend.

"A sample from the outcrop where the shale was first detected in Raasay gave 12 gallons of crude oil per ton of shale, with 6·2 lb. of sulphate of ammonia, which is equivalent to at least 12 lb. in a works retort.

"A compound sample from the Skye coast between Holm and Prince Charles' Cave yielded 12·8 gallons of crude oil per ton, and 7·4 lb. of sulphate of ammonia. Mr. D. R. Steuart, who kindly undertook these tests, states that the samples were so weathered that he did not expect to get any oil. Consequently these results indicate that the shale is worth further investigation."

The position of the shale on the east of the field forms a straight N.S. feature readily followed as far as the top of the cliff above Screapadal. On the west side of the field there is an exposure of the shale in the banks of the stream E. of Storav's Grave, but quite burnt by the proximity of the great granophyre intrusive sheet. Part of the seam is to be seen in the right bank of the stream N.E. of Storav's Grave, where it also appears to have suffered from the action of the igneous intrusion. During the original survey of the island by Woodward this exposure was mistaken for Upper Lias shale, and appears as such of the geological map published in 1896. A similar mistake was made in the case of a partial exposure on the stream above Druim an' Aonaich—1 mile further east, which was also mapped as a faulted outlier of Upper Lias. At these two localities the oil-shale is seen to pass gradually upwards from less and less argillaceous strata into carbonaceous sandstone which finally passes up into a massive white sandstone some 50 feet thick. The base of the carbonaceous sandstone has yielded plant-remains, fragments of a Limuloid crustacean, an *Estheria*, and fish remains. Thin lenticular layers of

coal have been observed at this level. The thick white sandstone is unfossiliferous, but is very constant, both in Raasay and in Skye, where it attains a thickness of 100 feet.

There is no exposure of the strata following upon the sandstone. The lowest seen is about 5 or 6 feet above the top of the sandstone in the bed of the stream above Druim an' Aonaich: laminated shale with a layer of *Modiola* and nodules of argillaceous limestone. There is no evidence regarding the beds in the next 50 feet or so of the sequence. An exposure which may be some 50 feet above the base occurs above the outcrop of oil-shale E. of Dun Caan, where the following section is to be seen: —

	Ft.	In.
Cyrena-shale.		
Brown crusted limestone full of comminuted *Cyrena*	0	6
Blue limestone with *Cyrena*	0	6
Decomposed friable limestone full of *Modiola*	1	0
Cyrena-shale	3	0
Argillaceous limestone with underside layer of *Modiola*	1	0
Cyrena-shale	3	0
Limestone with underside band of "beef"	0	2
Cyrena-shale	1	0
Argillaceous limestone.		
Cyrena-shale.		

The *Modiola* resembles *M. imbricata* J. Sow., but is smaller and more gibbous. The *Cyrena* belongs to *C. brycei* Tate and to the variety of *C. jamesoni* Forbes, represented by Fig. 8, of Plate V., accompanying Forbes' paper.* *Anomya æstuarina ?* Tate, was also found.

A section ½ mile N.E. of Dun Caan appeared to be higher in the sequence, and the following section was noted :—

	Ft.	In.
Shelly oolitic limestone	1	6
Shale	3	0
Sandy limestone and "beef"	1	0
Oolitic limestone	1	0
Cyrena-shale	2	0
Cyrena-limestone	1	0
Shale with band of "beef"	5	0
Blue sandy limestone	0	4
Shale	3	0
Limestone with hard blue core	1	0
Shale	3	0
"Beef"	0	2
Shale	2	0
Limestone with *Myoconcha*	0	3
Fine soft sandstone	0	1
Shale	4	0
Hard rib	0	2
Shale	3	0
Earthy limestone with *Myoconcha*	0	1
Soft papery shale, base not seen.		

The *Myoconcha* is a new species which Dr. F. L. Kitchin states to be a form that also occurs in the island of Eigg. It has the tooth and the muscular impression of *Myoconcha*, but does not possess radiating lines on the shell. The *Cyrena* is *C. brycei* Tate. A doubtful specimen of small *Ostrea hebridica* was also observed. These

* On the Estuary Beds and the Oxford Clay at Loch Staffin, in Skye. *Quart. Jour. Geol. Soc.*, vol. vii., p. 104, 1851.

beds, and others noted at approximately the same horizon, are hidden at the next locality to be considered, where their position—followed along the strike—is overlain by strata which give the following section at a good exposure forming a conspicuous bare face 1 mile S.W. of Screapadal.

	Ft.	In.
Basalt.		
Fine calcareous sandstone with small *Cyrena*	1	0
Cyrena-shale	1	0
Fine white calcareous sandstone	1	0
Grey sandy limestone with *Cyrena* and *Viviparus*	0	6
Sandy *Cyrena*-shale	1	0
Coarse sandy limestone with comminuted *Cyrena*	5	0
Sandy shale	2	0
Sandy limestone with large *Cyrena*	2	0
Limestone with comminuted *Cyrena*	3	0
Shaly sandstone	1	0
Soft fine calcareous sandstone with small *Cyrena*	3	0
Shale	2	0
Calcareous sandstone with *Cyrena*	1	0
Cyrena-shale	5	0
Soft calcareous sandstone	3	0
Hard fine calcareous sandstone	2	0
Pebbly limestone forming feature	6	0
Sandy shale with carbonaceous spots	6	0
Limestone made up of small *Cyrena*, with a layer of large ones	1	0
Gap	3	0
Hard fine white calcareous sandstone . . . about	4	0
Bank, in part soft decomposed sandstone	25	0
Coarse limestone with comminuted shells	4	0
White sandstone	5	0
Muddy calcareous sandstone full of triturated shells	2	0
? Sandy shale (obscure)	2	0
Fine calcareous sandstone	3	0
Gap	3	0
Sandy limestone with rusty weathering	2	0
Bank, mostly obscured, presumably the series of *Cyrena*-shale with " beef " and argillaceous limestone already noted . . . . . ?	150	0
Feature at position of white sandstone resting on oil-shale	50	0

The fossils, in spite of their immense numbers, belong to but few species. Of the specimens of *Viviparus* most are near to *V. aurelianus* Cossman, from which they differ in having a narrower base. *V. scoticus* (Tate) is present, but relatively scarce. In S.E. Skye Mr. Wedd has noted *V. scoticus* [=*Paludina scotica*] close to the top of the great Estuarine Series, while *V.* cf. *aurelianus* occurs lower down, below the *Ostrea hebridica* beds. Consequently, judging from the relative abundance of *V.* cf. *aurelianus*, it would seem that the *Viviparus* bed of Raasay does not represent the topmost *Viviparus* bed of Skye, but probably a lower one.

Cyrena is represented by several species occurring throughout the section. They are :

Cyrena brycei *Tate*
,, cunninghami *Forbes*
,, *aff.* cunninghami [more transverse]
,, jamesoni *Forbes*
,, *aff.* jamesoni [postero-dorsal slope less sloping]
,, sp.

A small *Actaeonina*-like shell was found a hundred yards south of this locality along the strike of the lower bed of hard, fine white sandstone.

The *Ostrea hebridica* beds were not seen *in situ* by the writer, but they were noted by Woodward and also by Mr. Thorneycroft on the slopes of Dun Caan. A large loose block was found above Screapadal in close proximity to the great boundary fault. Beside *O. hebridica* Forbes, it yielded *Cyrena cucullata* Tate, and a fragment possibly referable to *Potamomya*.

North-East Skye.

The area of N.E. Skye included in the districts described in the present Memoir is represented by a long coastal strip too narrow to contain the whole of the series, which has a general dip to the N.W., bringing the upper portion of the strata outside the margin of the map.

The sequence is very much like the Raasay development, and shows little lateral variation along the 18 miles of outcrop from Upper Ollach at the south end to the neighbourhood of Staffin at the north end of the area under consideration.

From Ollach to Bearreraig the basal bed of the series is, as in Raasay, an oil-shale resting conformably upon the marine clay of the Garantiana Zone. The seam consists of about 7 feet of shale proper, capped by some 3 feet of bituminous sandy shale. It is not yet known whether it may have any economic value; what was known of its contents in oil and ammonia at the time it was discovered is stated in the article already quoted from *Nature*, p. 53. At various points, notably south of Prince Charles' Cave, and on either side of Camastianavaig, the shale has been subjected to the destructive action of intrusive rocks and has lost all its oil-content. It appears in its unaltered state only north of Prince Charles' Cave and in the cliff north-east of Ben Tianavaig. The fossils found in the oil shale are *Cyrena* and plant-remains (fern-pinnule) (Pl. IV., Fig. 1).

In the southern part of the field the shale tends to pass laterally into impure coal. Burnt coal occurs in thin streaks at low water on the shore E. of Achnahannait, south of Tianavaig Bay. Further south on the coast at Upper Ollach attempts have been made to extract coal from a lenticular seam between tide marks. It is of very poor quality and of no economic value. Impure coals are known also from higher horizons in the Estuarine Series of Skye, for instance on the shore of Loch Bay, on the west side of the island. As regards the "Portree Coal," which once was mined at Camas Ban on the south side of Portree Harbour, it is a lignite of Tertiary age. North of Holm the oil shale is replaced by a black sandstone, generally inaccessible though often visible from the foot of the cliff. It reaches sea-level at Inver Tote, where two inches of shale separate it from another black sandstone, with marine lamellibranchs, almost certainly belonging to the Garantiana Zone.

Between Portree Bay and Holm the oil shale and underlying clay form a conspicuous shelf between the Inferior Oolite sandstone and the sandstone which follows upon the oil shale. This sandstone is generally white—sometimes greenish, soft and waterlogged, and is

unfossiliferous. It is remarkably constant: being easily recognised far away to the south in the Strathaird district. Near Holm it is 100 feet thick, and it is 50 feet thick further north at Inver Tote.

The strata next in ascending sequence are much obscured by peat and drift in the district between Portree and Inver Tote. The best exposures are between Inver Tote and Culnaknock. At Inver Tote the inaccessible sides of the stream-gorge show a fine section of black papery shales and their junction with the white sandstone. The shale contains thin bands of "beef" and limestones, of which one is finely brecciated. *Cyrena* is common. These shales, often much indurated by the igneous intrusions which traverse them, are well displayed in the cliff between Inver Tote and Culnaknock. Higher beds are seen in the bed of the Longfearn stream and in isolated exposures around Culnaknock. The sequence is as follows:—

	Ft.
Cyrena-limestone, seen	8
Isolated crops of soft sandstones with calcareous doggers and *Cyrena*-limestone bands, and presumably shales (not exposed) about	100
Shale	15
Soft sandstone with doggers and *Cyrena*-limestone bands . .	22
Shales	80
White sandstone (to sea-level at Inver Tote)	

As already stated, the higher members of the Great Estuarine Series are outside the limits of the map, but the top member of the above section is not far below the position of the *Ostrea hebridica* beds which are so well developed at Loch Staffin, and are also seen in small exposures on the banks of Loch Fada near Portree.

CHAPTER VIII.

CORNBRASH.

Bathian.

In Skye the Great Estuarine Series is succeeded by marine strata which are nowhere older than the Callovian. It is therefore of interest to note that in Raasay there is a small patch of strata referable to early Cornbrash (Bathian).

This was discovered during the recent survey $\frac{9}{10}$ mile N.E. of Storav's Grave, on the right bank of the middle branch of the Glam Burn, 300 feet W. of the basalt boundary. The ground is exceedingly difficult of interpretation owing to faulting, drift and peaty covering, which makes it impossible to estimate the extent of the Cornbrash area, though there is fortunately no doubt that the beds referred to it follow upon the Great Estuarine Series.

What is seen of the sequence consists of 15 feet of gritty white limestone, strikingly granular and unlike any other rock in Raasay, with comminuted fossils, resting on some 6 or 8 feet of gritty, flaggy limestone, darker and with red ironstone nodules. This lower limestone is full of comminuted fossils, but has also yielded a few that are entire and sufficiently determinable to give a clue to its age. Most of the fossils obtained are brachiopods, which were submitted to Mr. Buckman, who determined them as follows :—

Ornithella, two species.
Rhynchonella, three or four species.
Terebratula intermedia *J. Sow.*

A small crop of the upper, granular limestone juts out of the peat 1000 feet north of this locality, but there is no room for higher beds.

In the bed of the northern branch of the Glam Burn there is an exposure, several yards long, of a greenish sandstone, which, from its position, one would naturally have referred either to the Cornbrash or to the Callovian. A special search for fossils revealed the Middle Lias age of the stratum. The reason for its position at this level must remain a matter for conjecture, since the ground is so obscured by drift that it is not possible to determine whether it was brought to its present position by faulting or by glacial action.

CHAPTER IX.

UPPER CRETACEOUS GREENSAND.

Cenomanian ?

In Raasay no Jurassic strata more recent than the Cornbrash have been detected, and it is almost certain that there is no room for any to lie hidden under the cover of the Tertiary igneous rocks.

Rocks of Cretaceous age, which once covered large areas in the Highlands, are here nearly completely denuded away, except for a thin strip which emerges at one exposure only from beneath the basalt of Dun Caan, on the western side of the hill, on the track leading to the summit. The exposure is very imperfect, and shows only unfossiliferous glauconitic sandstone. A loose block of glauconitic sandstone, found on the other side of the hill, bore a fragmentary impression of *Neithea*—the only fossil found in this glauconitic sandstone of Raasay, which, from the analogy of the Cretaceous development in Mull and Morvern, may be referred to the Cenomanian.

CHAPTER X.

IGNEOUS ROCKS.

Although it is not intended to include the description of the Tertiary igneous rocks in this memoir, brief mention must be made of some of the more important members of the series.

With the exception of a few basalt dykes there are no Tertiary igneous rocks within the Jurassic area at Applecross. In Raasay they play a considerable part in the structure of the island, and cover extensive tracts of ground. Here the most conspicuous igneous rock is a coarse-grained granophyre forming a sill now exposed on the surface from the south end of the island to Storav's Grave. The sill does not follow one continuous stratigraphical plane, but cuts across different horizons from the Trias at the south end of the island to the base of the Estuarine Series near Storav's Grave. It shared in the dislocations which affected the area. The rock is hard and does not disaggregate readily; consequently its surface is generally bare, with little or no soil, and is thus the most barren from the point of view of agriculture or sheep grazing. A detailed account of this sill is given in Sir Archibald Geikie's *Ancient Volcanoes of Great Britain*. A thin sheet of the same granophyre follows a few feet above the oil shale on the east of the island.

Two basalt intrusive sheets occupy part of the Estuarine Series area from Dun Caan northwards. The higher of them was coloured as lava in the original edition of the map, but in his posthumous paper on Raasay (*op. cit.*, p. 190) H. B. Woodward states that this basalt should have been coloured as intrusive.

The faulted, semicircular area which stretches from Raasay House to Oskaig Point was also originally coloured as lava. The rock is very coarse, even gabbroid at some places, and is much more likely to be intrusive than contemporaneous.

Small basic dykes are fairly common in the middle and southern portions of the Jurassic area. Few of them are accompanied by any appreciable displacement. Owing to their small size they weather away rapidly, and so they do not form conspicuous features. Their direction varies from N.W. to N.E.

In the neighbouring portion of Skye most of the igneous rocks are basic, the principal exception being the crops of granophyre opposite Suisnish. Basalt lavas occupy the greater part of the ground in the area south of Portree Bay, while the basalt crags in the cliffs from Prince Charles' Cave to the north are intrusive sheets. Some of these persist for a long distance and attain a considerable thickness. Columnar structure is sometimes well marked. Basalt dykes with a N.W. direction can be seen at intervals along the foot of the cliffs.

CHAPTER XI.

FAULTS.

THE region described in the previous pages is traversed by a number of dislocations of variable importance. The most important have a direct bearing on the preservation of the different tracts of Jurassic rocks, and it will be noticed that their direction is N.E. The preservation of the Applecross outlier is in part due to a N.E. fault which forms its N.W. margin and can be traced further inland. Prof. Judd thought that a second great fault marked the south-easterly boundary of that same patch (*op. cit.*, p. 672), but the recent Survey work seems to show that that there is no real fault of appreciable magnitude. There are, however, several small dislocations probably due to local subsidence and swallet holes to which a more considerable part may have been attributed by Prof. Judd.

In Raasay the great N.E. fault which traverses the island obliquely from north of Holoman to Screapadal is of first importance, since it is to it that we owe the preservation of the Jurassic area lying south of it, with its deposit of ironstone. Its throw was estimated by Prof. Judd to be something like 1000 feet, which is in harmony with the various estimates of thickness as given in the present memoir. Within the Jurassic area of Raasay there are several other faults, one of which is also of economic importance, namely, that which let down the outlier of Beinn na' Leac with a considerable field for the future exploration of the iron-ore horizon. There is besides in connection with this fault a peculiar feature worth mentioning : its outer side is marked by a regular, moraine-like ridge of sandstone blocks which follows the base of the north-western slope of Beinn na' Leac, always at a regular distance. The materials forming this ridge are obviously derived from the crags immediately above, and it must be that they are scree materials, now separated from the slope on account of recent movement along the fault, which would have taken place since glacial times (Plate III., Fig. 2).

The small faults in the middle of the area west of Beinn na' Leac were detected by Messrs. Thorneycroft and Wedd, mainly from the information supplied by boring operations. The fault running south of Loch Storav forms a feature and has a considerable displacement which directly influenced the selection of the site of the principal mine.

A fault which runs from Oskaig to near the Manse and then further south through the granophyre forms distinct features, though there is very little actual displacement.

The fault which runs in a north-westerly direction from south of Hallaig through Loch na' Mna and Loch na' Meilich forms the main western boundary of the Estuarine Series area, with its underlying bed of oil-shale.

In the portion of Skye which comes within the area of the present map dislocations occur in the tract south of Portree Bay and produce a striking type of scenery. The whole of the eastern face of Ben Tianavaig is traversed by numerous faults, often of very low hade, and by great landslips which give it a markedly " tumbled " appearance. It is possible that these landslips may have taken place along the lines of true faults in post-glacial times.

Prof. Judd showed (*op. cit.*, p. 724) that a great fault with a throw of something like 1000 feet must traverse the Sound of Raasay : its presence is deduced from the rapid westward dip of the Jurassic strata in Raasay and their reappearance on the opposite shores of Skye.

Landslips.—At various occasions in the preceding pages allusion has been made to the presence of landslips. These attain a large size and may obscure considerable tracts of country. The largest is that of Hallaig, which involves immense masses of Middle Lias and of Pabba shales, with typical landslip-features. The eastern slope of Beinn na' Leac at Fearns is almost certainly partially made up of slipped materials—mostly Middle Lias—displaced without obvious dislocations, thus producing a great apparent thickness of Scalpa Sandstone.

As already stated, Ben Tianavaig, south of Portree Bay, shows striking examples of large landslips, which affect the basalts as well as the Jurassic strata. They are best seen from the steamer, when approaching the entrance of Portree Bay.* Great blocks of sandstone, fallen from the cliffs, occur frequently along the shores of Skye and the east of Raasay, even where there are no landslips : their presence adds considerably to the inaccessibility of these shores.

Fissures, probably due to a process similar to that which produced the landslips, constitute the feature which probably arrests first of all the attention of the visitor to Raasay. They occur at and near the margin of the eastern cliffs, from Beinn na' Leac to Screapadal, generally at right angles to the direction of the cliffs. They are deep and vertical and vary in width from one to ten feet. The narrower ones are often hidden by vegetation, and might easily prove a source of danger to any one unacquainted with their presence. The question may arise in the future, as to whether these fissures will be likely to interfere with the possible mining operations in the as yet unexplored ironstone field in the Beinn na' Leac outlier. Although a forecast is naturally impossible, it would seem that the Aalenian shales—here nearly 100 feet thick—are of sufficient thickness to afford protection to the roof of the seam (Pl. VI.).

Swallet holes occur in the Hettangian limestones at Applecross ; the largest is some 15 feet deep.

* The Storr Rock and the Quirang, which offer remarkable examples of landslips, are outside the area described in this memoir.

FISSURE IN INFERIOR OOLITE, SOUTH OF DUN CAAN, ISLAND OF RAASAY.

CHAPTER XII.

SUPERFICIAL DEPOSITS.

Drift.

The whole of the district under consideration shows evidence of glaciation, but drift deposits of appreciable thickness do not cover large tracts of ground except along the north-eastern portion of Skye. There, much of the Estuarine Series is hidden by boulder-clay, temporary sections of which were visible during the making of the new road from Portree to Staffin. In Raasay boulder-clay is not extensive, being restricted to small areas near Eyre burn, Rudha na' Cloiche and Fearns in the southern part of the island, and near Glam and Storav's Grave in the northern part. On the other hand, erratic blocks are common everywhere, and the bare glaciated surface of the hard granophyre sill shows conspicuous evidence of glaciation, which is also noticeable in the white sandstone of the Inferior Oolite. The ice striæ and trenches point to a movement of ice from south-east to north-west. The small lochs on the high ground of Raasay are probably of glacial origin, as can be inferred from their direction, which is approximately the same as that of the glaciation.

The Jurassic area of the Applecross district does not present any noteworthy glacial features, though such are conspicuous in the Torridon Sandstone area.

Raised Beaches.

Beach deposits are of small extent. There is a tract referable to the 25-feet beach west of Applecross House.

In Raasay some of the best cultivated land is on what may be the 50-feet beach, south of Oskaig, and the grounds west and south of Raasay House are situated on the same beach deposits. Small patches probably belonging to the same 50-feet beach occur also on the low cliffs near Suisnich and at the southern end of the island.

Woodward in his last paper (*loc. cit.*, p. 193) mentions a small tract of 100-feet beach deposit observed by Mr. Hinxman on the west coast of the Torridon Sandstone area of the island, north of Inver.

The strip of Skye coast which comes within the scope of this memoir, is, from its rugged nature, little suited to the development of raised beach deposits. The only good example is a clear-cut shelf of the 50-feet beach just north of Leac Tressirnish, some 10 miles N.E. of Portree.

APPENDIX I.

PALÆONTOLOGICAL CLASSIFICATION AND COMPARISON OF CERTAIN JURASSIC ROCKS OF RAASAY AND SKYE.

By S. S. Buckman, F.G.S.

CONTENTS.

I. Introduction.

Cephalopods and Brachiopods from certain Jurassic rocks of the islands of the Hebrides off W. Scotland were submitted to me. A fairly detailed examination of the Raasay material was possible; but, for various reasons, only a cursory glance at the collection from Skye could be taken. There is, however, so much new matter from the two places, both from the geological and the palæontological points of view, that much more prolonged work is desirable to do it justice. The following remarks must be regarded merely as a preliminary report.

The details from Raasay are first given, then those from Skye; later the strata and fauna of both are compared and correlated with those of English and other areas.

For kind assistance in the preparation of this report my best thanks are due to Dr. G. W. Lee, Mr. W. D. Lang, Mr. J. W. Tutcher, and others. The writing of this report led to a more extended paper to the Geological Society (read June 1917—Publ. *Quart. Jour. Geol. Soc.* 1918, lxxiii, p. 257). That paper contains a revision of the Lias Chronology and a much fuller

sequence of faunal horizons than could be introduced here: in certain respects it forms a supplement to this report, covering a much wider field.

II. RAASAY.

a. Cornbrash (Bathian).

In the middle branch of Glam Burn there were collected certain brachiopods not in good condition—Terebratuloids and Rhynchonellids. The *T. intermedia* group is represented, but the Rhynchonellids are unsatisfactory. This is the first recognition of definite Cornbrash strata in Scotland.

In the north branch of Glam Burn a fossiliferous mass was found which from its position should have been of about the same date as the rock of the middle branch. It yielded, however, Brachiopods of the Middle Lias (Domerian), see below, p. 69.

b. Inferior Oolite (Vesulian-Aalenian).

In the Isle of Raasay the sequence of Inferior Oolite deposits is very incomplete according to the palæontological evidence. The main mass consists of "600 feet of sandstone of marine origin, but unfossiliferous from the zonal point of view" (Dr. Lee).

North-east of Storav's Grave are clays which yield crushed specimens of *Garantiana* spp. and *Strenoceras* spp. indicating deposits of *Garantiana* and perhaps of *niortensis* hemera. "The oil shale directly rests on the *Garantiana* clay, and the great sandstone mass underlies it" (Dr. Lee).

On the path to Dun Caan specimens were collected *in situ* and from various loose blocks all within a few feet of one another. In many cases the Ammonites were only young examples, and their exact determination could not be insisted upon. But a Hildoceratid with a carinati-tabulate periphery suggested a deposit of the *discites* hemera, and removal of matrix revealed *Lopadoceras arcuatum*. *Discites* date was also confirmed by examples of *Braunsina* and *Depaoceras*. Examples of *Ludwigella cornu* and *L. attenuata* point to deposits of *concava* hemera; and other species indicate lower deposits to be referred to presently. The fossils, therefore, indicate various zones all close together, but supply no evidence for any deposits to fill the gap between *niortensis* and *discites*. This is probably represented by the great sandstone above mentioned—the Raasay Sandstone as it may be termed.

The rest of the Aalenian was collected from in considerable detail, mainly in relation to a datum line at the top of the deposit which may be called the Dun Caan Shales. These Shales are found by palæontological evidence to be in non-sequence to the Raasay Ironstone.

c. Inferior Oolite-Lias (Aalenian-Whitbian).

There are three datum-lines from which systematic collection has been possible—the top of the Dun Caan Shales, the Raasay Ironstone and the top of the Scalpa Sandstone. A thickness of nearly 100 feet of deposit is involved, and the results may be presented in tabular form.

The coincidence of the base of the Main Ammonite Bed with the datum line at the top of the Dun Caan Shales has not been definitely stated in the collectors' record, but it has now been assumed.* A fauna of *murchisonæ* date has been found about 3 feet above the Main Ammonite Bed, which itself is of *scissum* date. A few feet of the upper part of the

* "The Main Ammonite Bed of *scissum* date and the zones next to it occupy a thin calcareous phase at the very bottom of the great sandstone." Subsequent note by Dr. Lee.

Table I.—Aalenian to Whitbian, Isle of Raasay.

Ages.	Hemeræ.	Strata, Etc.	Feet above Scalpa Sandst.	Feet in ref. to Datum Line.	Fauna.
Aalenian	*murchisonæ*, about 3 feet	"About 3 feet above Main Ammonite Bed"		+4 to +3	*Welschia; Manselia; Hyattina.*
	scissum, about 1 foot	"Main Ammonite Bed," thickness not ascertained		+1	*Lioceras uncum gracile; Lioc. costosum; Lioc. subcostosum* and other spp.: cf. *Canavarella*; cf. *Rhæboceras tortum.*
	opaliniforme, about 4 feet	Datum line—junction of base of sandstone cliff with shale beds below, which form steep grassy and talus slope	85	0	
				4	*Cypholioc. opaliniforme*; *Pseudol. beyrichi*; *Walkeric. subglabrum.*
	Olim *aalensis* hemera. *venustula*, about 16 feet	The Dun Caan Shales	80	−5 to −6½	*Canavarina venustula*; *Pleurolytoceras leckenbyi.*
				−8½	*Walkericeras subglabrum.*
			75	−9½	*Canavarina venustula*; *Pleurolyt. leckenbyi.*
			70		
				−18	*Canavarina venustula*; *Cotteswoldia* (fine ribbed).
			65		
	digna, about 18 feet			−22	*Can. digna.*
			60		
				−26	*Pleurolytor. leckenbyi*; *Canavarina digna-steinmanni.*
				−28	*Canav. digna-steinmanni.*
			55		
				−33	*Can. folleata.*
			50	−38	*Cotteswoldia subcandida*; *Walkeric. delicatum.*
			45	−40	*Cottes. subcandida*; *Walkeric.* cf. *burtonense.*
				−42	*Pleydellia leura*; *Cott. costulata.*
				−44	*Cott. costulata*; *Pleydellia aalensis.*
			40	−45	*Cott. costulata.*
				−47	*? Can. folleata.*
				−48	*? Cott. superba.*
			35		
				−52	*Megateuthis tripartitus* group.
	Cotteswoldia, about 40 feet			−53	*Walkeric.* (pre-)*burtonense*; *? Cott. particostata.*
			30		
				−58	*? Cott. superba*; *? Cott. subcandida.*
				−65	
		"Shale on top of Ironstone." *Aalensis* Amm. "Three feet above top of Ironstone."			
		"Shale on top of Ironstone." *Aalensis* Amm. "Top of Ironstone to 1½ feet above."		−72	*? Walkericeras lotharingicum.* — *Pleydellia subcompta*; *Cotteswoldia* cf. *linatula*; *Walkeric. burtonense ?*
				−73½	*Megateuthis tripartitus* group.
		A considerable non-sequence→			
Whitbian	*subcarinatum*, about 3 feet	"Raasay Ironstone"		−75	←*Dactyloteuthis irregularis*—at 75 ft. below datum.
					Hildoceras bifrons d'Orbigny sp.; *Dactylioceras* cf. *crassiusculosum*; *Coeloceras dayi*—in upper part of Ironstone.
				−78	
	falciferum and perhaps *exaratum*	Portree Shales—shale beds of variable thickness below Ironstone			*Dactylioceras delicatum*; *D.* aff. *holandrei*, spp. var. *D.* cf. *vernis D. raristriatum*; *Peronoceras attenuatum*; *Harpoceratа*, cf. *H. falciferum* and *H. mulgravium*, *Dactyloteuthis tubularis ?* *Dactylot.* cf. *stimulus.*
		Top of Scalpa sandstone		−85	

Dun Caan Shales indicate *opaliniformis* date, and the main mass of them, some 80 feet, belong to *aalensis* date. From the great thickness, with definite changes of fauna revealed, it is possible to divide this *aalensis* date into three portions.

The Hildoceratids of the main mass of the Dun Caan Shales all belong to the *Am. aalensis* group; but they are not in good condition for exact identification: they are crushed or are mere impressions on the shale, and in such cases essential characters are often obscured. Allowance should be made for this; but the following general facts may be noted. In the upper part of the shales fine-ribbed species are dominant; in the middle well-ribbed species; while in the lower part occur species of a distinct and easily recognisable type—those of the *Cotteswoldia costulata* pattern,—in which rather strong distant ribs pass rapidly into smoothness. The hemeral terms are designed to record these three faunal changes; and further reference to the subject will be made later (p. 78).

The available evidence favours the assumption that Aalenian strata rest directly upon the Ironstone—Amm. of the *aalensis* group were collected from shale on top of the Ironstone at the Main Mine; more exact is the record of a specimen within 3 feet of the top of the Ironstone; and still more important perhaps is the record of Belemnites of the *Megateuthis tripartitus* group from the "top of Ironstone to 1½ feet above it," as they connect with a similar record some 23 feet higher.

The date of the Raasay Ironstone is about the *subcarinatum* hemera of the Whitbian—at any rate it is later than *falciferum* hemera. The important fossil for dating the Ironstone is *Hildoceras bifrons* d'Orbigny (*non* Bruguière) sp.; *Dactylioceras* cf. *crassiusculosum* seems to point to something earlier and suggests that the Ironstone may be really conglomeratic.

The shales below the Ironstone may for distinction be called the Portree Shales—they are more developed in Skye. Here, in Raasay, they are of variable thickness—the Ironstone is sometimes no more than 2 feet from the Scalpa Sandstone. But then according to the information given the base of the Ironstone is indefinite—lenticules of ironstone occurring in the shales—which perhaps again points to conglomeratic conditions with possible redeposition.

More will be said about the Portree Shales in the remarks on Skye.

d. The Middle Lias (Domerian and Lower)—the Scalpa Sandstone.

The Scalpa Sandstone reaches 240 feet in thickness (Dr. Lee); and the main mass of it belongs to the Domerian. A few feet at the top may be taken as Whitbian, and some part of the base is certainly Charmouthian.

It has not been possible to carry out detailed collecting in the Scalpa Sandstone. The majority of the specimens of Ammonites have been obtained from loose blocks—only in a few cases have definite positions been noted. The following table gives the evidence; but it must be remembered that where there is no positive record the position accorded is an assumption.

The Scalpa Sandstone reveals a considerable thickness of strata, the main of which is presumably of Domerian date, though its exact zonal allocation is not possible on the information given. Towards the upper part is a fauna quite distinct in certain respects from that of English localities—in its abundance of *Amaltheus lævis* and in a new series of massive Rhynchonellids of somewhat primitive features (*Grandirhynchia*).* It may therefore be understood why it seems desirable to introduce an

* The record of this fauna in Table II. as obtained from "? near the top of the Scalpa Sandstone" is presumably to be explained by local denudation of the sandstone.

Table II.—The Scalpa Sandstone, Isle of Raasay.

Ages.	Hemeræ.	Strata, Etc.	Fauna.
Whitbian	*tenuicostatum* or *acutum*	"Top of Scalpa Sandstone"	*Dactylioceras* spp.
		"6 feet from top"	*Dactyl.* of the *holandrei* group; *Dact. anguinum?*
Domerian	*spinatum*	"150 feet up Scalpa Sandstone"	*Paltopleuroceras elaboratum.*
		"From dark calcareous sandy shale"	*Megateuthis paxillosus* group.
		"From loose blocks"	*Paltopl. elaboratum, P. pseudospinatum, P. pseudocostatum.* Massive Rhynchonellids (*Grandirhynchia*, S. Buckm.).*
	lævis	"? Near top of Scalpa Sandstone, Road into Main Mine"—a light sandstone	*Rh. acuta* (small), *Aulacothyris florella, Zeilleria* cf. *subnumismalis.*
		"From fallen blocks" of light sandstone	*Amaltheus lævis* (abundant); *Amaltheus* spp. (small examples), *Amauroceras* cf. *ferrugineum; Rhynch. rosenbuschi* (*Grandirhynchia*) *Rh. capitulata*, all in one block. Fauna corresponding to this and the Main Mine series yielded by other blocks.
	margaritatus?	"From fallen blocks"	*Amalth. nudus.*
	algovianum?	"Base of Scalpa Sandstone"	*? Seguenziceras.*
		"From fallen blocks"	*Amaltheus clevelandicus.*
Charmouthian (Hwiccian) †	3rd *Capricorn* and/or lower?	,, ,,	*Androgynoceras* cf. *maculatum* = *? Capricorn Amblycoceras.*[1]
		,, ,,	*Lytoceras salebrosum.*

* See later, p. 80. † See later, p. 86.

[1] Cf. Trueman, *Q.J.G.S.*, lxxxv, 1919, p. 280.

additional dating term, *lævis* ; but the significance of this may be suitably discussed later.

The large fossiliferous mass found in the north branch of Glam Burn, alluded to above (p. 65) yielded *Rhynchonella acuta*, *Aulacothyris florella* and *Zeilleria sp.*—Brachiopods of *lævis* horizon ; but curiously enough there were no associated Ammonites. This seems to suggest that this block, so out of place stratigraphically, was not a native of Raasay, but had been transported from some other locality. At such place it may be surmised was an even greater thickness of Domerian strata, in which there was room for the Ammonites and the Brachiopods to occupy separate levels ; or it was an area favourable to Brachiopods but unfavourable to Ammonites—a shallow more or less landlocked bay, for instance.

e. Charmouthian—the Pabba Shales.

The Charmouthian Strata of Raasay, with the exception of a small portion represented in the base of the Scalpa Sandstone (see Table II, p. 68), are designated by the term Pabba Shales.

Dr. Lee writes : " The total thickness of Pabba Shales is round about 600 feet. Of this some 200 feet at the top would include the *valdani-jamesoni-armatum* Zone. The remaining 400 feet would thus be all *raricostatum*, but I think the bottom 100 feet is not represented owing to faulting in the great Allt Fearns section. . . . In Skye the total thickness of the Pabba Shales is even greater : 700 feet is the estimate of Wedd and Woodward."

The great thickness of the strata of the so-called *raricostatum* zone, that is, of the beds yielding *Echioceras*, is a special point of stratigraphical interest.

The specimens of Ammonites and Brachiopods submitted were collected in sequence up the Allt Fearns stream, and so the faunal succession was obtained. The results are given in the annexed Table III with some details from other places.

Another record of specimens collected at definite levels in part of the *Echioceras* strata is given in Table IV, wherein is also marked the presumed equivalence to certain collecting spots in the former table.

It will be noticed in the above faunal tables that the thick Pabba Shales disclose a series of horizons with distinctive species. It is necessary to have names for these horizons so as to identify them without circumlocution ; so a series of names has been proposed about which more will be said later. More species might have been quoted in the first table, but sufficient have been given to show the different general characters of the various faunal episodes. These episodes may be summarised as follows :—

Leckenbyi. A fauna of large-spined Derocerates.
Aplanatum. A fauna of carinati-sulcate Echiocerates.
Macdonnellii. A fauna of catagenetic Echiocerates.
Raricostatoides. A fauna of crassicostate Echiocerates.
Bispinigerum. A fauna of Derocerates.
Densinodum. A fauna of polygyral, spinous species of perhaps two families, and of Echiocerates.

It is not contended that the faunas are arbitrarily confined to these limits, but only that these are the salient successive features. Derocerates are to be expected before *bispinigerum* on biological grounds, and their sporadic appearance in the intervals between *bispinigerum* and *leckenbyi* is shown to a certain extent by the fauna of the Pabba Shales. I have surmised that the Derocerates of Hallaig shore are from a horizon later

Table III.—Pabba Shales, Isle of Raasay.

Mainly from Allt Fearns along Stream.

Ages.	Hemeræ.	Strata.	Fauna.
Charmouthian: Wessexian *	*valdani*	"The highest beds in Allt Fearns Valley'	*Acanthopleuroceras* spp. *Platypleuroceras* spp.
		"Two Mile Burn—above waterfall"	Do. Do.
	jamesoni	"Two Mile Burn—below waterfall"	*Rimirhynchia* sp. (large).
		Do. lower	*Uptonia* spp.
	leckenbyi	"Shore near high water mark, 80 yards S. of Hallaig Fisherman's Hut"	*Deroceras* spp.
Raasayan *	*aplanatum*	"Allt Fearns Stream—[oc. 13"	*Deroceras hastatum? Echioceras aplanatum? E. subquadratum.*
		" ,, ,, Loc. 12"	*Deroc. miles?* † *Echioc. oosteri?*
	macdonnellii	" ,, ,, Loc. 11"	*Echioc. scoticum* (type), *E. modestum? E. hugi?*
		" ,, ,, [Loc. 10*b*]"	*Echioc. macdonnellii, E. faivrei.*
		" ,, ,, [Loc. 10*a*]"	*Echioc. macdonnellii, E.* cf. *deciduum.*
	raricostatoides	" ,, ,, Loc. 10"	*Echioc. raricostatoides, E. boreale* (type), *E. zieteni.*
		" ,, ,, Loc. 9"	*Deroceras milleri?*
		" ,, ,, Loc. 8"	*E. zieteni? E. costidomus? E. robustum? E. gracile?*
		" ,, ,, Loc. 7"	*E. lævidomus, E. edmundi, E. robustum, E.* cf. *zieteni, E.* cf. *polygyratum, E. prorsum, E.* cf. *rhodanicum.*
		" ,, ,, Loc. 6"	*Rhynchonella* cf. *gryphitica juvenis* (smaller than below).
	bispinigerum ‡	" ,, ,, Loc. 5"	*Deroceras anguiforme.*
		" ,, ,, Loc. 4"	*Rhynchonella* cf. *gryphitica juvenis* (large), *Deroceras* (of the *armatum* type) loose at this point.
		" ,, ,, Loc. 3"	*Deroceras* (*Microceras*) cf. *densinodus*, Wright sp.
	densinodum and *1st Echioceras*	" ,, ,, Loc. 2"	*Deroceras* (*Microceras*) aff. *obsoletum*, Blake sp., *Bifericeras subplanicosta?, B. vitreum?*
		" ,, ,, Loc. 1"	*Echioceras* cf. *patti*, Reynès sp., *E.* cf. *boreale, Deroc.* (*Microc.*) *obsoletum.*

* See later, p. 81. † Subsequent Dorset Coast evidence throws doubt on this record: *Deroc.* cf. *miles* may be more correct. See Table XI.
‡ *Deroceras bispinigerum*—name given in *Quart. Jour. Geol. Soc.* Holotype is *Deroc.* sp., S. Buckman, *Id.* Vol. lix, 1903, Pl. XXVII, Figs. 5, 6.

than *aplanatum*—one not tapped at Allt Fearns; and I have constructed Table III on this supposition, which is based on other considerations than the Scotch evidence.*

TABLE IV.—PABBA SHALES WITH *ECHIOCERAS.*

Allt Fearns, above road.

HEMERÆ.	STRATA, ETC.	FAUNA.	PRESUMED EQUIVALENCE.
Aplanatum	Allt Fearns, above road, 185 feet up in Shales †	*Echioceras aplanatum?*	= Loc. 13.
Macdonnellii	,, ,, 165 ,, ,,	*E.* aff. *deciduum*	
	,, ,, 156 ,, ,,	*E. subobsoletum* (type)	
	,, ,, 115 ,, ,,	*E. macdonnellii*	= Loc. 10 *a*, *b*.
Raricostatoides	,, ,, 100 ,, ,,	*E. raricostatoides?* *E. zieteni.*	= Loc. 10.
	,, ,, 60 ,, ,,	*E. gracile?*	= Loc. 8.
	,, ,, 40 ,, ,,	*E. rhodanicum*	= Loc. 7.

On similar grounds—not on the evidence actually before me from Scotland—I surmise a wave of Echiocerates in or below *densinodum* developing somewhat parallel to the waves of Echiocerates in the horizons after *bispinigerum*. The *pre-bispinigerum* wave presumably came to an end so far as its advanced species were concerned, and left only primitive species which should appear in *bispinigerum* time, to give rise to the *post-bispinigerum* waves which develop on parallel lines, but perhaps in more elaborate and varied fashion.

It seems possible to make the following conjectural apportionment of the Pabba Shales.:—

TABLE V.—PABBA SHALES, SUMMARY.

Zones.	Thickness in feet.
Valdani	50
Jamesoni	50
Leckenbyi	100
Aplanatum	40
Macdonnellii	60
Raricostatoides	100
Bispinigerum	20
Densinodum	80
	500
Unexplored at base	100
	600

f. SINEMURIAN AND HETTANGIAN—THE HALLAIG SANDSTONES.

"There are few Ammonites in the Sinemurian: we made a systematic search, but no ammonite bed was found. They occur quite sporadically. It is a *Gryphœa* facies almost throughout" (Dr. Lee).

* "The Derocerate horizon of Hallaig was allocated to the '*Armatum Zone*' by previous geologists; it is seen passing into *Jamesoni*."—Note sent by Dr. Lee.

† Note by Dr. G. W. Lee (1917) "Aneroid levels; no allowance made for dip and horizontal distance."

These Sinemurian strata of Hallaig Burn and shore, with an underlying *Lima* bed possibly of the date of *marmorea* (Hettangian), may be grouped under a stratigraphical term as Hallaig Sandstones. Their supposed sequence may be set out in the following Table VI.

TABLE VI.—THE HALLAIG SANDSTONES, ISLE OF RAASAY.

HEMERÆ. *	HALLAIG BURN AND SHORE.
Brooki *Turneri* *Birchi*	1. "FUCOID SANDSTONE"—Sandstone above Waterfall. *Arietites* spp. 2. *Microderoceras birchi* "found on shore about 100 yards N. of Waterfall."
Arnioceras *Agassiceras*	3. *Arnioceras spp.* from the sandstone forming the fall. 4. *Agassiceras sauzeanum, Ag. halecis Spiriferina walcotti* "S. side of Waterfall, shaly beds about 12 feet below 3."
Vermiceras *Post-marmorea*	5. Gryphæa Sandstone with *Vermiceras.* 6. Lima bed, 30 feet below *Gryphæa* sandstone.

"Loose blocks on the shore S. of waterfall" yielded Coronicerates, namely, *C. gmuendense, C. nodosaries* ? *C. alcinoe* ? These may represent an intermediate horizon or horizons between 4 and 5. See Table XIV.

The strata given in this table are not directly connected to the base of the Pabba Shales in the chronological sense: whether they be so physically lacks evidence. But chronologically there is the following gap †:—

Strata.	Hemeræ.
Pabba Shales (base)	*densinodum.*
Missing	*oxynotum.* *stellare.* *obtusum.*
Hallaig Sandstones (top)	*brooki.*

From *brooki* downward the Sinemurian sequence seems to be fairly complete according to the evidence from Hallaig.

III. SKYE.

a. INFERIOR OOLITE (VESULIAN-AALENIAN).

The collection of specimens submitted from the Isle of Skye is not so large as that from the Isle of Raasay, and it does not extend over so long an interval of time, but it supplements the latter in certain important particulars.

The highest strata to which the specimens point is Inferior Oolite, or, more exactly, early Vesulian—*Garantiana* hemera. The sequence thence through Bajocian down to late Aalenian is fairly complete—the most noticeable omission being any evidence for *niortensis* beds.

In the main the evidence has only been obtained from loose blocks on

* See Table XIII, p. 87.

† According to the dating system in "Geol. Whitby," Ed. 2, 1915, p. 61. A much more extended sequence has been proposed by the author in his later paper. See Bibliography (1918).

the shore of the N. side of Bearreraig Bay. These loose blocks show various matrices with different faunas, as in the annexed table.

TABLE VII.—INFERIOR OOLITE, ISLE OF SKYE.

AGES.	HEMERÆ.	STRATA, ETC.	FAUNA.
Vesulian	*Garantiana*	Clay and dark earthy stone, Bearreraig Bay	*Garantiana* spp.
Bajocian	*blagdeni?*	Darkish sandstone with black particles	*Megateuthis* cf. *aalensis* (large examples).
	blagdeni	Greyish-brown sandy stone	*Teloceras* cf. *coronatum* (Quen.) *Stemmatoceras* cf. *subcoronatum*.
	sauzei	Light grey sandstone with many small black specks	Mammillate *Sonniniæ* of the *S. mesacantha* type; tuberculate spp. like *S. sowerbyi*; and many other alticarinate forms; *Poecilomorphus macer* and allies common.
	Witchellia?	Much the same matrix as above, perhaps coarser	*Witchellia* sp.
	Shirbuirnia	Darker and coarser matrix, more crystalline	Two stout Sonninines—one cf. *Shirbuirnia*, one perhaps forerunner of *fissilobata* series.
	discites?	Cliff S. of Bearreraig river	Homœomorph of *Dissoroceras excavatum*.
Aalenian	*concava*	Darkish sandstone	Cf. *Lucya magna*, *Ludwigella*.
	bradfordenis	Cliff S. of Bearreraig river	*Brasilia decipiens*.
	murchisonæ	Hard bluish-black compact sandstone, crowded with Ammonites. Between tide marks on south shore of Bearreraig Bay, south of the river; but majority from loose blocks.	*Crickia reflua*, *Ludwigina*, *Strophogyria*, *Cosmogyria*, *Apedogyria*, *Ludwigia*, etc.

The following Table gives stratigraphical information supplied by Dr. Lee after the report was written.

The general correspondence of Table VIIA with Table VII may be seen by the hemeral terms supplied in the margin.

The position of the bed with large Belemnites (*Megateuthis*) is doubtful in my table. I should place it in close proximity to *blagdeni*, but just earlier rather than just later, except for the matrix: this is very distinctive, intermediate in character between those of *blagdeni* and *garantiana*.

Dr. Lee's information places the bed with big Belemnites well below *sauzei*; but this is contrary to present experience:—(1) The *Megateuthis* horizon is probably to be correlated with the Belemnite Beds of the Scarborough Limestone of which the upper part is of *blagdeni* date *; (2) large Belemnites of the *Meg. aalensis* and *giganteus* types are known from *blagdeni-niortensis* beds of Sherborne, Dorset; (3) a presumed bio-

*"Geol. Whitby," Ed. 2, *Mem. Geol. Surv.*, 1915, p. 84.

logically-earlier type (*Meg. ellipticus*) is from *sauzei* of Dundry and Sherborne, and (4) Oppel says that the " Hauptlager " of *Bel. giganteus* is the *Humphriesianum* (i.e., *blagdeni*) zone (Juraf. 1856, p. 364).

TABLE VIIa.—INFERIOR OOLITE SEQUENCE, ISLE OF SKYE.

(Aneroid measurements and field observations, Dr. Lee.)

HEMERÆ.	STRATA.	THICKNESS IN FEET.
	" Great Estuarine Series with oil shale at base.	
Garantiana	1. " *Garantiana.* Clay S. of Bearreraig, black sandstone N.	5
——— ?	2. " Calcareous grit	20
Blagdeni	3. " Yellow weathering sandstone with calcareous bands and calcareous doggers, with ' Stephanoceratids ' (sensu lato) in upper half and	
Sauzei and Witchellia ?	*Sonninia* in lower half	150
——— ?	4. " Bluish sandy shale or shaly sandstone with hard bands with discoid Ammonites and large Belemnites	150
——— ?	5. " Sandstone scarp."	50
Murchisonæ	6. " Shaly fucoid sandstone "	25

The difference in the Inferior Oolite deposits of Raasay and Skye is the palæontological evidence yielded by the latter for several zones of the Bajocian. Thus the date of the Raasay Sandstone may now be surmised : it corresponds to Beds 2, 3 and perhaps also to 4, 5 of Table VIIa, giving in the former case 170 feet, in the latter 370 as against 600.

The strata of *sauzei* date are richly ammonitiferous, yielding well-preserved specimens. The evidence for *Witchellia* beds is poor ; that for *Shirbuirnia* rests on two ammonites, but is reasonably conclusive.

The evidence for strata of *discites* date is poor : that for *concava* and *bradfordensis* is not satisfactory. The specimen cited as " cf. *Lucya magna* " is noticeable : it is well in accordance with the side-view of the type * and is a specimen of similar size ; but the periphery is quite different, it is more defined, is flatly fastigate, and distinctly parvicarinate. I have noticed similar small distinctions in other cases of specimens from somewhat separated localities, of which, at first sight, there seems to be no doubt about the identification. The significance of such differences is not clear : whether they are to be ascribed to difference of locality, or to difference of stock (homœomorphy), or to difference of date.

The strata of *murchisonæ* date are remarkable for their extreme richness in ammonites : the specimens are crowded together in masses with a very small amount of cementing matrix. They all belong to what may be called Ludwigoids—*murchisonæ* group. Some are large—8–11 inches in diameter—but many are quite small. Conspicuous are *Crickia reflua* and especially a species of *Crickia* in a stage prior to that, recognisable by the anguliradiation and irregularity of ornament ; *Ludwigina* forms, especially those of *L. umbilicata* type ; *Strophogyria* ; *Apedogyria* ; *Hyattina brasili* ; *Brasilina baylei* ; *Ludwigia* ; and so on. There are also species which cannot be placed : they have radial lines almost straight. In fact, the number of different forms of Ludwigoids from

* Mon. I. O. Amm. (*Pal. Soc.*) 1887, Pl. VI, 1904, p. lxxvi.

the Black Bed of Bearreraig is remarkable: there are new species of known genera and species of new genera. Yet there are some absentees, which will be noticed presently (p. 77).

b. Inferior Oolite-Lias (Aalenian-Whitbian).

Comparison with the Raasay Strata will show that there is a considerable unexplored gap in the Isle of Skye below the *murchisonæ* horizon. The next horizon of which there is evidence is situated in the lower part of the Dun Caan Shales—strata of *scissum*, *opaliniformis*, *venustula*, *digna* and part of *Cotteswoldia* are not represented by specimens in the collection submitted.

The section prescribed in Table VIII has been measured from the datum line of the top of the Scalpa Sandstone.

Table VIII.—Aalenian-Whitbian, Isle of Skye.

"Section in Cliff ¾ m. S. of Holm and 5½ m. N.N.E. of Portree."

Ages.	Hemeræ.	Strata, Etc.	Feet above Datum.	Fauna.
Aalenian	*Cotteswoldia*	Dun Caan Shales	+61	*Cotteswoldia superba;* cf. *Cott. costulata.*
			+60	*? Cott. crinita; Cott. costulata.*
			+57	*Cott. costulata; ? Cott. misera; ? Cott. superba.*
			+51	*? Walkericeras lotharingicum.*
		A considerable non-sequence ——→		
Whitbian	*subcarinatum*, about 4 feet	"Raasay Ironstone"	+48 +46 +44	*Dactyloteuthis digitalis* forms, common.
	falciferum, about 20 feet	Portree Shales	+38	*Dactylioceras* cf. *athleticum.*
			+36	*Dactylioc.* cf. *holandrei*, common.
			+34 +30	*Dactylioceras* cf. *vermis.*
			+29	*D.* cf. *vermis; Harp.* cf. *mulgravium; H.* cf. *falciferum.*
			+26	*Dactylioc.* cf. *holandrei; D.* cf. *gracile; Harp.* cf. *mulgravium.*
			+23	*D.* cf. *holandrei*; *Harp.* cf. *mulgravium.*
			+19	*Dactyl. holandrei ?*
	exaratum		+16	*Harp. exaratum.*
			+14	*Harp.* aff. *exaratum; ? Elegantulic. elegantulum.*
		Top of "Scalpa Sandstone"	0	

Correlation with Raasay is not difficult. The dozen feet at the top of the section belong to the *Cotteswoldia* horizon of the Dun Caan Shales. Below these is a stratum recorded as "Raasay Ironstone," and that it

is practically on the same horizon as the Raasay bed may be seen from the fauna recorded from the shales above and below it. Yet it yields only Belemnites of the *Dactyloteuthis digitalis* group, which are not recorded from the Ironstone of Raasay: only one example of an allied form, *D. irregularis*, is from there. So some difference in date seems to be indicated; what this is cannot be solved until more is known as to the chronology of Belemnites.

The Portree Shales are much thicker than in Raasay—they are over 40 feet.* Twenty feet of this may be assigned to the *falciferum* horizon, below which beds with *exaratum* are in evidence. Then there is a thickness of 14 feet unexplored, above the Scalpa Sandstone.

The Dactyliocerata do not give much evidence for zoning: their horizons in other localities are insufficiently known. But in Skye and Raasay it may be noted that polygyral Dactyliocerates of the *holandrei* and *athleticum* types, with a good deal of variability in costation, especially in the inner whorls, occur from 6 feet below the top of the Scalpa Sandstone to some 40 feet above it.

IV. COMPARISON WITH ENGLISH AND OTHER AREAS.

a. Cornbrash (Bathian).

The limestone strata which have received the name of Cornbrash in English localities belong to three different horizons, which may be noted in descending order as follows:—

1. *Macrocephalus.*
2. *Lagenalis.*
3. *Intermedia.*†

In south and mid-England the lowest horizon is the one most usually met with in Cornbrash quarries, the middle horizon being found somewhat locally, while the upper horizon, being sometimes clay, is regarded as the base of Oxford Clay or Callovian. In Yorkshire it is the upper horizon which is Cornbrash—the two lower horizons appear to be lacking.

In Yorkshire the strata which underlie the Cornbrash are estuarine deposits; but it is possible that there is a very considerable non-sequence between these Estuarine Beds and the marine Cornbrash. The finding of marine Cornbrash of the *intermedia* horizon in Raasay shows that marine deposition began earlier on the west of Scotland than it did in Yorkshire.

Continental authors urge that the *macrocephalus* horizon should be regarded as Callovian: this is really the position assigned to it by English geologists on stratigraphical grounds when they meet with its argillaceous development. The two lower horizons are regarded as belonging to the Bathian.

b. Inferior Oolite (Vesulian-Aalenian).

Skye and Raasay may be taken together. They show more or less evidence for a complete sequence of horizons from the base of the

* "The Portree Shales swell at one place to 70 feet, as stated on p. 39. South of Holm a jet band occurs in proximity to layers that yielded *Harp.* aff. *exaratum* and *Elegantuliceras*, 14 feet above Scalpa Sandstone."—Note sent by Dr. Lee.

† Since this was written I have found that a set of beds lower than the *intermedia* horizon is coloured as Cornbrash in South England in the Geol. Survey Maps, such beds presumably representing the Hinton Sands of the Forest Marble in other places.

Aalenian up to the *Garantiana* beds of the Vesulian. In English localities (and the same may be said of Continental) this is unusual—there is generally a very considerable gap prior to the *Garantiana* beds.

The *sauzei* horizon of Skye is a misnomer. It is remarkable for many well preserved alticarniate Sonninines, comparable with those from the ironshot of Dundry, Somerset, and the top layer of the fossil-bed of Sandford Lane, Sherborne, Dorset, where they are in association with the name fossil (*Otoites sauzei*). From these English localities a remarkable number of new species of these Sonninines await description; and until this work be done exact names for the Scottish species are impossible.

On present evidence it may be doubted if the Scottish strata will present such a rich series of Sonninines as the English rocks yield; but there is good promise for future work. At present the Scottish strata of *sauzei* date give no evidence for any species of the *sauzei* genus (*Otoites*), nor, in fact, for any Stepheoceratids or allies (Coronati). English localities yield these in the *sauzei* horizon with Oppelids and spinose Rhynchonellids: none of these were among the specimens from the Scottish islands.

On the present evidence, admittedly imperfect, the northward range of Sonninines was greater than that of Coronati. It would seem as if the migration of Coronati was from the south: they appear in Scotland in the next hemera—*blagdeni*.

The faunal evidence for horizons below *sauzei* is insufficient for any remarks until that of *murchisonæ*. Here the extraordinary number of Ludwigoids and their great variety arrests attention. They are excellently preserved specimens, and the Skye deposit not only rivals English localities in its richness in this respect, but it surpasses them by a long way. In most English localities Ludwigoids are rare: the only place where they are frequent is in the Wild Bed of Chideock, near Bridport, Dorset; and perhaps if the *murchisonæ* beds of this English locality were to be adequately quarried, it might become a rival to Bearreraig Bay.

In the Scottish deposits of *murchisonæ* date, however, rarity or absence of certain southern species is all the more noticeable on account of the very abundance of specimens. Thus there is only one example noted comparable to the very distinct genus *Pseudographoceras*; there is a rarity of tuberculate species, and there is entire absence of the very massive forms of which *Kiliania armipotens* is a type.

Outside of Ludwigoids there are no examples of any other genera—no specimens, for instance, of any Hammatoceratidæ—*Hammatoceras*, *Erycites* and like forms. These genera are represented by perhaps a score of species in the South of England, though the Hammatoceratidæ, especially *Erycites*, are really at home in the Mediterranean area. Their absence, therefore, from W. Scotland at a time very favourable to Ammonites, as the swarm of Ludwigoids testifies, is an interesting fact; but whether due to zoological or stratigraphical causes has yet to be determined.

The abundance of Ludwigoids in West Scotland suggests at first sight that this area was the original home for Ammonites of this group, which thence passed to other localities. But against that would be reasonably urged the absence of massive forms and the rarity of tuberculates. In the original home, species at or about the acme of development would be expected—the stout tuberculates of which the inner whorls of Ludwigoids are the morphic representatives. Such species are not in W. Scotland on present evidence: the species as a whole are well on the down grade—they are in the first stage of catagenesis—the costate stage—or beyond it.

It may, however, be suggested that if W. Scotland was not actually the original home for Ludwigoids it was not far distant from that spot, which presumably lay to the west or north-west.

There is no evidence for *scissum* beds in the collection from Skye, but the stratum termed the "Main Ammonite Bed" of Raasay belongs to that date. It is thickly charged with *Liocerata* mostly of small size: there are no large species of the genus such as are found in the South English stratum. There are also no species of Ammonites except *Lioceras* and allies (Opalinoids), no Hammatoceratids (*Bredya*); *Tmetoceras* (the *scissum* genus) is absent; but this is a Mediterranean group, for, though it extends to S.W. England, the specimens there are small. *Tmetoceras* may point to northward migration which did not extend so far as Scotland.

The Dun Caan Shales are of the date of the Bridport Sands on the Dorset coast, and the sequence presented in Table I may well be compared with the Chideock section given in my paper on South Dorset.* The main mass of the Dun Caan Shales may be correlated with the *aalensis* strata of Chideock, where already had been noted that fine-ribbed *aalensis*-like Ammonites occurred above the coarse-ribbed.† The Scotch strata with their greater thickness allow of this sequence being noted much more clearly, showing, too, that the time element was considerable. They also show that there is a lower fauna of *aalensis* pattern than that noted at Chideock, where, however, there is significantly a thickness of several feet without record, just in the place required.

On the Dun Caan evidence there are quite three faunal sequences or Ammonite hemeræ in what was formerly assigned to *aalensis* date. Comparison may be made with Chideock as below.

TABLE IX.—COMPARISON OF *Aalensis* STRATA.

HEMERÆ.	STRATA. Amounts of deposit in Feet.	
	Chideock.	Raasay.
Venustula	4‡	16
Digna	25§	18
Cotteswoldia	15‖	40

The equivalent of the Dun Caan Shales (*aalensis* portion) is a layer only a few inches thick in the upper part of the Cotteswold Cephalopod Bed, which not so many years ago was classed as one with the *moorei* beds. The much thicker strata on the Dorset Coast showed plainly an *aalensis* fauna sequent to a *moorei* fauna, with indications that further faunal sequences would be recognisable. The still thicker Dun Caan Shales have fulfilled expectations and more: they have shown that the fauna of *Cotteswoldia costulata* type—hitherto relegated partly to *aalensis*, partly to *moorei* date, due in a measure to old labels, but also due to non-recognition of any sequence—occupies a definitely higher horizon than the *moorei* fauna.

Beds with the *moorei* fauna and, in fact, all the Yeovilian and the

*Jur. Strata South Dorset; *Quart. Journ. Geol. Soc.*, lxvi., 1910, pp. 60, 64.
† Id. pp. 59, 64.
‡ P. 64, Beds 7 a, b. § Beds 7, c-f. ‖ Possibly upper 15 feet of Bed 8, with no record. See also p. 61.

greater part of the Whitbian are missing from the Scottish islands, and so there is a very considerable non-sequence between the Dun Caan Shales and the Raasay Ironstone.

Reference to Table VI of my paper on South Dorset * will show that there are the deposits of nine hemeræ missing, these deposits may total as much as about 700 feet of strata.† The time, therefore, between the ending of the deposit of Raasay Ironstone and the beginning of that of the Dun Caan Shales is equal to the time taken to deposit some 700 feet of strata elsewhere.

What was the time on such a basis? It was suggested by Prof. Sollas ‡ that "1 foot of sediment might accumulate in a century in an area of maximum deposition." On such a basis the time between the top of the Ironstone and the base of the shales would be 70,000 years; but this seems far too little time for all the faunal differences and developments during the space of nine hemeræ. A multiplication by twelve might give the necessary time; but the point to be made is that a very considerable period of time elapsed between the date of the deposition of the Ironstone and that of the Dun Caan Shales.§

c. Upper Lias (Whitbian).

The Raasay Ironstone is not of the date of the Cleveland Iron deposits (Domerian), but is of Upper Lias (Whitbian) date, of the same time as part of the Alum Shale deposit of Yorkshire. At about this time and later more or less iron-ore deposits were laid down at various places in Somerset—Dundry, Wellow, Batcombe; while the well-known ferruginous deposits of the Rhone basin are partly of the same date as that of Raasay, and were also continuous into later times.

The Portree Shales, as the beds separating the Raasay Ironstone from the Scalpa Sandstone may be called, correspond to the Bituminous Shales and the Jet Rock of the Yorkshire Coast.‖ Whether the lower 14 feet not explored in Skye (Table VII) belong to the Whitbian, representing the Grey Shales, cannot be stated; but it is a legitimate supposition.

d. The Scalpa Sandstone.

The Scalpa Sandstone represents in a general way the Ironstone Series and the Sandy Series of Yorkshire: it may even cover somewhat more at top and bottom. It thus embraces the Domerian and part of the Charmouthian, but the interest lies in the part which is of Domerian date.

In England the thickness of the Domerian strata is due to accumulation of deposit in the two early zones on the Dorset Coast as much as 200 feet. In Scotland there is reason to suppose that some of the thickness of the Scalpa Sandstone may be due to accumulation in later zones. Scotland shows a fauna different from what is found in England, and this fauna seems to indicate a new horizon of inter *spinatum—margaritatus* date, for which a distinctive term, *lævis* hemera, seems to be required. This involves the supposition that in the English localities there is more

* *Op. jam. cit.*, p. 88.

† *Q. J. G. S.*, lix., 1903, p. 456; see also Geol. Whitby, 1915, ch. v., p. 75.

‡ Discussion to paper quoted, see p. 109.

§ Since the above was written a paper has been received from Mr. L. D. Burling, in which he states that deposition "has averaged, according to a recent estimate, one foot in 833 years," but he does not give the authority (*Pro. Am. Assoc. Museums*, vol. viii., 1914, p. 93.)

‖ Geol. Whitby, p. 76, and see pp. 39 and 88 of this paper.

or less of a break in the sequence at the time of the *lævis* hemera, and that the Scottish deposits are more complete.

The evidence is zoological at present: geological confirmation should be a feature of further work. There are many examples of the dwarf species *Amaltheus lævis* (Quenstedt)—a Würtemberg species, which, so far as memory serves, has not been found in England at all, certainly not in abundance. Then there are many massive forms of Rhynchonellids, quite a new feature for British strata. For these Scottish Rhynchonellids I have made a genus *Grandirhynchia*:* they are allies of the *tetraedra* group, but show a more primitive condition. They attain proportions which rival or surpass those of the English Domerian Rhynchonellids: that is, while the latter may occasionally produce a larger example, the Scottish show a greater number of specimens of large proportions.

Other species associated with these are small (young) examples of *Amaltheus*, a small form of *Rhynchonella acuta*, and two brachiopods which are more characteristic of Yorkshire than elsewhere, namely, *Aulacothyris florella* and *Rhynchonella capitulata*, species quoted from the *spinatum* zone.

The above-mentioned fauna seems to show a mingling of species from the *spinatum* and *margaritatus* zones. The suggestion now made is that as Raasay shows a distinct Domerian fauna, a new horizon has to be dealt with—that this horizon, if it be found at all in English localities, will be in the contact beds of the *spinatum-margaritatus* zones.

To a certain extent Yorkshire bears this out. When the Raasay strata are compared with those of Yorkshire, it seems that a similar intermediate period of deposit may be definable for the latter area—the top beds assigned to *margaritatus* and the lower beds assigned to the *spinatum* zones may be partly of the date of the *lævis* hemera, that is, the strata of the Pecten seam and some beds above.† But it is necessary to assume that the deposit of the *lævis* hemera is incomplete in Yorkshire, to account for the absence of *Amaltheus lævis* and of the massive Rhynchonellid fauna.

In the Midlands and in South England the post-*margaritatus* strata are generally rather thin. No noticeable deposit of *lævis* date is to be expected, though a trace of the fauna may be detected now that the Scottish beds have given a clue.

Interesting problems of migration and of faunal distribution may be raised by the new Scottish finds; but only a few remarks can be made now. W. Scotland and S.W. Germany are linked together in *Amaltheus lævis*, possibly too by *Grandirhynchia*; for some of the *tetraedra*-like forms of Germany belong, I expect, to that genus. But this linking may be due to preservation of the *lævis* zone at these places more completely than in intermediate localities.

Northward migration seems to be indicated by *Amaltheids*, southward migration by *Grandirhynchia*. Scotland, like Yorkshire, seems to lack large forms of *Amaltheus* and massive forms of *Paltopleuroceras*: such forms belong to the south.

Grandirhynchia, however, shows its massive forms in the north, and some of the Scottish species take the *tetraedra* group back to a quite

* *Gen. Jur. Brach.*, London, 1914, p. 1. The genotype and another species are depicted in Pl. XIII, figs. 5, 6, Brach. Burma, *Pal. Ind. N.S.*, iii. (2), 1917.

† Beds 14–17 of Tate and Blake's Section of Hawsker (Yorkshire Lias, 1876, p. 127), with Beds 15–17 of their Section of Grosmont (p. 148); Beds 12–18 in p. 73, Geol. Whitby, ed. ii, *Mem. Geol. Surv.*, 1915.

primitive condition.* As the *tetraedra* group is traced southward it shows more and more advanced forms: the S. England and Normandy forms of the *tetraedra* group occur in the *spinatum* zone: they are much more advanced than any of the Scottish examples, but are not descendants, only collaterals. There is no evidence for their occurrence in the *spinatum* zone of Raasay, and if their absence be confirmed by further research it will mean that the *tetraedra*-like form of Rhynchonellids, which show a more primitive condition in Scotland than in England, ceased their development earlier in the northern area, but continued later in the south.

e. The Pabba Shales.

The Pabba Shales represent the main of the Charmouthian, but the highest beds of these shales are of *valdani* date. So there is either a hiatus or unexplored ground between them and the base of the Scalpa Sandstone dated as pre-*Oistoceras*; but the base of the sandstone may be earlier—the evidence about its zones is quite meagre.

The upper third of the Pabba Shales coincides in a general way with the Pyritous Shales of Yorkshire and with the Stonebarrow or Belemnite Beds of the Dorset Coast. The lower two-thirds are a very much expanded representative of the top portion of the Siliceous Shales of Yorkshire—the part assigned to the zone of *raricostatus*, upon which more will be said later. It is doubtful if the Ironstone Shales of Yorkshire are represented by the top of the Pabba Shales, for there is a faunal difference. Yorkshire lacks the *valdani* fauna above *jamesoni*, but shows a *Polymorphites* fauna; the Scottish deposits show the former but lack the latter. The true sequence is perhaps to be expressed as—

valdani.
Polymorphites.
jamesoni.†

Perhaps strata of *Polymorphites* date are represented in the Pabba Shales by the beds which yield large rimosiform Rhynchonellids: they lie between strata yielding the *valdani* and *jamesoni* faunas. These rimosiform Rhynchonellids (*Rimirhynchia*, S. Buckman, 1914) are a new find, remarkable not only for their large size—they are about twice the size of the Radstock species of *Rimirhynchia*, and many times larger than the German examples of *R. rimosa*—but because they are biologically much earlier.‡ They show the special rimosiform character—coalescence of costæ anteriorly—only at a very late period of growth, much later than any other species. As the species of *Rimirhynchia* when traced southwards decrease considerably in size and become much more advanced biologically, it seems reasonable to seek the origin of the genus in the north, in the neighbourhood of W. Scotland—a case of southward migration.

As to the lower two-thirds of the Pabba Shales, their exceptional thickness and fossil richness reveal a faunal sequence not noticed in thinner deposits. But, as soon as the revelation is made by the Pabba Shales, an examination of the strata of other areas shows that they conform.

Such comparison, however, reveals still more striking results. It is found that the strata hitherto classed at various localities in the zones

* Pl. XIII, fig. 6, Brach. Burma, *Pal. Ind. N.S.*, iii. (2) 1917.

† Since this was written, investigation in other areas suggests that the sequence is much more complex. See *Abs. Proc. Geol. Soc.*, 1917 (1009), p. 84, and the paper to which it refers.

‡ The species is illustrated in Pl. XIII, figs. 17, 18, Brach. Burma, *Pal. Ind. N.S.* iii (2).

of *armatus-raricostatus* are on different horizons. There is zonal duplication due to the fact of there being two sequent horizons with *Amm.* of the *raricostatus* group (*Echioceras*) followed by *Amm.* of the *armatus* group (*Deroceras*). Hitherto these horizons had been correlated; but it is now seen that they are in the following order :—

Upper *Deroceras* horizon,
Upper *Echioceras* horizon,
Lower *Deroceras* hozizon,
Lower *Echioceras* horizon;

and the thick development of the lower two-thirds of the Pabba Shales shows that the Upper *Echioceras* horizon contains at least three independent faunas.

It is necessary, therefore, to employ a new set of zonal (hemeral) terms. The following Table X shows the stratigraphical facts with prior interpretations given for the sake of clearness.

TABLE X.—ZONAL COMPARISON.

HORIZONS.	HEMERAL TERMS.	PRIOR INTERPRETATIONS.			
		Yorkshire.	Midlands.	Somerset.	Dorset Coast.
Upper *Deroceras*	*leckenbyi*	*armatum*		*armatum*	*armatum.*
Upper *Echioceras*	*aplanatum*			*raricostatum*	
	macdonnellii				
	raricostatoides				
Lower *Deroceras*	*bispinig rum*	*raricostatum*	*armatum*		*raricostatum.*
Lower *Echioceras*	*densinodum* and *Echiocerata*		*raricostatum*		

The correlation of the Scottish deposits with those of four English districts may now be given in more detail, to show the general facts. Where further information may be found is stated in footnotes.

It will be seen from Table XI, pp. 84, 85, that the Raasay sequence is fuller than that in the English areas; but when the English areas are placed together they supply each others deficiencies and repeat the sequence of the Scottish area.

The approximate thicknesses of the strata in these areas may be usefully compared : they show how the great development of the Pabba Shales has assisted in disclosing the due sequence. The thicknesses given in the heading of Table XI are those of the strata which have been preserved. In some cases the thinness is due to the denudation of whole zones, not merely to slow accumulation during the whole time.

The *leckenbyi* horizon is remarkable for its large and often strongly spined Derocerates. Such a fauna is found on the Hallaig shore of Raasay. It has its counterpart in Yorkshire in the beds above the *aplanatum* zone, according to Simpson's records. Then, so far as I know, it is not met with till the Radstock district of Somerset, where the species are many and

the specimens of exceptional size. The fauna also occurs on the Dorset Coast, but is comparatively poor; and on the Continent, in the Rhone Basin and in Würtemberg. Of the localities mentioned Radstock appears to be the richest in species and to have the largest specimens; and these facts seem to indicate a westward origin for the fauna. There is no evidence in literature for these remarkable Radstock Derocerates, though they are well known to geologists who have studied that locality. In this, as in other cases, English palæontological literature fails to be a safe guide to geological discoveries; it has very great lee-way to make up.

From the Upper *Echioceras* horizon an abundant fauna of Echiocerates in all three zones rewarded the labours of the officers of the Scotch Geological Survey, and there is evidently much new material.* Raasay is richer in these Echiocerates than any English locality. The Radstock district comes next, but nearly all the specimens are derived, though often excellently preserved in nodules—there is only a thin layer of the original stratum left in one or two places. There is faunal evidence for all three zones having once been laid down, but the *macdonnellii* fauna is, perhaps, incompletely represented.

Yorkshire seems to lack the *raricostatoides* fauna, but shows its two successors. In North Ireland the *macdonnellii* fauna is evident. In the Midlands all three faunas are wanting. In Worcestershire and Gloucestershire there may be local traces of some faunas of the Upper *Echioceras* horizon—judging by odd specimens which have come under notice. On the Dorset Coast, according to the specimens kindly submitted by Dr. W. D. Lang, F.G.S., only the *raricostatoides* fauna is present, ranging through several beds: there is no evidence for the *aplanatum* and *macdonnellii* faunas, and no room for their beds.

The *bispinigerum* fauna owes its recognition to the evidence carefully gathered by Dr. Lang on the Dorset Coast. Dr. Lang has noted it in two beds; and, possibly, it might be correct to divide it into two—an *armatus* (*miles*) fauna above and a *bispinigerum* fauna below. Only for the upper is there evidence at Raasay as a distinct deposit: if found in the other areas it would presumably be in derived condition. For the lower fauna there is no real evidence in any of the British areas except Dorset.

The *densinodus* (*subplanicosta*) and first *Echioceras* horizons require much further investigation, but there seems to be evidence for such a sequence both in Scotland and England. In the Raasay and Yorkshire strata many of the specimens are crushed or are in poor condition, and there is admitted laxity in the use of the names, *Am. densinodus*, *Am. subplanicosta*, as there obviously is in the records cited from other areas. In Cheltenham there is a noticeable *subplanicosta* fauna hitherto reckoned as *armatus* Zone, and I surmise that Mr. Thompson has struck the same fauna in the Midlands; but I am not yet satisfied that quite the same fauna occurs in Raasay or Yorkshire. Both in the Midlands and South Gloucestershire the cited records indicate an *Echioceras* fauna earlier than *densinodus* (*subplanicosta*), and this substantially agrees with Raasay and Yorkshire. But in Dorset the lowest *Echioceras* fauna is certainly lacking, and the explanation of Oxynotes with *Am. obsoletum* in Bed 92 seems to be that they are derived. I surmise a very considerable gap below Bed 92 of Dorset, and possibly incomplete sequences in other English localities; but the thick deposits of Raasay which have given so much valuable information as to the sequence in other cases will, it is to be hoped, do the same in this.

It will be seen from the above account that old labels of "*armatus raricostatus* zone" will have to be interpreted according to their localities.

* See Yorkshire Type Amm. ii, 1914, p. 96c.

Table XI.—Stratal Correlation—Scotland and England.

Hemeræ.	Strata.				
	Raasay,* about 400 feet.	Yorkshire,† about 85 feet.	Midlands,‡ about 20 feet.	Somerset (Radstock),§ about 5 feet.	Dorset Coast,‖ about 45 feet.
Leckenbyi	Beds on Hallaig Shore, with large Derocerates	Beds 13–16 with large Derocerates.		"*Armatus* bed" with large Derocerates."	"Bed 105. *Armatus* Limestone." "*Deroceras pugnax?* S. B." "*D.* aff. *leckenbyi*." [*D. leckenbyi* Wright sp. Pl. XXX, 1–3.] "Bed 104. *Armatus* Clay." "Bed 103. Hummocky limest." [*Microd.* aff. *lorioli*, Hug sp.]
Aplanatum	Loc. 12, 13. Beds with carinati-sulcate Echiocerates.	Bed 18. "The Upper *Coneybearei* bed" with *Ech. aplanatum.*			No evidence for these faunas and no room for them.
Macdonnellii	Loc. 10A–11. Beds with degenerate *Ech.* of the *macdonnellii* type.	Bed 20. Shale with *E. macdonnellii.*	Absent.		
Raricostatoides	Loc. 7–9. Beds with mainly crassicostate Echiocerates.			The faunas of these three horizons are found in derived condition in the "*armatus* bed."	"Bed 102. [Crassicostate *Echioceras.*"] "Bed 100." [*a. Ech.* cf. *boreale.* *b. E.* like above, but more strongly costate. *c. E.* cf. *rhodanicum*, *E. gracile*, *E. costidomus.*] "Bed 99. Watch Amm. Stone." [*E. microdiscus* and a crassicostate sp.] "Bed 98." [*E.* cf. *costidomus* (crushed).]

Bispinigerum	Loc. 4–6. Beds with Rhynchonellids, *Deroceras anguiforme* and *D.* of *armatum* type.	[The type of *Am. miles* came from Whitby.] [The type of *Am. armatus* came from Whitby.]	Absent.		Bed 96. [*a*] "11′ below 99." [*Deroc. miles.*] [*b*] "12′–14′ below 99." [*Deroc. armatum.*] "Bed 93. 25′ below 99." [*Deroc. bispinigerum.* S. Buckm., *Q. J. G. S.*, 1918, lxxiii, p. 302.]
				Sodbury, Gloucestershire,¶ about 30 feet.	
Densinodum (Subplanicosta)	Loc. 3. *Deroc.* (*Microc.*) cf. *densinodus*, Wright sp. Loc. 2. *Deroc.* aff. *obsoletum*, Blake sp. *Bifericeras subplanicosta?*, *B. vitreum?* Simpson sp.	Bed 23. *Amm.* of *subplanicosta* type. *Deroceras obsoletum*, Blake (*non* Simpson) = *Am. densinodus* Auctt., *D. nodoblongum.*	"*Armatus* zone, *A. densinodus* (several spp.) *A. muticus*, *A. subplanicosta* common."	"Thin shale with a few limestone bands, 30 feet. *Am. densinodus?*"	"Bed 93." [*Amm.* of *densinodus* and *subplanicosta* types.] "Bed 92. *Oxynotus bed.*" [*Am. obsoletus* Blake non Simpson.] "Pyritised Oxynoticerates" [? derived.]
1st Echioceras	Loc. 1. *D. obsoletum*; Echiocerata.	[Bed 23]. "*A. densinodus* [*obsoletus*] is plentiful in a band about 2 feet above [*A. raricostatus*]" Tate & Blake, p. 77.	"*Raricostatus* Zone. *A. densinodus.* *A. raricostatus.*"	"Pyritous limestone and shale, 2 feet *Amm.* aff. *armatus.* *Amm. raricostatus.*"	

* For fuller details see above, Table III. † See Geol. Whitby, Ed. 2, *Mem. Geol. Surv.*, 1915, p. 70.

‡ See B. Thompson, Geol. G. C. Ry., *Q. J. G. S.*, 1899, lv, p. 71. § Information from Mr. J. W. Tutcher and personal observation.

‖ See W. D. Lang, Geol. Charmouth; *Pro. Geol. Assoc.* xxv. (5), 1914, p. 321. My best thanks are due to Dr. Lang for very kindly submitting a series of specimens from these beds: the results of my examination are placed in square brackets.

¶ See Reynolds and Vaughan, Jur. South Wales Line; *Q. J. G. S.*, 1902, lviii, p. 727.

The difference in time between the "*armatus* Zone" of the Midlands (pre-*bispinigerum*) and the "*armatus* Zone" of Radstock (*leckenbyi*) is represented by a deposit some hundreds of feet thick in W. Scotland.

A cursory glance at Continental literature shows plainly that the faunas of the horizons into which the lower Charmouthian has now been divided are present in different areas; but that only some of them are present in a given area, where there is no evidence for the others. Literature, however, may not be a safe guide as to the latter, as is shown by the Radstock case of the Derocerates, and of the Echiocerates too, for that matter.

The information may be summarised in the following table.

TABLE XII.—CONTINENTAL REPRESENTATIVES.

HEMERÆ.	Rhône Basin.*	Freiburg Alps.†	Bavaria.‡	Würtemberg. §	Hierlatz. ‖
Leckenbyi . .	×			×	
Aplanatum . .	×		×		
Macdonnellii .	×	×	×		
Raricostatoides .	Partly	×		×	
Bispinigerum .		×			×
Densinodum .	?			×	
1st *Echioceras* .	?				?

The fact that these faunas are distributed in this manner is a strong argument for their distinction.

It may be remarked that Würtemberg does not seem to show a *pre-bispinigerum Echioceras* fauna, but that Hierlatz does show some peculiar Echiocerates which may be of *bispinigerum* or *pre-bispinigerum* date.

As the strata of the lower Charmouthian of Raasay showed a much more extended faunal sequence than had hitherto been suspected, with a kind of faunal repetition—alternation of *Echioceras* and *Derocceras*—investigation was carried further into the sequence of the Upper Charmouthian, possible from the excellent work of Dr. Lang on the Dorset Coast. The result is to show that the faunal sequence in the Upper Charmouthian is also much more complicated than had been supposed, and that there is faunal repetition. For reasons stated elsewhere ¶ it has been deemed advisable to divide the Charmouthian into three Ages:

Hwiccian—Age of Liparoceratidæ.
Wessexian—Age of Polymorphidæ.
Raasayan—Age of Deroceratidæ and Echioceratidæ.

* Dumortier, Basin Rhône.
† Hug, *Pal. Schweiz*, xxvi, 1899.
‡ Böse, *Zeit. Deutsch. Geol. Soc.*, xlvi, 1894.
§ Quenstedt, Amm. Schwäb, Jura.
‖ Geyer, *Abh. K. K. Geol. Reichsanst.*, xii, 1886.
¶ See p. 64.

So far as is known at present the Raasayan is more complete and more finely developed in the Hebrides (Raasay and Skye) than anywhere else in Europe.

f. The Hallaig Sandstones.

These Sandstones represent the Sinemurian in part, and presumably a portion of the Hettangian. They correspond in the main to the Calcareous Shales of Yorkshire and to something below them, while on the Dorset Coast their representatives are the lower part of the Black Ven Beds and the upper part of the Lyme Regis Beds.

The fauna collected from the Hallaig Sandstones is too small to call for any particular notice. Nevertheless, if comparison be made with Dorset strata, certain questions present themselves showing where further research is desirable. The comparison is as follows :—

Table XIII.—Sinemurian and Hettangian—Stratal Correlation.

Dates.		Strata.	
Hemeræ recognised.	Possible Sequence.	Raasay.	Dorset Coast.*
Sinemurian. *brooki.*	Mercian (pars). *brooki.*	Fucoid sandstone.	78–82.
turneri.	*turneri.*		76, 77.
birchi.	Lymian. *birchi.*	Loose block.	75.
Arnioceras.	*Arnioceras.*	Sandstone of waterfall.	50–72.
gmuendense.	*Agassiceras.*	Shales below waterfall.	49 ?
	gmuendense.	Loose blocks.	Absent ?
rotiformis.	*vercingetorix.*		(40–47) ?
	bucklandi.		
	rotator.		(26–29) ?
	Vermiceras.	*Gryphæa* sandstone.[1]	21.
Hettangian. *marmorea ?*	Hettangian. *Post-marmorea.*	*Lima* Bed.	9-11 ?

The reasons for suggesting the extended faunal sequence in the Sinemurian, not only in the portion represented in Raasay, but also in regard to later strata for which there is no present evidence from Raasay, are given elsewhere,† with the further suggestion that the strata of the Sinemurian should be divided into three Ages :

Deiran—Age of Oxycone Arietids.
Mercian—Age of Catagenetic Arietids.
Lymian—Age of Anagenetic Arietids.

* For further details see W. D. Lang, *op. cit.*, pp. 310 *et seqq.*; also Woodward and Ussher, Geol. Lyme Regis, *Mem. Geol. Surv.* 1906, and Ed. 2, 1911. For evidence of *rotator* fauna at Lyme see Wright, Mon. Lias Amm., sub. *Arietites rotiformis.*

† See p. 64.

[1] The *Gryphæa* goes up to *Arnioceras* (Dr. Lee).

The further investigation of the Scotch strata may throw much light on the subject of the full faunal sequence of the Sinemurian.

One great difficulty in the correlation of strata on the extended scale arises from the very incorrect use of the name *Am.* (*Coroniceras*) *bucklandi*: the record must be wholly suspect, except in regard to its original locality.

g. West Scotland and North-East England: Generalised Correlation.

A comparison of the Jurassic strata of the islands of Raasay and Skye with those of Yorkshire as given in my chapter in the Whitby memoir [1] may be presented in the following tabular form. A —— indicates beds which are not represented in the respective areas.

Table XIV.—W. Scotland and N.E. England: Generalised Correlation.

Raasay and Skye.	Yorkshire.
——	Cornbrash.*
Cornbrash.*	—— ?
Great Estuarine Series.	Upper Estuarine Series.
Clays above Sandstone.	Moor Grit.
Raasay Sandstone (upper part).†	Grey Limestone Series.
Raasay Sandstone (lower part).†	Middle Estuarine Series.
Beds subjacent to Raasay Sandstone.	Millepore Bed. Lower Estuarine Series.
Black Bed of Bearreraig.	Dogger.
Main Ammonite Bed of Raasay.	——
Dun Caan Shales.	——
——	The Yellow Sands.
——	The Grey Sands.
——	The *striatulus* Shales.
——	The Peak Shales.
——	Cement Shales.
The Raasay Ironstone.	The Main Alum Shales.
——	The Hard Shales.
The Portree Shales.	The Bituminous Shales. The Jet Rock.
Unexplored ?	The Grey Shales.
The Scalpa Sandstone.	The Ironstone Series. The Sandy Series.
—— ?	Ironstone Shales.
The Pabba Shales.	Pyritous Shales. Siliceous Shales.
—— ?	Calcareous Shales.
The Hallaig Sandstones.	

This is only an approximate correlation, but it shows that the main difference in the two areas commences after the deposition of the Raasay Ironstone. The gap between the Dun Caan Shales and the Raasay Ironstone is occupied in Yorkshire by five deposits; but these deposits happen only to be preserved in Yorkshire in a very limited area near the Peak. Afterwards the case is reversed, beds which are present in Scotland are lacking in Yorkshire.

[1] Geol. Whitby, Ed. 2, *Mem. Geol. Survey*, 1915, pp. 60, 61.

* See p. 76. † From the evidence of Skye; see p. 74.

V. SUMMARY.

The following is a summary of some of the principal points of this notice :—

1. The presence of marine Cornbrash (p. 65).
2. The presence of deposits of the *blagdeni* zone (p. 73).
3. The find of an interesting fauna of *Sonniniæ* (p. 77).
4. The discovery of a remarkably abundant fauna of Ludwigoids (pp. 73, 74).
5. The finding of a highly fossiliferous bed of *scissum* date (pp. 68, 78).
6. The great development of strata at the base of the Aalenian (Dun Caan Shales) and the sequence thus disclosed (p. 66).
7. The considerable non-sequence between Aalenian (Dun Caan Shales) and Whitbian (Raasay Ironstone) (p. 79).
8. The Raasay Ironstone is not of Middle Lias but of Upper Lias (Whitbian) date (p. 79).
9. The abundance of *Amaltheus lævis* in the Domerian (Scalpa Sandstone)—a find new to Great Britain (pp. 67, 80).
10. The discovery of a new series of massive Rhynchonellids in the Domerian (p. 67).
11. The discovery of the largest and biologically earliest rimosiform Rhynchonellid in the Pabba Shales (Charmouthian) (p. 81).
12. The great thickness of the Pabba Shales in the so-called *armatus-raricostatus* zones (p. 69).
13. The discovery of a sort of zonal duplication in the Charmouthian requiring a new table of terms to express the faunal sequence (p. 82).
14. The discovery of a rich *Echioceras* fauna occupying several horizons (p. 83).

The Jurassic area of West Scotland rivals in interest and in faunal richness any other area in the United Kingdom.

The present notice by no means exhaust the interesting discoveries —to do so prolonged palæontological research would be required.

It seems desirable to mention that the present report though published later than my paper on "Jurassic Chronology," 1918 (see Bibliography), was really written long before. That paper is an extended investigation on similar lines, and this Scottish evidence may be regarded as having given the main stimulus to such research. To the present report it has only been possible to add a few footnotes and other remarks to indicate the more detailed results set out in the later written but earlier published paper.

APPENDIX II.

BIBLIOGRAPHY.

LIST OF WORKS REFERRING TO THE GEOLOGY OF THE AREA INCLUDED IN THE MEMOIR.

1819. Macculloch, J. *A Description of the Western Islands of Scotland, including the Isle of Man.* 2 vols. and Atlas. London.

1827. Murchison, R. I. "On the Coalfield of Brora in Sutherlandshire, and some other Stratified Deposits in the North of Scotland." *Trans. Geol. Soc.*, Ser. ii., vol ii., p. 293.

1828. Murchison, R. I. "Supplementary Remarks on the Strata of the Oolitic Series and the Rocks associated with them in the Counties of Sutherland and Ross, and in the Hebrides. *Ibid.*, p. 353.

1873. Bryce, J. "On the Jurassic Rocks of Skye and Raasay." *Quart. Jour. Geol. Soc.*, vol. xxix., p. 317.

1873. Tate, R. "On the Palæontology of Skye and Raasay." *Ibid.*, p. 339.

1874. Bryce, J. "The Upper Secondary Rocks of Skye and Raasay." [Abstract.] *Trans. Geol. Soc. Glasg.*, vol. iv., p. 321.

1874. Judd, J. W. "The Secondary Rocks of Scotland." Second Paper. "On the Ancient Volcanoes of the Highlands and the Relations of their Products to the Mesozoic Strata." *Quart. Jour. Geol. Soc.*, vol. xxx., p. 220.

1876. Bryce, J., and Armstrong, J. "The Jurassic Strata of Skye and Raasay: with List of the Jurassic Fossils of Skye, Raasay and Mull." In *Catalogue of the Western Scottish Fossils.* Glasgow.

1878. Judd, J. W. "The Secondary Rocks of Scotland." Third Paper. "The Strata of the Western Coasts and Islands." *Quart. Jour. Geol. Soc.*, vol. xxxiv., p. 660.

1888. Geikie, [Sir] A. "The History of Volcanic Action during the Tertiary Period in the British Isles." *Trans. Roy. Soc. Edin.*, vol. xxxv., p. 21.

1893. Woodward, H. B. "On a Bed of Oolitic Iron-ore in the Lias of Raasay." *Geol. Mag.*, Dec. iii., vol. x., p. 493.

1894. Woodward, H. B. "Geology in the Field and in the Study." [Presidential Address.] *Proc. Geol. Assoc.*, vol. xiii., p. 236.

1896. Geikie, Sir A. "The Tertiary Basalt-plateaux of North-Western Europe." *Quart. Jour. Geol. Soc.*, vol. lii., p. 331.

1897. Geikie, Sir A. *Annual Report of the Geological Survey and Museum of Practical Geology* for the year 1896. [Notes on Raasay by L. W. Hinxman and by H. B. Woodward, pp. 15, 68, 69, 74.]

1898. Geikie, Sir A. *The Ancient Volcanoes of Great Britain.* 2 vols., London.

1904. HARKER, A. "The Tertiary Igneous Rocks of Skye." *Mem. Geol. Survey.*

1910. PEACH, B. N., HORNE, J., WOODWARD, H. B., CLOUGH, C. T., HARKER, A., and WEDD, C. B. "The Geology of Glenelg, Loch-alsh and South-East part of Skye. *Mem. Geol. Survey.*

1913. LEE, G. W. "The Occurrence of Oil-shale among the Jurassic Rocks of Raasay and Skye." [Communicated by the Director of the Geological Survey of Great Britain.] *Nature,* Oct. 9, 1913, p. 169.

1914. WOODWARD, H. B. "Notes on the Geology of Raasay." *Trans. Geol. Soc. Edin.*, vol. x., part 2, p. 164.

1914. THORNEYCROFT, W. "Note on the Upper Lias of the Western Islands in Reference to the Iron-ore Deposit therein. *Ibid.*, p. 196.

1914-1916. *Summary of Progress of the Geological Survey of Great Britain* for the years 1913 to 1915. [Notes by G. W. Lee on the Geology of Raasay.]

1917. BUCKMAN, S. S. "Correlation of Jurassic Chronology." *Abstracts of the Proceedings of the Geological Society of London,* p. 83.

1918. BUCKMAN, S. S. "Jurassic Chronology: I.—Lias." *Quart. Jour. Geol. Soc.*, vol. lxxiii., part. 4, pp., 257-327.

INDEX.

LIST OF PUBLICATIONS OF THE GEOLOGICAL SURVEY OF SCOTLAND.

Geological Map (25 miles to the inch) **of the British Islands.** (Second edition, 1912.) Price, Colour-printed, 2*s.* ; Uncoloured, 1*s.*

Maps on the Scale of Four Miles to One Inch. (Colour-printed.)

Sheet 12. Perthshire, Forfarshire, Kincardineshire, &c. (1910.) 2*s.* 6*d.*
,, 15. Fifeshire, Edinburghshire, Haddingtonshire, &c. (1912.) 2*s.* 6*d.*
,, 16. Galloway and part of Ayrshire, &c. (1907.) 2*s.* 6*d.*
,, 17. Roxburghshire, Dumfriesshire, &c. (1907.) 2*s.* 6*d.*

Colour-printed Maps on One-inch Scale, showing Solid and Drift Geology.

Arran. (1910.) 2*s.* (See references to Sheets 13 and 21 under Hand-coloured Maps.)
Glasgow District (embracing parts of Dumbartonshire, Lanarkshire, Renfrewshire and Stirlingshire). (1911.) 2*s.*
28. Knapdale, Jura and North Kintyre. (1911.) 2*s.* 6*d.*
32. Edinburghshire, Linlithgowshire, Fifeshire and Peeblesshire (parts of). (1910.) 2*s.* 6*d.*
33. Haddingtonshire and parts of Edinburghshire and Berwickshire. (1910.) 2*s.* 6*d.*
35. Colonsay and Oronsay, with part of the Ross of Mull. (1911.) 2*s.* 6*d.*
53. Argyllshire N. ; Inverness-shire, S.W. (Engraving.)
64. Inverness-shire, Perthshire, Aberdeenshire, Banffshire (parts of). (1913.) 2*s.* 6*d.*
65. Aberdeenshire, S.W. ; Perthshire, N.E. ; Forfarshire, N.W. (1911.) 2*s.* 6*d.*
70. Inverness-shire (West-Central Skye, with Soay). (1913.) 2*s.* 6*d.*
71. Glenelg, Lochalsh and the South-East part of Skye. (1910.) 2*s.* 6*d.*
74. Inverness-shire, N.E., with small parts of Nairn, Elgin, Banff. (1917.) 2*s.* 6*d.*
82. Ross-shire, Central. (1913.) 2*s.* 6*d.*
83. Ross-shire, South-East ; Inverness-shire, North. (1918.) 2*s.* 6*d.*
92. Ross-shire, Central and Western. (1913.) 2*s.* 6*d.*
93. Ross-shire, Cromartyshire (parts of). (1912.) 2*s.* 6*d.*
110. Caithness (N. part). (1914.) 2*s.* 6*d.*
116. Caithness (S. part). (1914.) 2*s.* 6*d.*

Hand-coloured Maps on One-inch Scale.

1. Wigtownshire, South-Western Districts. (1871.) 2*s.* 3*d.*
2. Wigtownshire, South-Eastern Districts. (1872.) 2*s.* 3*d.*
3. Wigtownshire, Western Districts. (1871.) 5*s.* 9*d.*
4. Wigtownshire, East Part ; Kirkcudbrightshire, portion of S.W. Division. (1877.) 9*s.* 6*d.*
5. Kirkcudbrightshire, Southern Districts. (1879.) 13*s.* 3*d.*
6. Kirkcudbrightshire, E. margin ; Dumfriesshire, S. margin. (1879.) 3*s.* 6*d.*
7. Ayrshire, South-Western Districts. (1898.) 7*s.* 3*d.*
8. Kirkcudbrightshire, Ayrshire and Wigtownshire (parts of). (1893.) 16*s.* 3*d.*
9. Kirkcudbrightshire, N.E. ; Dumfriesshire, S.W. (1874.) 11*s.* 9*d.*
10. Dumfriesshire. (1885.) 10*s.* 3*d.*
11. Roxburghshire and Dumfriesshire (parts of). (1883.) 5*s.* 9*d.*
12. Argyllshire (Kintyre, S. half of). (1894.) 11*s.*
13. Ayrshire, Turnberry Point, and S. part of Arran (Solid (1902) and Drift (1906)). 7*s.* 3*d.* each. (See Colour-printed Map of Arran.)
14. Ayrshire, Central Districts. (1868.) 14*s.*
15. Dumfriesshire, N.W. ; Ayrshire, S.E. ; and Lanarkshire, S. (1870.) 11*s.*
16. Dumfries, Selkirk, Peebles, Lanark and Roxburgh shires (parts of). (1889.) 11*s.*
17. Roxburghshire, Selkirkshire and Dumfriesshire (parts of). (1883.) 10*s.* 3*d.*
18. Roxburghshire, E. part. (1883.) 2*s.* 9*d.*
19. Argyllshire (S. part of Islay). (1898.) 10*s.* 3*d.*
20. Argyllshire (Kintyre, Gigha I., part of Islay). (1896.) 9*s.* 6*d.*
21. Argyllshire ; Arran, Central and N. part ; Bute, S. part ; Cumbraes, Ayrshire (part of N.W.) Solid (1901) and Drift (1906). 16*s.* 3*d.* each. (See Colour-printed Map of Arran.)
22. Ayrshire, Renfrewshire, Lanarkshire (parts of). (1870.) 14*s.* 9*d.*
23. Lanarkshire, Central Districts ; Ayrshire (part of W.). (1872.) 19*s.* 3*d.*
24. Peeblesshire, Lanarkshire, Edinburghshire, Selkirkshire (parts of). (1868.) 8*s.* 9*d.*
25. Berwick, Roxburgh, Selkirk, and Edinburgh shires (parts of). (1879.) 8*s.* 9*d.*
26. Berwickshire and Roxburghshire (parts of). (1883.) 3*s.* 3*d.*

27. Argyllshire; parts of Islay, Jura and Oronsay. (1900.) 8*s.*
29. Argyllshire, Ayrshire, Buteshire, Dumbartonshire and Renfrewshire (parts of). (1892.) 21*s.* 6*d.*
30. Renfrewshire; parts of Dumbarton, Stirling, Lanark and Ayr. (1878.) 16*s.* 3*d.*
31. Lanarkshire, Stirlingshire, Linlithgowshire, Dumbartonshire, Edinburghshire (parts of). (1875.) 16*s.* 3*d.*
34. Eastern Berwickshire. (1863.) 3*s.* 6*d.*
36. Seaboard of Mid Argyll (Solid and Drift editions, 1909). 16*s.* 3*d.* each.
37. Mid Argyll (Solid (1903) and Drift (1908) editions). 25*s.* 3*d.* each.
38. Perthshire, Stirlingshire, Dumbartonshire, Argyllshire (parts of). (1901.) 14*s.* 9*d.*
39. Perthshire, Clackmannanshire, Stirlingshire and Fifeshire (parts of). (1882.) 17*s.* 9*d.*
40. Fife and Kinross. (1898.) 14*s.* 9*d.*
41. Fife, East part; Haddingtonshire, North part. (1889.) 5*s.* 9*d.*
45. Argyllshire, Country near Oban and Dalmally (Solid and Drift editions). (1909.) 25*s.* 3*d.* each.
46. Perthshire, Argyllshire (parts of). (1900.) 19*s.* 3*d.*
47. Perthshire. (1888.) 16*s.* 3*d.*
48. Perthshire, Forfarshire and Fifeshire (parts of). (1883.) 11*s.*
49. Forfarshire and Fifeshire (parts of). (1884.) 5*s.*
55. Perthshire (Solid (1902) and Drift (1906) editions). 22*s.* 3*d.* and 25*s.* 3*d.*
56. Perthshire, Forfarshire (parts of). (1895.) 22*s.* 3*d.*
57. Forfarshire and Kincardineshire (parts of). (Revised edition, 1897.) 10*s.* 3*d.*
57A Kincardineshire, S.E. corner. (1881.) 1*s.* 9*d.*
60. Rum, Canna, Eigg, Muck. (1908.) 10*s.* 3*d.*
66. Kincardineshire, Forfarshire, Aberdeenshire (parts of). (1897.) 23*s.* 9*d.*
67. Kincardineshire and Aberdeenshire (parts of). (Revised edition, 1898.) 5*s.* 9*d.*
75. Inverness-shire, Elginshire, Banffshire, Aberdeenshire (parts of). (1895.) 19*s.* 3*d.*
76. Aberdeenshire, Kincardineshire (parts of). (1886.) 13*s.* 3*d.*
77. Aberdeenshire, S.E. part; Kincardineshire, N.E. corner. (1885.) 8*s.*
81. Ross-shire, S.W.; Islands of Raasay and Rona, part of Skye. (1896.) 14*s.* 9*d.*
85. Elginshire, Banffshire, Aberdeenshire (parts of). (1898.) 20*s.* 9*d.*
87. North-East Aberdeenshire and Banffshire (detached portions). (1885.) 13*s.* 3*d.*
91. Ross-shire (part of). (1893.) 15*s.* 6*d.*
94. Ross-shire, Cromartyshire, Sutherlandshire (parts of). (1889.) 8*s.* 9*d.*
95. Elginshire, Banffshire (parts of). (1886.) 5*s.* 3*d.*
96. Aberdeenshire, Banffshire (parts of). (1895.) 7*s.* 3*d.*
97. Aberdeenshire and Eastern Banffshire (parts of). (1881.) 4*s.* 6*d.*
100. N.W. Ross-shire (part of). (1888.) 2*s.* 6*d.*
101. Ross-shire, Cromartyshire and Sutherlandshire (parts of). (1892.) 14*s.*
103. Sutherlandshire, E. (1896.) 8*s.* 9*d.*
107. Sutherlandshire (part of). (1892.) 25*s.* 3*d.*
113. Sutherlandshire, N.W. (part of). (1886.) 5*s.* 3*d.*
114. Sutherlandshire (part of N.). (1889.) 13*s.* 3*d.*
115. Sutherlandshire, Caithness-shire (parts of). (1898.) 19*s.* 3*d.*

Maps on Six-inch Scale, illustrating N.W. Highlands and Skye.

Sutherlandshire. Sheets 5 (1892) 11*s.*; 71 (1891) 20*s.* 3*d.*
Skye. Sheets 38, 20*s.*; 39, 16*s.*; 44, 22*s.* 9*d.*; 45, 24*s.* (1905.)

For list and prices of Six-inch Maps, Vertical and Horizontal Sections of Scottish Coalfields, *see* List of Maps, Memoirs, Sections, &c., of H.M. Geological Survey (6*d.*), published by Ordnance Survey Office, Southampton.

Memoirs of the Geological Survey of Scotland.

(1.) General Memoir:—
Silurian Rocks of Britain. Vol. I. Scotland. (1899.) 15*s.*

(2.) Economic Memoirs:—
The Oil-Shales of the Lothians. (Second edition, 1912.) 2*s.* 6*d.*
The Central Coalfield of Scotland.
Area II. Denny and Plean, Banknock, Carron and Grangemouth, Cumbernauld, Castlecary and Bonnybridge, Falkirk and Slamannan. (1917.) 4*s.* 6*d.*
,, V. Glasgow East, Chryston, Glenboig and Airdrie. (1916.) 4*s.* 6*d.*
,, VIII. East Kilbride and Quarter. (1917.) 2*s.*
The Iron Ores of Scotland. (1920.) 10*s.*

(3.) MUSEUM GUIDE :—
Guide to the Collections of the Geological Survey. (1912.) 1*d.*

(4.) DISTRICT MEMOIRS :—
Cowal, Argyllshire. (1897.) 6*s.*
The Geology of the Neighbourhood of Edinburgh. (Second edition, 1910.) 7*s.* 6*d.*
East Lothian. (Second edition, 1910.) 4*s.* 6*d.*
Central and Western Fife and Kinross. (1900.) 5*s.* 6*d.*
Eastern Fife. (1902.) 8*s.*
Skye, the Tertiary Igneous Rocks of. (1904.) 9*s.*
Islay, &c. (1907.) 2*s.* 6*d.*
The Geological Structure of the North-West Highlands of Scotland. (1907.) 10*s.* 6*d.*
The Geology of the Glasgow District. (1911.) 4*s.* 6*d.*
The Geology of Caithness. (1914.) 4*s.*

(5.) PALÆONTOLOGICAL. The Higher Crustacea of the Carboniferous Rocks of Scotland. (1908.) 4*s.*

(6.) SHEET MEMOIRS :—
Sheet 1. Wigtownshire, South-Western Districts. (1872.) 3*d.*
,, 2. Wigtownshire, South-Eastern Districts. (1873.) 3*d.*
,, 3. Wigtownshire, Western Districts. (1873.) 3*d.*
,, 4. Wigtownshire, E. part; Kirkcudbrightshire, portion of S.W. Division. (1878.) 9*d.*
,, 5. Kirkcudbrightshire, Southern Districts. (1896.) 1*s.* 6*d.*
,, 7. Ayrshire, South-Western District. (1869.) 3*d.*
,, 9. Kirkcudbrightshire, N.E. ; Dumfriesshire, S.W. (1877.) 1*s.*
,, 13. Ayrshire, Turnberry Point. (1869.) 3*d.*
,, 14. Ayrshire, Southern District. (1869.) 3*d.*
,, 15. Dumfriesshire, N.W. ; Ayrshire, S.E. ; and Lanarkshire, S. (1871.) 3*d.*
,, 21. Buteshire (Arran, Central, and N. and S. Bute), Argyllshire, Ayrshire (parts of). (1903.) 4*s.*
,, 22. Ayrshire, Northern District, and parts of Renfrewshire and Lanarkshire. (*Out of print*).
,, 23. Lanarkshire, Central Districts. (*Out of print*).
,, 24. Peeblesshire, Lanarkshire, Edinburghshire, Selkirkshire (parts of). (1869.) 3*d.*
,, 28. Knapdale, Jura and North Kintyre. (1911.) 3*s.*
,, 31. Lanarkshire, N. ; Stirlingshire, S. ; Linlithgowshire, W. (1879.) 2*s.* 3*d.*
,, 34. Eastern Berwickshire. (1864.) 2*s.*
,, 35. Colonsay and Oronsay, with part of the Ross of Mull. (1911.) 2*s.* 3*d.*
,, 36. Seaboard of Mid Argyll. (1909.) 2*s.* 3*d.*
,, 37. Mid Argyll. (1905.) 3*s.*
,, 45. Argyllshire, The Country near Oban and Dalmally. (1908.) 2*s.* 6*d.*
,, 53. Ben Nevis and Glen Coe. (1916.) 7*s.* 6*d.*
,, 55. Perthshire, The Country round Blair-Atholl, Pitlochry, Aberfeldy. (1905.) 3*s.*
,, 60. The Small Isles of Inverness-shire. (1908.) 4*s.* 6*d.*
,, 64. The Geology of Upper Strathspey, &c. (1913.) 2*s.*
,, 65. Braemar, Ballater and Glen Clova. (1912.) 2*s.* 6*d.*
,, 70. Inverness-shire. West-Central Skye, with Soay. (1904.) 1*s.*
,, 71. Inverness-shire. Glenelg, Lochalsh and the South-East part of Skye. (1910.) 3*s.* 6*d.*
,, 74. Mid-Strathspey and Strathdearn. (1915.) 2*s.* 6*d.*
,, 75. Inverness-shire, Elginshire, Banffshire, Aberdeenshire (parts of). (1896.) 1*s.* 6*d.*
,, 76. Aberdeenshire, Central. (1890.) 1*s.*
,, 82. Ross-shire, Central. (1913.) 2*s.* 3*d.*
,, 83. Ross-shire, Inverness-shire, The Country round Beauly and Inverness. (1914.) 2*s.*
,, 85. Lower Strathspey. (1902.) 1*s.* 6*d.*
,, 87. Aberdeenshire and Banffshire (parts of). (1886.) 9*d.*
,, 92. Ross-shire, The Fannich Mountains, &c. (1913.) 2*s.* 6*d.*
,, 93. Ross-shire, Ben Wyvis, Carn Chuinneag, Inchbae, &c. (1912.) 4*s.*
,, 97. Northern Aberdeenshire. Eastern Banffshire. (1882.) 4*d.*

(7.) CATALOGUE OF GEOLOGICAL PHOTOGRAPHS. Series B and C. (1910.) 6*d.*

(8.) DESCRIPTION OF ARTHUR'S SEAT VOLCANO. (1911.) 6*d.*

(9.) GUIDE TO THE ASSYNT MODEL. (1914.) 1*d.*

List of Publications of the Geological Surveys of Great Britain and Ireland (6*d.*) *from the* ORDNANCE SURVEY OFFICE, *Southampton ; and Agents.*