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[FOURTH SERIES.]

Art. I.—*Silicate Specific Heats. Second Series;* by Walter P. White.

This paper extends in scope and accuracy some work previously published.[1] The several objects in view are indicated in the discussion of the results. The methods were described briefly in the earlier publication, and in more detail in two later papers;[2] some further improvements, which were used in most of the work here described, will be presented in a paper following this. Here it seems sufficient to recall the main features of the experimental procedure, which were: (1) The charges of silica or silicate were heated in electric or steam heaters, with particular care to secure both constant and uniform temperatures. (2) These charges were dropped into the calorimeters by an automatic arrangement, which secured uniformity and quickness. (3) The container was also dropped empty, in order to eliminate the heat losses in the drop. (4) A special guard was used to prevent water from splashing on the outside of the calorimeter. (5) The calorimeter after the drop was completely inclosed away from the air of the room, and its temperature was measured thermoelectrically with a sensitiveness of 0·0003° or (usually) of 0·0001°.

The questions of interest connected with these specific heats usually depend on relatively small differences either between the specific heats of similar substances or between those of the same substance at different tempera-

[1] Walter P. White, Specific Heats of Silicates and Platinum, this Journal, 28, 334, 1909.

[2] Walter P. White, Some Calorimetric Apparatus, Phys. Rev. 31, 670, 1910; Easy Calorimetric Methods of High Precision, J. Am. Chem. Soc. 36, 2313, 1914.

tures; hence greater precision seemed desirable than has generally been sought in work of this kind. It therefore seems specially necessary to inquire what precision was attained.

A glance at almost any comparative table of calorimetric values will suffice to show that calorimetry is one of those subjects in which the systematic errors are usually much larger than the accidental, and deserve, therefore, the more careful consideration. The amount of accidental error in the present work is easily seen

Table I.

Accidental Errors.

Showing one of the best and one of the worst cases of agreement. Original interval specific heats from 0° to the temperature given.

	Quartz	Pseudo-Wollastonite
300°	·21689	·20452
	93	39
500°	·23804	·21697
	03	707
700°	·25433	·22577
	33	93
900°	·25956	·23244
	50	49
1100°	·26410	·23788
	05	87
		92
		75
		77
1300°		·24270
		62
		61
		46
1400°		·24470
		506
		488
		473

from Table I. The maximum disagreement in any series runs from 1·5 per mille in the worst case (pseudo-wollastonite) to 0·23 per mille in one of the best (quartz). It averages about 0·5 per mille, as appears from Table IV. (The *mean error* would be from a half to a fourth as great as the maximum disagreement here given.)

The systematic errors of course can not be completely known, but considerable light on their amount can still be obtained. In such an attempt, however, the familiar and crude distinction between accidental and systematic errors is a rather imperfect guide. Dr. M. D. Hersey has informally proposed a suggestive classification into "visible" and "concealed" errors, where the visible errors are those ordinarily called accidental. But the concealed errors are of several different kinds. The most useful basis of classification is perhaps according to the constancy of the causes of error. Following it, we may distinguish 3 sorts of error:

1. The visible or "accidental" errors, that is, errors due to conditions which are almost continuously varying.
2. Errors from constant causes of deviation whose presence will not appear at all unless as a result of special investigation (the systematic errors *par excellence*).
3. Errors from slowly or occasionally varying causes, often the hardest to detect of all.

It is always likely that the rapidly varying deviations do not vary impartially about zero; hence there is always reason to suspect concealed errors due to the same causes as the visible errors. It is, therefore, especially important to inquire how far the visible errors can be accounted for by causes which would not produce concealed error.

These various causes of error can be partly estimated by considering the methods and precautions used, and also by examining the results.

Methods and Precautions.

The High Temperature Standard.

The *furnace temperatures* were based on the identical "Element G" used by Day and Sosman in establishing their high temperature scale, checked by six concordant determinations of the silver and gold melting points, and by comparisons with 2 other standards, standardized by silver and gold, and directly intercompared at 4 temperatures from 500° to 1400°.

The maximum discrepancy in these various observations was 0·7°. Since even these small discrepancies are largely accidental their final effect is quite negligible; of far more consequence is the question whether the thermoelements read the same in actual work as they did in the calibrations. Whether they did or not depends, of course, on the homogeneity of the thermoelements and on the constancy of the position of the temperature gradient.[3] The homogeneity of the standards was thoroughly

[3] Cf. Walter P. White, The Thermoelement as a Precision Thermometer, Phys. Rev. 31, 137, 1910; or, Thermoelements of Precision, especially for Calorimetry, J. Am. Chem. Soc., 36, 2293, 1914.

tested by raising or lowering them in the furnace. A special furnace of small diameter was constructed to assist in this part of the work. The gradient wás kept as constant as possible in the platinum-wound furnace by keeping the depth of insertion of the thermoelement constant to 2 mm. or so; in the lead-bath furnace the thermoelement was not moved at all from day to day.

The standards were used only occasionally in the platinum-wound furnace. The working element in that furnace was compared with the standards 15 times during the ten months in which that furnace was in use. It changed less than 0·3° at 800° in all that time. Two working thermoelements, in different parts of the lead-bath furnace, were safe from change at 500° and under, and served to check each other and to test the uniformity of the furnace temperature. It seems fairly certain, therefore, that in applying the temperature scale to the present work there was no error as great as 0·3° at 1000°, or 0·3 per mille. This, of course, is less than the other errors in the work and possibly in the high temperature scale itself.

The High Temperature Scale.

The Day and Sosman high temperature scale was applied in the form presented by Adams' thermoelement curve.[4]

The 100-degree Reading.

The temperature, always close to 100°, in the steam heater, was read by a thermoelement which was calibrated in the heater by several times determining with a barometer the pressure of the steam. Comparison was also made with a regular hypsometer, and 3 thermoelements were used. In 6 standardizations of the best one of these the maximum discrepancy was only 0·008°.

The Calorimeter Temperature Scale.

The calorimeter temperature reading was based on the thermoelement calibration made in 1907, and described in 1910,[5] but this use of that calibration was merely a convenience, for the real standardization was by an elec-

[4] L. H. Adams, Calibration Tables for Copper-Constantan and Platinum-Platinrhodium Thermoelements, J. Am. Chem. Soc., 36, 72, 1914.

[5] W. P. White, H. C. Dickinson and E. F. Mueller, The Calibration of Copper-Constantan Thermoelements, Phys. Rev., 31, 159, 1910.

trical calibration of the whole calorimetric installation,[6] giving in joules the heat corresponding to a given interval measured with the thermoelement, so that the exact value of that interval *in degrees* is of no importance for the present purpose. In expressing the result, 4·183 joules were called a calory, and this value undoubtedly differs from the 15-degree calory by less than the probable error of one of the specific heat determinations, but the 1911 "international" joule is the real unit used.

The final accuracy of this calibration was almost certainly several times as good as 1 per mille, but changes subsequently made in the calorimeter rendered its equivalent doubtful, possibly by as much as 1 per mille. The value of the equivalent was therefore checked at the close of the work by dropping water at 100° sealed in a silver bulb, into the calorimeter. Two determinations, agreeing (as it happened) to 0·1 per mille, gave 0·999 for the specific heat of water from 30° to 100°. The best available values are ·998 and 1·0016, so that the calorimeter equivalent seems still to be known as well as the mean calory. The not improbable systematic error of 1 per mille in all the results is of no great importance, since it is relative values that are important.

Uniformity of Furnace Temperature.

At high temperatures the relation of the mean temperature of the charge to the temperature of the thermometer used to read it is harder to know satisfactorily than is the calibration of the thermometer. The furnace used above 600°, like most of its kind, was really a vertical air bath, heated along the sides and cooled at the ends. Within such furnaces strong temperature gradients are to be expected. To diminish these in the charge itself (*a*) the furnace chamber was made relatively slender, 20 cm. high by 4·8 cm. in diameter; (*b*) the furnace winding was somewhat concentrated at the ends; (*c*) platinum-faced partitions were used above and below the container; (*d*) the thermoelement ran into the middle of the charge (a scheme used by Regnault); (*e*) this portion of the thermoelement, to reduce thermal conductivity, was made of specially fine wire (0·2 mm.), and was protected only by the capillary insulators, which were ground flat on an emery wheel, so that they would enter a platinum

[6] Walter P. White, A Test of Calorimetric Accuracy, Phys. Rev., 31, 686, 1910.

tube 4 mm. in diameter. This rather tightly fitting thermoelement was withdrawn just before the drop of the charge, so as not to interfere with a free fall. The platinum tube was, of course, part of the container.

The effectiveness of these arrangements for temperature uniformity was tested in several different ways at different times, by observations which, all told, extended over several weeks. Thermoelements, 3 or 4 in number, were welded to the platinum container or placed in different parts of the charge and finally, at the close of the work, 4 junctions of very fine wire (0·2 mm.) connected in parallel were distributed through the charge so as to give its mean temperature, and this, in 3 different charges, was compared with the temperature read by the charge element in the central tube. The results were: The maximum difference of temperature observed was 3·3° over the platinum container and 2° within the charge, but the mean temperature of the charge differed scarcely 0·2° from the thermoelement in the small tube. These various tests are not inconsistent with each other, and seem to indicate that the problem of determining the charge temperature, the most critical in this work, was satisfactorily solved, even without the complication of extra furnace coils. The results given in Table I of the following paper and those in Table X of this paper tend to confirm this conclusion.

In the lead-bath and steam heaters, used below 700°, the temperature was very uniform,[7] and the problem of knowing the charge temperature was far easier. It was possible here to have the thermoelement outside the charge, which simplified manipulations considerably. It was then only necessary to be sure that the heating was continued long enough. The method used to test this point was simply to have a thermo-couple read the difference between the center of the charge and the furnace cavity outside it, and thus ascertain the time necessary to bring the whole of that particular charge to the furnace temperature.

Normal results with the metal-bath furnace are doubtless still less affected by systematic error than those at higher temperatures. Owing, however, to several accidental circumstances, treated in the following paper, some of the results obtained with this furnace are not certain to

[7] For a discussion of this point see the following paper.

better than 4 per mille and are really preliminary results. These were being repeated when the furnace was disabled by a short circuit and it seemed best to discontinue the work. The results as they stand are sufficient to establish all the conclusions which seem possible at present; and experience in the present work had shown that when better results seem to be needed they can be obtained more rapidly and accurately by a somewhat different procedure.

The Heat Determination in the Calorimeter.

The calorimeters had shown themselves capable of a precision approaching 0·2 per mille;[8] the thermoelectric sensitiveness was further increased to 0·0001°, which was far more than was necessary for most of the determinations; the unusual practice was followed of computing for a single specific heat determination 3 or more cooling corrections, from data mostly different; all determinations were made in duplicate. (These last two precautions were of course more effective in avoiding accidental errors and mistakes in computation than systematic errors.) The critical calculations which were not controlled by duplication, including those in the original calibration of 1910, were carefully revised and for the most part done and written out anew at the close of the work in 1916.

Special Measures disclosing Systematic Errors.

The simultaneous use of 2 furnace thermoelements, and the employment of 2 radically different methods of calorimeter calibration have already been mentioned. The 2 furnaces could also be compared by using both for the same substances at 500°. There were, besides: 2 separately calibrated calorimeters, which were intercompared with 2 silicates at 900°; 2 calorimetric thermoelements, of different type and sensitiveness, also thoroughly intercompared in work on regular charges; 2 very different steam heaters; and 2 platinum containers. Every part of the measuring system (but two) was thus replaced by another at some time.[9] Again, while the 112 points observed called for 224 duplicate determinations, over

[8] A Test of Calorimetric Accuracy, loc. cit., p. 700.

[9] These two parts were: (1) the thermoelement used above 600°, and this was frequently standardized; (2) the potentiometer, which certainly did not cause appreciable error.

100, or 50 per cent, more than this necessary number were made for various extra checks and comparisons.

Except in one case there was not even a perceptible effect from interchanging calorimeters, thermoelements, etc. This of course, tends to indicate the absence of *constant sources* of concealed error. This indication is corroborated by other things mentioned already, that is: by the excess precision obtained in the calibrations of thermoelements and calorimeters; by the great constancy of the working thermoelement in the platinum furnace; and by the temperature uniformity attained in that furnace, since almost the only possible sources of constant error lie in the temperature and heat determinations. The exceptional case of perceptible constant error is shown in Table II, which gives all the comparisons made between the two furnaces at 500°, and indicates that the platinum furnace was possibly 1 per mille low at this temperature. This difference is no greater than the value often reached by the visible (or accidental) error.

Table II.

Determinations of the Interval Specific Heat from 0° to 500° of Quartz and of glasses formed from Magnesium Silicate, Microcline and Calcium Silicate. Comparison of the two furnaces at 500°.

Furnace	Quartz	$MgSiO_3$ gl	Micro. gl	$CaSiO_3$ gl
Pt-Wound	·23781	·24729	·23222	·22034*
	764	723	219	019
Metal bath	·23799	·24754	·23200	·22095*
	791	746	212	077*

* Preliminary determination.

Tests of Slowly Varying Causes of Error.

The insidious, slowly or occasionally varying causes of error can only be tested by numerous intercomparisons. Many of the extra determinations were devoted to repetitions of the same result at different times. The most important of these are given in Table III and give no indication of appreciable long period variations.

A more comprehensive test of insidious errors is given by comparing the results obtained with similar silicates. This can be done with the aid of Table X at the end of this paper, whose data cover the work from beginning to end. Such discrepancies as occur there are clearly sporadic; and out of 45 comparable results above 100° all but 9 depart from the probable smooth curve less than 0·3 per mille, and only 3 as much as 1 per mille. There is, therefore, almost no irregularity except the small visible errors already shown to characterize the original observations. An even more important thing is the agreement between the mean of anorthite and albite on the one hand and andesine, whose composition is the mean of the two, on the other, and the similar agreement between pseudo-wollastonite, magnesium silicate pyroxene, and diopside, for these go far to show the absence of errors systematic with the different substances.

TABLE III.

Results of repetition of the same determination at different times. (At 100° mean values only are given. The individual results here differed more from each other than the means at different times.)

The values are specific heats for even intervals.

0°–100°	Quartz	$MgSiO_3$	Microcline	
1911	·18680			
1911	·18680		·18715	
1914	·18682	·20336		
1916	·18688	·20323	·18707	
	Quartz 0°–500°	Quartz 0°–300°	Quartz 0°–900°	$CaSiO_3$ 0°–300°
1912	·23803	·21689		
	804	693		
1913			·25956	
			950	
			954	
			950	
1914			·26971	
			963	
1915				·20449
				448
1916	·23799	·21685		·20452
	791	674		439

Concealed Errors as Indicated by the Visible Errors.

It remains to inquire if the visible errors are entirely accidental. Errors can often be made to be accidental, and that is mainly true of the visible error in the present case, for by subtracting the heat given by the empty container from that given by the container with charge all *constant* error *due to the container* is necessarily eliminated. On the other hand, there is no important source of accidental error except those affecting the container, as is shown by the fact that below 1000° the visible errors average about as large (in calories) with the container empty as when the charge is added,[10] although the total

[10] See Table I in the paper following this.

heat measured was over 8 times as great with the load. The visible errors of 0·5 per mille or more, therefore, are completely accounted for by causes which give only accidental errors, and hence do not seem to be associated with any concealed or constant error.

On the whole, then, it appears that errors, from all causes whatever, greater than 3 per mille are probably exceptional, and this indication comes from an unusually extensive combination of checks and tests.

Materials.

Of the materials used, three substances, quartz, microcline, and albite, were natural, the silica glass was made[11] from quartz of practically the same composition, the cristobalite was made by crystallizing the silica glass, the rest were synthetic. The making of these synthetic forms required in some cases considerable skill and intimate knowledge of the peculiarities of the substances. I am very grateful to several colleagues, namely E. T. Allen, N. L. Bowen, J. L. Crenshaw, John Johnston, and E. G. Zies, for the help they gave in making these preparations. The solid impurities of the synthetic materials are undoubtedly negligible in their effect on the specific heat. Probably this is also true of the gaseous impurities, and since satisfactory facilities for determining these are not now at hand, it has seemed best to leave the question of such impurity open for the present, meantime preserving samples for future testing, if this should ever become desirable. The gaseous impurities originally in the natural minerals were presumably greater than in the synthetic.

Reduction of the Results.

The first results of the present determinations are interval[12] specific heats, *i. e.*, specific heats over considerable temperature intervals, and as such are similar to most of the specific heat determinations made by others. Such values are unsatisfactory in two respects: (1) The

[11] Arthur L. Day and E. S. Shepherd, Quartz Glass, Science, N. S., 23, 670, 1906.

[12] Since it will be necessary in this paper to deal with several kinds of mean, it seems desirable to distinguish by using the unambiguous term "interval heat" in this case.

intervals are seldom the same for different observers, so that their results are, as a rule, comparable only with great difficulty. (2) Each result is the average of a varying quantity whose law of variation is unknown, so that the specific heat at any given temperature, the quantity most often really wanted, is much more uncertain than the result given. To avoid one of these objections in the present case, all the results as given are reduced to even intervals; the other is avoided by the number and treatment of the results, since the results, forming, as they do, regular series, enable the law of variation with temperature to be known, and the actual specific heat at any given temperature to be found. For while a single actual specific heat may be more useful than a mean value, a set of mean values for different intervals defines the total specific heat function as well, theoretically, as a series of actual heats. In practice, actual heats are apt to be known more accurately if they are determined directly, but in the present case the interval-heat method, enabling the calorimeter to be operated at room temperature, was thought to give even the actual heats more accurately than a direct determination in an electric furnace and was, in fact, adopted as more accurate after the research had been begun with the other plan.

In reducing to even intervals, the slight variation of the upper temperature from the round number was corrected for by interpolating along the curve defined by the series of results for widely differing upper temperatures. This correction was seldom as much as one unit in the 4th place, so that no appreciable error can have occurred in it.

The change of specific heat corresponding to a change of the lower temperature to zero was very much larger than the above and was determined in accordance with the following reckoning:[13] If M_0 is the observed interval heat, for the temperature interval θ_1 to θ_2, m_1 the known interval heat from 0° to θ_1, and M_2 the desired heat for the total interval $0 — \theta_2$, then equating total heats,

$$\begin{cases} M_2\theta_2 = m_1\theta_1 + M_0(\theta_2 - \theta_1), \text{ whence} \\ M_2 = M_0 - (M_0 - m_1)\frac{\theta_1}{\theta_2}. \end{cases}$$

[13] Here repeated from the 1909 paper, loc. cit., this Journal, 28, 339.

This formula is well adapted for computation; m_1 was determined from the values for 0-100,° 0-300°, 0-500°, by assuming that a quadratic equation in θ represented the interval specific heat from 0° to 500°. The required equation must of course be satisfied by the values which result from its application to the experimental values; it was very easily reached by a process of successive approximation. As to the possible error resulting from the assumption of a quadratic relation, if we instead assume, first, that all the curvature is above 300°, and second, that all is below 300°, the resulting difference in the final value for 0°—100° is in each case about 6 units in the last place (though of opposite sign in the two cases) and is much less at higher temperatures. The error from the reduction is therefore almost certainly negligible above 100° and probably there also.[14]

The true specific heats were, in an earlier research, obtained by a graphic method[15] which involved drawing a tangent to the plotted curve of interval heats. It seemed possible to improve this method by drawing chords instead of a tangent, but this scheme proved to be merely a graphic way of differencing the original values, so that the end could be obtained more easily and directly as follows: If the interval specific heat is sufficiently well expressed by polynomial equations with 5 constants, $A + B\theta + C\theta^2$, etc., where θ is Centigrade temperature, the total heat from 0°C up is $A\theta + B\theta^2 + C\theta^3$, etc., and the true specific heat at any temperature, which is the differential of the total heat, is[16] $A + 2B\theta + 3C\theta^2$ etc., so that the quantity which must be added to the mean specific heat to get the true heat is:

$$B\theta + 2C\theta^2 + 3D\theta^3 + 4E\theta^4.$$

But in a series of 4th degree polynomials each first difference is:

$$BP + 2CP\theta + DP(3\theta^2 + \frac{P^2}{4}) + EP(4\theta^3 + \theta P^2);$$

[14] The values can also very easily be adjusted back to a lower temperature of 20°, by using the same quadratic again, when the remaining error will certainly be quite insignificant.

[15] Walter P. White, this Journal, 28, 341, 1909, op. cit. Also used in 1909 by A. Dumas, Chaleur Specifique des Substances Ferromagnétiques, Arch. Sci. Phys. et Nat., 27, 460.

[16] Mr. P. D. Foote has kindly called my attention to an error in my former paper where I gave this formula as the one for reducing true specific heat to interval specific heat. As the relation is simple and well known I may hope that my slip has done little harm.

each 3rd difference is $6DP^3 + 24EP^3\theta$, where P is the temperature interval between each two successive values in the series. It follows at once that by subtracting 1/24 of the 3rd difference from the 1st, and then multiplying by θ/P the difference of true and interval heats is obtained. The method is exactly equivalent to obtaining a series of 4th degree equations and thus computing the true specific heat, but is much easier. It is also easier[17] than the graphic method, and has over it the further advantages: (2) That it is not at all subjective, and (3) that the error due to the inadequacy of the 4th degree equation is almost certain to be less than that involved in drawing the curve and tangents.

In practice, the 1st differences of course do not apply to the temperatures of the original observations, and the mean of the differences (for the temperature interval P) immediately above and below the temperature θ is not the difference for θ, but is rigorously half the 1st difference at θ for the interval 2P, and was taken as such. But the 3rd difference contains P^3 as a factor so that the sum of the 3rd differences above and below θ is 1/4 the 3rd difference at θ for interval 2P, and was therefore divided by 6, not 24, before combining it with the 1st difference for 2P.

The experimental error in the true heat thus obtained can be found as follows: if *a b c d e* are the 5 consecutive mean heat values which enter into the true heat at the temperature of C, the 1st differences are $b - a$, $c - b$, etc., the 3rd, $e - 3d + 3c - b$, etc.; the true specific heat is $C + \left(\frac{4(d-b)}{3} - \frac{e-a}{6}\right)\frac{\theta}{2P}$. 2P in the present case is 400°, so that for C at 500° the true heat is:

$$C + \frac{5}{3}(d-b) - \frac{5}{24}(e-a); \text{ for } 1100°,$$

$$C + \frac{11}{3}(d-b) - \frac{11}{14}(e-a).$$

Hence at 1100° the experimental error in the true heat may be 5 times the error in a single one of the deter-

[17] Of course, it requires *evenly spaced* values of the mean specific heat. When these are absent, graphic methods are easier, as in almost every case where the independent variable increases by unequal increments.

minations,[18] at 500°, nearly 3 times, and this is the possible error of almost any value based on these determinations. The further error due to inadequacy of a 4th degree equation is probably small by comparison.

This method evidently does not give results for the highest or lowest interval heat in the series, since there are not first differences on both sides of these. At the lower end of the scale an arbitrary but quite unsubjective procedure was adopted to get the true heat. A 2nd-degree equation was passed through the 3 lower values, a cubic through the lower four, the true heats taken at 0°, 100°, and 300° were the means of those obtained from the two equations. The uncertainty due to the computation is probably under 3 per mille at 100° and 300°, perhaps 6 per mille at 0°. At the upper end of the scale, where the rate of variation is less, a slight extrapolation is not out of the question for the present results. At 1100° the total effect on the true heat of a third difference of the interval heat is only about 2 per mille, so an estimated value could be safely used. For the diopside first difference from 1100° to 1350°, a 200-degree interval was constructed by multiplying the observed difference by 4/3, and then diminishing this result to fit the hypothesis that the 3rd difference was constant from 900° to 1300°. The error from the assumption is demonstrably negligible, but the effect of the accidental error of the short interval is increased. A similar procedure was used in getting the three values at 1300°. For silica glass at 900° a value for the difference 900°-1100° (namely ·1370) was derived from several silicates whose first differences below 900° were close to that of silica glass, but in other cases it has been regarded as unsatisfactory to attempt by extrapolation to get a value of the true heat for the highest temperature observed.

The above method, as carried out in this case, reduces the effect of accidental error by basing each final value mainly on three original results, covering an interval of 400°, but this involves assuming the validity of a regular law over this wide interval. It is also possible to obtain a true heat mainly from two adjacent readings, which is thus less dependent on the assumption of a

[18] This of course implies that all the errors are of the same size and that their signs are distributed in a certain one, out of 32 different ways. But an error nearly as large might occur 1 time in 8.

single, simple law for all temperatures, and can also, without serious extrapolation, be obtained for a temperature closer to the highest observed. This is often, and properly, done for short intervals by assuming a linear law. It seems worth while to inquire what error is thus incurred, that is, what correction is needed to make the result more exact, and how such a method will work out in the present case.

If the total heats at temperatures θ_1 and θ_2 are $m_1\theta_1$ and $m_2\theta_2$, the interval heat between θ_1 and θ_2 is evidently $\frac{\theta_2 m_2 - \theta_1 m_1}{\theta_2 - \theta_1}$ which may crudely be put for the true heat at $\frac{\theta_1 + \theta_2}{2}$, the middle of the interval. If we put simply θ for the mean temperature $\frac{\theta_1 + \theta_2}{2}$, and h for half the interval, or $\frac{\theta_2 - \theta_1}{2}$, this crude value is easily shown to be

$$\frac{\theta}{h}\left(\frac{m_2 - m_1}{2}\right) + \frac{m_2 + m_1}{2}. \qquad (1)$$

If we take, as before, $m = A + B\theta + C\theta^2 + + E\theta^4$, it is easy to show (1) is equal to

$$\begin{aligned} a + 2B\theta + 3C\theta^2 + 4D\theta^3 + 5E\theta^4 \\ + h^2C + 4h^2\theta D + (10h^2\theta^2 + h^4)E \end{aligned}$$

that is, to the true heat at θ plus

$$h^2C + 4h^2\theta D + (10h^2\theta^2 + h^4)E \qquad (2)$$

The first difference across the interval $2h$ between θ_1 and θ_2 has already been used as $m_2 - m_1$. The second difference as regularly obtained will not come opposite θ, but opposite θ_1 or θ_2. We may, however, use the difference at θ_1, expressing it in terms of θ and h. In all the differences the interval, P, will be $2h$. It is now not hard to show that if we add:

$$\left.\begin{aligned} &\frac{1}{8}\text{ the lower second diff.} \\ &+ \frac{1}{16}\text{ the third} + \frac{\theta}{48h} \times \text{ the third} \end{aligned}\right\} \qquad (3)$$

we get (2) plus $9h^4$E. Since the 4th difference is $384h^4$E the discrepancy $9h^4$E can usually be ignored. Then (3) is the error of taking (1) for the true heat at θ, and may be subtracted to get a better result. The effect of accidental error can be estimated as in the former case, and proves to be about the same for the same effective values of θ and P.

The applicability of both methods of deriving the true heat is shown in Table VII, where the even-hundred values were obtained by the second method, that of equations 1, 2, 3, and the odd-hundred by the first method. There is no systematic difference between the two. The even-hundred set, having the interval P effectively half as great, show greater irregularities resulting from the original accidental errors.

The original results for cristobalite were smoothed before the derivation of the true heat, because they were shown by the run of the differences to lie on a curve less smooth than those of the other substances. The agreement of the original duplicates was excellent, however. In the smoothing no change was greater than 1 per mille, the tolerated error; the maximum resulting change in a true heat, at 1200°, was 1·1 per cent.

Results.

The Interval Specific Heat Results.

Table IV gives all the results for which the regular procedure was used without accident. It also contains preliminary determinations, most of which were not repeated, and some determinations in which an accident occurred, but which still seemed to be concordant. Determinations affected by accident are omitted if also non-concordant, but none are omitted unless there was evident cause of possible error. The few which are non-concordant without special evident reason are in parenthesis. Determinations were taken as concordant which did not differ by more than 0·001 from their duplicates. The most usual mishap was a failure of the charge to drop true into the calorimeter. In most of these results one unit in the last (fourth) figure is evidently of some significance, two units of some importance in making comparisons. It is clear that in performing arithmetical operations on these values a significant distortion might

TABLE IV.

Interval Specific Heats.

Quartz

0°–100°	0°–300°	0°–500°	0°–550°	0°–600°	0°–700°	0°–900	0°–1100°
·1875*	·2167*	·2380*	·2439*	·2518*	·2543	·2596	·2641
·1875*	69	84*	39*	20*	43	96	40
63*	69	80		18*		95	
65*	68	80		·2498‡		95	
66	67†	(2377)		·2501‡		95	
70		80				97	
69		79				96	
66		79					
70		(2376)					
69		79					
67		77‡					
67		77‡					
64†							
69							
69							

Pseudo-Wollastonite.

0°–100°	0°–300°	0°–500°	0°–700°	0°–900°	0°–1100°	0°–1160°	0°–1300°	0°–1400°
·1844	·2045	·2170	·2258	·2324	·2379	·2393	·2427	·2447
43	45	71	59	25	79	94	26	(2451)
	45			24	79		26	49
	44				78		25	47
					78			

	0°–100°	0°–300°	0°–500°	0°–700°	0°–900°	0°–1100°	0°–1300°	0°–1400°
Cristobalite	·1882	·2334	·2426	·2508	·2569	·2625	·2663	·2680
	83	33	25	09	68	25	61	80
	83							
Anorthite	·1902	·2143	·2296	·2399	·2481	·2552	·2629	·2674
	00		97	98	78†	(43)	28	74
	02					50		
Andesine	·1925		·2332	·2441	·2523			
	25		29	40	26			
Albite	·1947*	·2203*	·2363*	·2474	·2561	·2630		
	49*	15*	64*	73	61	29		
		196*	63*					
Microcline	·1872*	·2108	(2260)	·2371	·2450	(2512)	0°–1160°	0°–1250°
	71*	07	(63)	70	51	(09)		
	70	08						
	70							
Wollastonite				·2273	·2344	·2402	·2416	
				75	44	01	15	
Diopside	·1924	·2163	·2314	·2421	·2500	·2563		·2603
		(66)	14	20	00	62		04
		64						
Mag.-Sil. Amphibole	·2034	·2297	·2462	·2576	·2662	·2730		
	33	99	60	76	60	32		
	31				61			
	33							
Mag.-Sil. Pyroxene	·2039	·2309	·2485					
		10	83					

* Preliminary determination.
† Determination accompanied by some mishap.
‡ Platinum furnace.

Interval Specific Heats. Glasses.

	0°–100°	0°–300°	0°–500°	0°–700°	0°–900°	0°–1100°
Silica	·1845	·2124*	·2302*	·2422	·2511	
	46	25*	03*	24	12	
				22	12	
				23		
Anorthite	·1881*	·2152*	·2306*	·2406		
	80*	52*	03*	04		
	85					
	84					
	85					
	85					
Andesine	·1932*	·2212*		·2484	(2618)	
	36*	10*			15	
		11*			13	
Albite	·1977	(2236)	·2410		·2639	
	76	38	10		41	
		39				
Microcline	·1919*	·2163	·2320	·2431	·2515	·2598
	18*	63	21		14	99
			22‡			
			22‡			
Wollastonite	·1852*	·2077*	·2210*	·2356		
	53*	79*	08*	54		
			03‡			
			02‡			
Diopside	·1934*	·2189*	·2335*	·2438		
	44*	90*	30*	40		
	38*					
Mag.-Silicate	·2039	·2300	·2475	·2598		
	41	04	75	99		
			73‡			
			72‡			

* Preliminary determination.
‡ Platinum furnace at 500°.

Table V.

Mean Atomic Weights, or Molecular Weights divided by the number of atoms, used as Multipliers to reduce Specific Heat to Mean Atomic Heat.

Silica	20·1
Calcium Metasilicate	23·27
Magnesium Metasilicate	20·12
Diopside	21·70
Anorthite	21·45
Andesine	20·84
Natural albite	20·33
Natural microcline	21·23

The andesine is more exactly Ab_1An_1. The compositions taken for microcline and albite were those found by E. T. Allen* for Mitchell Co. N. C. orthoclase and Mitchell Co. N. C. albite, without H_2O.

* A. L. Day and E. T. Allen, The Isomorphism and Thermal Properties of the Feldspars, this Journal, 19, 119, 1905. The densities of these minerals and their glasses are given in this paper; those of nearly all the others in the Smithsonian Physical Tables, 6th Revised Edition.

soon arise from the mere fact that each operation necessarily involves a possible error of one-half in the last place. Hence everything was done with 5 figures up to the final copying into this or the following tables.

TABLE VI.

Interval Mean Atomic Heats.

	0°–100°	0°–300°	0°–500°	0°–700°	0°–900°	0°–1100°	0°–1300°	0°–1400°
Silica glass	3·708	4·272	4·627	4·870	5·049			
Quartz	3·755	4·359	4·784	5·112	5·217	5·308		
Cristobalite	3·784	4·689	4·876	5·042	5·163	5·276	5·351	5·388
Anorthite	4·079	4·596	4·926	5·144	5·322	5·472	5·638	5·736
Andesine	4·012		4·857	5·086	5·263			
Albite	3·960	4·479	4·805	5·030	5·207	5·346		
Microcline	3·971	4·474	4·801	5·031	5·200	5·332		
Microcline glass	4·073	4·591	4·926	5·160	5·337	5·516		
Pseudo-wollastonite	4·290	4·758	5·050	5·256	5·409	5·534	5·646	5·697
Mag. Sil. Amphibole	4·090	4·624	4·952	5·182	5·354	5·496		
Mag. Sil. Pyroxene	4·103	4·647	4·997				0°–1250°	
Diopside	4·175	4·697	5·021	5·252	5·425	5·560	5·649	

For quartz and silica glass the values of the *interval* specific heat to 100°, 300° and 500° satisfy the expressions:

$$\text{Quartz} \ldots\ldots\ldots\ 0{\cdot}1685 + 0{\cdot}000194\theta - 0{\cdot}000000111\theta^2 \qquad (4)$$

$$\text{Silica glass} \ldots\ldots\ 0{\cdot}1670 + 0{\cdot}000189\theta - 0{\cdot}000000125\theta^2 \qquad (5)$$

TABLE VII.

"Instantaneous" or true Mean Atomic Heats, that is, Heats at different Temperatures.

	0°	100°	300°	400°	500°	600°	700°	800°	900°	1000°	1100°	1200°	1300°
Silica glass	3·33	4·05	4·95	5·17	5·35	5·48	5·58	5·68	5·75				
Quartz	3·37	4·1	5·1		5·9		5·46	5·58	5·66	5·72			
Cristobalite						5·46	5·55	5·62	5·67	5·72	5·77	5·82	5·86
Anorthite	3·74	4·39	5·22	5·43	5·58	5·69	5·82	5·95	6·04	6·14	6·31	6·54	6·82
Andesine					5·53	5·66	5·78	5·89					
Albite	3·61	4·28	5·10	5·31	5·46	5·59	5·71	5·83	5·91	5·97			
Microcline	3·64	4·27	5·09	5·30	5·47	5·61	5·72	5·79	5·86	5·92			
Microcline glass	3·73	4·38	5·22	5·44	5·61	5·75	5·85	5·95	6·11	6·34			
Wollastonite									6·11				
Pseudo-woll.	3·98	4·58	5·32	5·50	5·65	5·77	5·87	5·95	6·02	6·10	6·18	6·26	6·33
Diopside	3·82	4·49	5·32	5·52	5·69	5·83	5·94	6·03	6·10	6·17	6·24		
Mag. sil. Amphibole	3·73	4·42	5·26	5·46	5·62	5·76	5·87	5·96	6·04	6·13			
Nernst-Lindemann Formula for Silica glass			4·95		5·35		5·55		5·67	5·71	5·75		5·80

Quartz at 550° 6·3

The mean atomic interval heats in Table VI are obtained by multiplying the interval specific heats by the mean atomic weights of Table V. They are liable to slight, quite constant errors due to possible error in the value taken for the mean atomic weight, especially in the natural minerals and their glasses.

The "true" or "instantaneous" mean atomic heats, or atomic heats at definite temperatures, obtained by the procedures already described, are given in Table VII. The true specific heats can of course be obtained from them by dividing by the numbers in Table V.

Comparison with Previous Work.

The present results indicate that my results published in 1909 were correct to the degree there estimated, 5 per mille. On the whole, the differences are not systematic. K. Schulz[19] has given a list of published specific heat determinations made on minerals and other solids from 1831 to 1912. In this list, microcline and quartz and the corresponding glasses are the only substances which also appear in the present paper.

For both quartz and orthoclase or microcline the observers frequently differ from themselves by 1 per cent or more, and for quartz, where the results of different observers were compared,[20] the differences between them were somewhat larger. This applies to results between 0° and 100°. At higher temperatures the discrepancies were larger still. Bartoli (1891) was 30 per cent above the present paper for quartz from 30° to 530°, though he agreed at 100° to 1/2 per cent, or best of all in the list. For silica glass Dieterici (1905) agrees to 0·5 per mille, that is, practically perfectly, at 100°. At 300° he comes 5 per mille lower. Our result at 300° is a preliminary determination, and should be too *low* if anything, so there is a real discrepancy here. Heinrichs (1906) is 1/2 per cent higher at 100° and at 300°. Stierlin (1907) is over 2 per cent higher, and Schulz (1912) nearly one per cent higher, at 100°. (Schulz was nearly 2 per cent

[19] K. Schulz, Die spezifische Wärme der Mineralien und der künstlich hergestellten Stoffe von entsprechender Zusammensetzung, Fortschr. der Mineralogie, 2, 259, 1912, 3, 273, 1913.

[20] By comparing each of them with the corresponding value from equation 4, which could be applied to the very various temperature intervals involved.

lower on quartz.) Impurity is, of course, an evident possible cause of discrepancy, but it does not seem a very probable general cause in quartz, and still less so in silica glass. Apparently considerably more accurate work can be done, but this is perhaps not worth while for the majority of rather impure materials. A. Magnus[21] has determined quartz and silica glass to 550°. His results to 100° are for quartz about 6 per mille lower than ours, for the glass about the same. The difference is not material at present. For the interval 17°-550°, however, he is 12 per mille lower for quartz, and 22 for the glass. In reducing his results he takes the interval heat as equal to the true heat at the middle temperature of the interval, remarking that this causes only a very small error, since the course of the specific heat is nearly linear at high temperatures. In fact, however, it follows from equations 4 and 5 that by doing this for the 500-degree interval he introduces gratuitous errors of 3 per cent or more for quartz and the glass, making his results *lower*.

Conclusions.

1. *In General.* Considered as constants of nature, or as data for geological calculations, the present results seem to need no further discussion here. They have, however, a bearing on various theoretical questions which deserves comment.

The least variable magnitude in connection with specific heat is the atomic heat, which is a universal constant according to the classical form of the kinetic theory. The simplest way, apparently, to treat the subject is to consider the variations from this constant. The variations may be classified as due, in part, to secondary thermal effects connected with expansion, change of state, or chemical action, and in part, to the universal tendency toward a gradual development (that is, an increase toward a maximum value) of the atomic heat with rising temperature, a phenomenon which is at present most frequently formulated in terms of the quantum hypothesis.

[21] Messungen spezifische Wärmen fester Körper bei hohen Temperaturen, Phys. Zs., 14, 55, 1913.

FIG. 1.

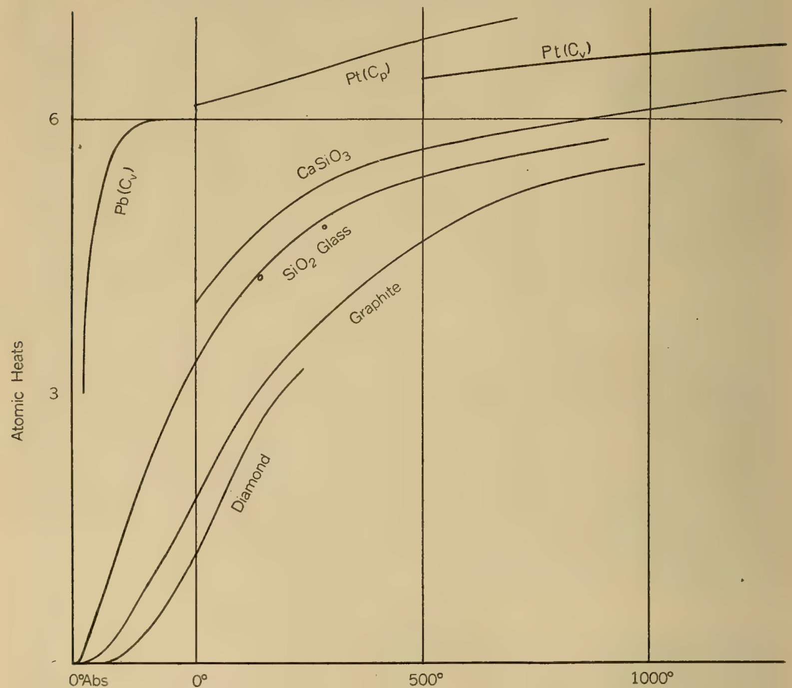


FIG. 1. Small circles, Magnus' values, used by Nernst.

The relation of the present results to this general tendency is shown in fig. 1, which gives various atomic heats, mainly determined by Nernst and his collaborators, along with 3 from the present investigation. Different as these heats are, they are all alike in approaching zero at zero temperatures, and then rising to near 5·96, the value given by the classical kinetic theory, along a characteristic curve. It is clear that the most striking character of the silicate atomic heats, their low value, with rapid increase at a diminishing rate, is due simply to the fact that they are, at room temperatures, on the steep portion of their development curve. Russell[22] has definitely connected a similar location of this curve in many substances with the presence in them of combined oxygen; indeed, with present knowledge of the general

[22] A. S. Russell, Messungen von spezifischen Wärmen bei tiefen Temperaturen, Phys. Zs., 13, 64, 1912. The quantity actually given by Russell is $\beta\nu$ but the value of $\beta\nu$ determines the location on the temperature scale of the steep part of the curve.

character of specific heats, such curves might have been predicted from Kopp's early observation that the atomic heat of oxygen in combination is abnormally low at room temperatures, since this shows that it is part way up its curve.

According to most treatments of the subject, the development curve of the specific heat is found at higher and higher temperatures as the natural vibration period, ν, of the atoms of a substance is more rapid. And it is, regardless of any theory, a physical fact that for elementary substances the location of the development curve is roughly in accord with values of vibration frequency calculated from the atomic weight and from other properties involving force, such as compressibility, fusibility, etc.—that is, calculated as if the atoms vibrate as rigid bodies under the influence of the forces of cohesion.[23] There is some tendency to regard the same values of ν as characteristic of the atoms when in combination also. From atomic heat data Russell[24] and Nernst[25] obtain for oxygen in combination a frequency, ν, of from 13×10^{12} to 30×10^{12} per second, or from ·3 to ·75 that of the diamond, while the same quantity for chlorine is only about $5{\cdot}4 \times 10^{12}$. It follows readily that if the atoms really vibrate in the way just referred to, as single bodies restrained by cohesional forces, the forces called into play by displacement must be about four times as strong for oxygen as for chlorine; the general character of the specific heats given in this paper is the consequence of this greater force. These values of the forces, however, exist only in compounds; for the elementary substances the values of ν are only 2·6 for oxygen and 2·5 for chlorine. This difference between element and compound would seem to show conclusively that the value of ν, the atomic frequency, is not a property of the atom.[26] Indeed, the supposition that it is seems inconsistent with the notion that the forces are cohesional, since the forces external to the atom must be different in different compounds. On the other hand Russell finds that in 13 metallic oxides the value of ν attributable to oxygen varies only 20%, although the heats of formation of these oxides show an

[23] W. D. Harkins and R. E. Hall, The Periodic System and the Properties of the Elements, J. Am. Chem. Soc., 38, 205, 1916.

[24] Loc. cit.

[25] W. Nernst, Der Energieinhalt fester Stoffe, Ann. Phys., 36, 424, 426-430, 1911.

[26] A conclusion also reached by Russell (loc. cit.) on other grounds.

extreme variation of 1 to 7 and the attractive forces also might be expected to vary considerably. Hence, while ν is not a constant, its variations are sometimes surprisingly small. It is possible, however, that the compressibilities, that is, the reciprocals of the *resultant* atom-constraining forces, of these oxides, if we had them, would not be inconsistent with the comparative uniformity in ν. This would involve a very considerable discrepancy between reciprocal of compressibility and heat of formation. Further data, especially as to compressibility, would seem likely to prove particularly interesting.

Conclusions: 2. Specific Heats at High Temperatures.

The discussion thus far has related the present results to the general subject of atomic heat, and has shown that their most striking features, their low value and rapid increase, are a familiar manifestation of a universal phenomenon. It remains to deal with such things as are new or peculiar. The precision and the temperature range here attained both appear to be greater than in previous work, so that the present results throw some light on the general question of atomic heats at rather high temperatures. Above 700° the development, prominent at low temperatures, of the atomic heat from a zero value has been largely passed in all substances, and the further variation in specific heat is commonly referred to another and very different cause. The atomic heat *at constant volume,* after it has reached normal value, has usually been supposed to remain constant if no change of state occurs; the specific heat *at constant pressure,* the one always observed with solids, is greater than this merely by reason of the work done in expanding the solid against its own cohesion. A standard thermodynamic formula gives the difference of the two:

$$C_p - C_v = \frac{A(3\alpha)^2\Theta}{Kd} \tag{6}$$

where 3α is the cubic expansion coefficient, K the (cubic) compressibility, d the density, Θ the absolute temperature, and A a dimensional constant.[27]

[27] Consisting of 1013600 (or 981000) the ratio of the atmosphere (or kilogram) which enters into K, to the dyne, in which K should be stated if it is to be in c.g.s. units, divided by $4{\cdot}183 \times 10^7$, the ratio of the calory to the erg. Very clearly presented in Planck's Thermodynamik, p. 118 of 2d German edition. For pressure in kg, A = 0·02345.

The constancy of C_v at high temperatures has been questioned, and for platinum and some other metals C_v certainly is not constant. A satisfactory test is often precluded by lack of the mechanical data, but in silica glass we have a substance whose expansion and compressibility[28] are known. For it the expansion is so small that the calculated value of $C_p - C_v$ would be imperceptible in fig. 1. The C_p curve is the same as the C_v curve. If this curve is compared with the theoretical curve for silica glass derived by Nernst[29] from experiments between $-247°$ and $+283°$, it appears that above 600° the substance is above the theoretical value. Even the lower values of cristobalite, which lie on the theoretical curve up to 900°, rise above it at 1100° and higher. Above 600° quartz contracts with rising temperature for 400° or more, and if the thermal effect of this contraction is computed and applied A_v for quartz comes to about that of silica glass within the uncertainty of all the data, which is, however, perhaps 1 per cent. By analogy it seems probable that the low value of cristobalite compared to silica glass may be partly due to the thermal effect of a contraction, so that for it A_v may be even higher than the values given. Hence these substances agree in indicating that for non-metallic substances A_v at high temperatures rises above the present accepted theoretical value. Of the two, cristobalite is more significant than the glass, for the theory applies strictly only to solids, and the glass, being amorphous, has some of the properties of a liquid.

For albite, C_p is probably considerably above C_v. Roughly approximate calculations, the only ones now available, indicate at 1000° a possible difference, but not one of great magnitude, between C_v and the theoretical value, which should be higher than for silica, since the substance contains a smaller proportion of oxygen atoms. Hence these substances confirm as well as can be ex-

[28] Compressibility $3{\cdot}2 \times 10^{-6}$ from unpublished results of Leason H. Adams and Erskine D. Williamson in this laboratory.

[29] Op. cit., p. 430. The curve here is slightly adjusted to coincide with the curve of the observations at 283°. Nernst had used at that temperature Magnus' result, whose error has already been treated. From 700° upward the Debye formula and the original Einstein formula for the theoretical atomic heat do not differ perceptibly from the Nernst-Lindemann, used by Nernst, so there is no uncertainty regarding the form in which the theory is represented.

pected, though not very positively, the evidence of the forms of silica that the theoretical value of A_v is exceeded at high temperatures. Microcline is at most temperatures very close to albite; its differing values from 800° to 1000° are the direct result of its unsatisfactory value at 1100° and that of albite at 700°, shown in Table X. The difference at the lower temperatures between albite and microcline and the other silicates seems to offer an opportunity for further investigation.

The high values of pseudo-wollastonite and especially of anorthite above 1000° are very likely due to latent heat from a slight melting, caused by a very slight amount of impurity. Such effects have been regularly observed in connection with melting point determinations on silicates. It is very unlikely, though, that such an effect was present in silica itself, or in albite or microcline, since these substances crystallize with extreme difficulty, hence whatever portion of them might be melted (or amorphous) at high temperatures would cool to a glass in the calorimeter, giving out no latent heat. Indeed, since the effect of impurities on melting often increases as the square of the temperature, such substances are peculiarly adapted to the investigation of the problem treated in this section, and to some others.

Table VIII.

Differences Between Vitreous and Crystalline.
Interval specific heats: Glass minus crystal, given as a fraction of the heat of the crystal form.

	Pseudo-Wollastonite	Diopside	Magnesium-silicate Pyroxene	Magnesium-silicate Amphibole
0°–100°	·005*	·008*	000	·003
0°–300°	·016*	·012*	—·003	·002
0°–500°	·017*	·008*	—·004	·006
0°–700°	·043	·008		·009

	Anorthite	Andesine	Albite	Microcline
0°–100°	—·009	·004	(·015)	·026*
0°–300°	·004*		(·016)	·026
0°–500°	·003*		(·020)	·026
0°–700°	·002	·018		·025
0°–900°		·035	·031	·026
0°–1100°				·035

* Preliminary determination.

Conclusions: 3. Comparison of Glass and Crystal. One important characteristic of silica compounds is the comparative ease with which they may be obtained as glasses. In the present case every crystalline substance examined was also examined in the form of glass, and in all but two instances the same sample was used, first in one state and then in the other. The differences of glass and crystal, evident from Table IV, are brought together in Table VIII. These results, it should be noted, are for the interval specific heats.

Three facts appear from Table VIII: (1) The specific heat of the glass is usually little if any greater than that of the crystal; (2) the exceptions to this rule occur in the glasses containing sodium or potassium, and may be connected with the fact that sodium and potassium tend to impart exceptionally high expansion coefficients to glasses in which they occur; (3) several of the glasses show a decided increase in specific heat at some fairly elevated temperature. No explanation has been established for any of these facts. It seems probable that the increase in specific heat would have appeared in other glasses if they had been carried higher. It may be a phenomenon of considerable importance, but for its complete investigation a knowledge of the expansion and perhaps of other properties of the glasses is desirable.

Anorthite at 0°-100° furnishes a well-marked case of a glass of less specific heat than the crystals, which appeared so anomalous[30] as to be somewhat doubtful. Hence the glass was repeated very carefully with a different heater. The repetition (3d to 6th results in Table IV) confirms the difference first observed. The crystal results were not repeated, since they were more trustworthy, and there was no probability of a large *positive* error. Table X also indicates that these results were not unduly high.

Conclusions: 4. Inversions and Specific Heat. These determinations cover five cases of inversion, or transformation in the solid state, belonging to at least three different types.

[30] The anomaly in the case of silica glass is more apparent than real, as appears above 600°. Below 550° for quartz, and probably at 100° for cristobalite, the specific heat of the crystal is increased by the approaching inversion, as explained below.

a. Magnesium metasilicate in the amphibole form is metastable, undergoing at a temperature high enough to release the molecular rigidity (say, 1300°) a monotropic inversion into pyroxene with *evolution* of heat. This unstable form has a specific heat over 1% below the other. Here the form of greater specific volume (of less density), namely, the amphibole, has the smaller specific heat, contrary to Richarz' rule.[31] It is of course possible that the difference in the atomic heat of these forms of magnesium metasilicate is due to a difference in the rate of expansion, *i. e.*, that there is no difference in the atomic heat at constant volume.

b. Wollastonite (Calcium metasilicate) undergoes at the definite temperature 1170° an enantiotropic inversion into pseudo-wollastonite with absorption of heat, about 10 calories per gram.[32] The high temperature form, pseudo-wollastonite, has a lower specific heat. The transformation is sluggish and the reverse transformation on cooling does not take place at all without the assistance of a solvent. The pseudo-wollastonite was in fact investigated down to 100°. It retains the lower specific heat down at least to 700°. Here it is metastable, and would change into wollastonite with evolution of heat but for the sluggishness. Neither form shows any perceptible irregularity in its specific heat curve near the temperature of inversion, though wollastonite was carried within 10° of that temperature, and pseudo-wollastonite was carried through it.

c. Quartz undergoes a reversible, or enantiotropic, inversion at 575°, from α-quartz to β-quartz, which is very sharp and prompt on both falling and rising temperature. Randall,[33] Day, Sosman, and Hostetter,[34] Rinne

[31] Richarz' rule (Wied. Ann., 48, 708, 1893) in strictness only applies to elements, but it has also been supposed to hold for most compounds. But Bridgman's results, referred to later, seem to contradict this supposition very completely.

[32] E. T. Allen, W. P. White and F. E. Wright, On Wollastonite and Pseudo-Wollastonite, this Journal, 21, 93, 1906; Walter P. White, Melting Point Methods at High Temperatures, ibid., 28, 486, 1909; republished in Zs. anorg. Chem., 69, 348, 1911.

[33] H. M. Randall, On the Coefficient of Expansion of Quartz, Phys. Rev., 20, 10, 1905.

[34] Arthur L. Day, R. B. Sosman, and J. C. Hostetter, The Determination of Mineral and Rock Densities at High Temperatures, this Journal, 37, 1, 1914.

and Kolb,[35] and Wright[36] have shown that the volume increases, and most of the optical properties of quartz also change, at a continually increasing rate through an interval of 400° or more up to the inversion, after which the volume diminishes slowly for an interval of probably 500° more. The specific heat, as Table VII shows, follows, in the main, these other changes. But if the effect of the expansion on the specific heat is calculated by formula 6, taking for the compressibility 0·00000265, the value at room temperatures, a remarkable discrepancy appears as is shown in Table IX. The increase in specific heat, great as it is, is, even at 25° below the

TABLE IX.

Components of Atomic Heat of Quartz due to Expansion, etc.

$C_p - C_v = 3340\alpha^2\vartheta$ by (6), if K is 0·000 002 65

$A_p - A_v = (C_p - C_v) \times 20.1 = 67000\alpha^2\vartheta$.

	Expansion* per degree in parts of Vol. at 0°	$A_p - A_v$ calc. from expansion	$A_p - A_v$ taken as quartz minus glass
100°	·000 043 36	0·0463	0·060
300°	058 47	0·1313	0·170
500°	1290	·862	0·563
550°	2631	3·832	0·868

* Taken from the original (not fully published) data of Day, Sosman, and Hostetter.

inversion point, over 4 times too small to account for the work demanded by the expansion. This result is discussed later.

Cristobalite undergoes an inversion from α-cristobalite to β-cristobalite at from 198° to 277°,[37] which it was not convenient to investigate in detail during the present work. There is little doubt, however, from the relatively high specific heat of cristobalite at 100°, that the cristobalite inversion is of the same type as that of quartz. Moreover, above its inversion cristobalite is like quartz in having a specific heat lower than that of silica glass, which has practically no expansion. The resulting probability of a negative expansion has already been pointed out.

[35] F. Rinne und R. Kolb, Optisches zur Modifikationsänderung von α- in β-Quarz sowie von α- in β-Leucit, Neues Jahrb., 1910, 2, pp. 138-158; Geometrisches zur Modifikationsänderung von α- in β-Quarz, Neues Jahrb. Centrbl. 1911, pp. 65-74.

[36] F. E. Wright, The Change in the Crystal Angles of Quartz with Rise in Temperature, J. Wash. Acad. Sci., 3, 485, 1913.

[37] C. N. Fenner, Stability Relations of Silica Minerals, this Journal, 36, 369, 1913.

Below 1470 cristobalite is metastable, as is quartz above 870°, and between 870 and 1470 tridymite, not investigated in the present work, is the stable form of silica. The transformations of these forms into each other are very sluggish; for this reason, and on account of the relative smoothness of the specific heat curves of quartz and cristobalite above 600°, their transformations are to be classed rather with that of calcium metasilicate (wollastonite-pseudo-wollastonite) than with the prompt change between the different forms of quartz, α and β.

We have, then, represented in the present substances, besides the magnesium silicate inversion, which is monotropic, two different kinds of enantiotropic inversion: (1) Between β-quartz and β-tridymite, β-tridymite and β-cristobalite, and wollastonite and pseudo-wollastonite, sluggish inversions marked by no perceptible change of specific heat near the inversion points, though with differences of 1 or 2 per cent between the two forms. (2) In quartz and probably in cristobalite, a prompt inversion characterized by change in specific heat and in many other properties below the inversion.

In trying to relate these facts to others, we naturally start with the picture of crystal structure which is given by the recent X-ray investigations. This is a picture of atoms joined in a way that seems quite regardless of the chemical molecule as formerly known, but doubtless connected by linkages which are somewhat similar to the valence bands of ordinary chemical union, and which are not all of the same kind except in crystals of the simplest composition.[38] A change in crystalline form must be the result of a change in these linkages, and by analogy with the behavior of chemical valences we may feel fairly certain that the change consists in a virtual weakening of them, perhaps a suppression of some, with rising temperature. Observation shows that the change may have one of at least two different characters. The crystal may change *en masse*, or as nearly so as is consistent with the fact that heat must be gained or dissipated as the change takes place. This, as might be supposed, appears to occur when the change of form is slight, presumably involving rather a stretching than a rearrangement of the atomic pattern. This is the case with the

[38] Irving Langmuir, The Constitution and Fundamental Properties of Solids and Liquids, J. Am. Chem. Soc., 38, 2233, 1916.

prompt α-β quartz and cristobalite inversions. In other cases the rearrangement of atoms seems to be too complex to take place all at once, and there is no general shifting at all, but the new crystals grow at the expense of the old as they might grow in glass, only often more slowly. The final result is then usually an aggregate of small crystals. The wollastonite-to-pseudo-wollastonite and quartz-to-cristobalite inversions proceed in this way. It does not seem necessary to suppose that these two kinds of inversion are fundamentally different, to suppose, for instance, that one is "chemical," the other "physical," or that each comes from a change in a different kind of linkage. This may be the case, of course, but the mere amount of change may determine the way the change proceeds.

Fenner, in his comprehensive study of the various silica inversions,[39] puts the α-β inversions in a different class from the quartz-tridymite, etc., inversions on the ground of their greater promptness and the smaller change in crystallographic properties involved. A still more fundamental reason for distinguishing seems to be the fact that the two kinds of inversion are, so to speak, superposed upon one another; that is, the prompt inversion remains when quartz changes to tridymite or cristobalite,[40] and conversely, its occurrence does not in the least change either of these more permanent forms. Different mechanisms, therefore, determine the different sorts of change, though these mechanisms can affect each other, since the prompt inversion has a somewhat different character in each of the three permanent forms.

Our knowledge of crystal atomic patterns does not seem to be extensive enough at present to permit developing a theory of inversion phenomena out of considerations like those first given. A theory has been formulated which attempts to correlate inversions with the equilibrium changes which have been studied in liquids, or in liquid-and-solid systems.[41] This theory (or hypothesis)

[39] Loc. cit.

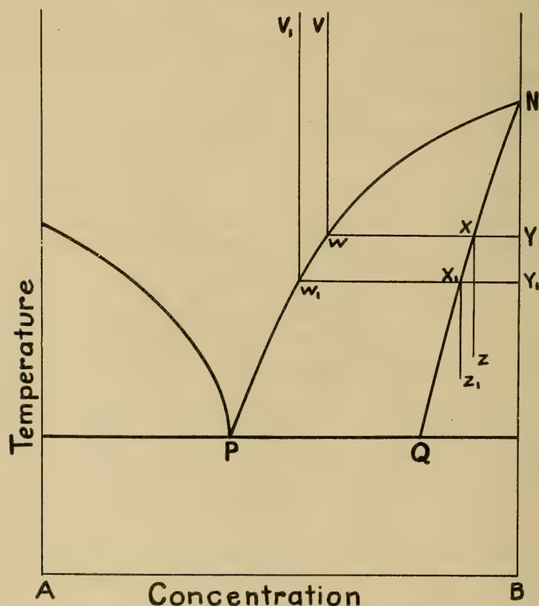
[40] Probably, that is, it is not yet *proved* that these prompt inversions are not of different nature, whose occurrence where they are is a coincidence, but this is unlikely.

[41] A. Smits, Nouvelle Théorie du Phénomene de l'Allotropie, Revue génerale des Sciences, 15 March, 1914; Zs. Phys. Chem., 76, 421, 1911.

G. Tammann, Zur Atomistischen Theorie des Polymorphismus, Zs. Phys. Chem., 82, 179, 1913.

has been connected with the inversion phenomena of silica by Fenner and by Smits,[42] and seems to deserve further mention here. The European writers who have presented the theory have differed quite warmly among themselves, but seem to be in agreement upon as much of the theory as is of importance in this paper. Its essentials will probably be clear in the light of figs. 2, 3, 4. Fig. 2 is the common melting diagram of a 2-component system, where the two components dissolve each other in

Fig. 2.

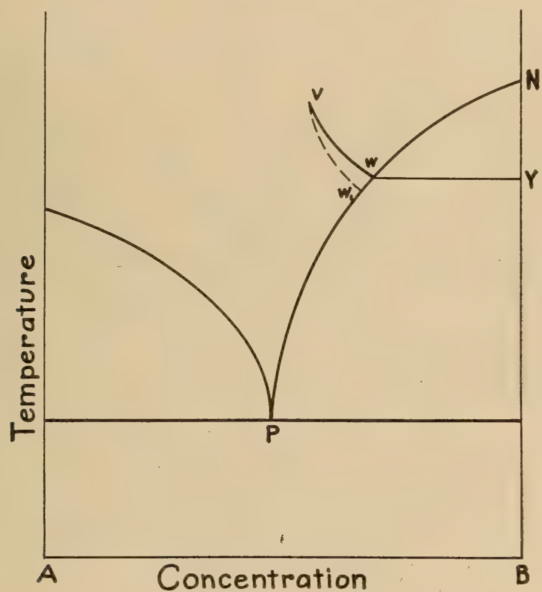


the liquid state, but not completely in the solid. Motion from left to right in this diagram corresponds to a change of composition. The mixture of composition V, if cooled in the liquid state, does not at first change its composition and thus its representative point on the diagram travels vertically down VW. It will usually reach some temperature, as at W, at which one of the components begins to crystallize out, forming a solid which may be represented in composition and temperature by the point Y. If the solid component B can take A up into its

[42] Fenner, op. cit., p. 364; Smits, "Nouvelle Thëorie," etc., p. 31.

crystal, we may have instead of the pure component at Y the mix crystal X, containing both A and B. For a different composition, as V_1, the temperature at which crystallization begins will generally be different, as W_1; the line, NP, is the locus of the points representing such temperatures and compositions, and, similarly, NQ represents the resulting solids. NP and NQ are thus lines marking the compositions of liquid and solid which at each temperature are in equilibrium with each other; that is, which can exist in contact indefinitely. The

FIG. 3.

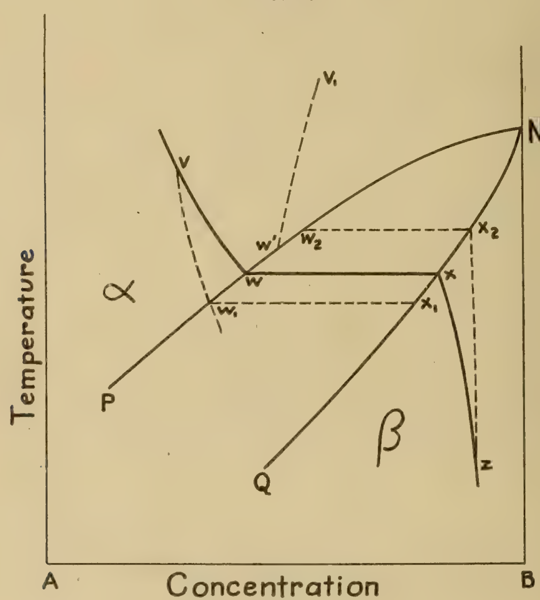


equilibrium is a question of solution. This is not a theory of the changes, merely a statement of them.

From the above there follows an important corollary as to the progress of a solidification. The abstraction from the solution of material of composition X makes the remaining liquid richer in the other component, so that further crystallization takes place from this altered liquid and at a correspondingly altered temperature; the composition and temperature thus move down the line NP, with corresponding changes in the solid.

Fig. 3 illustrates a type of cases, first explained by Bancroft.[43] where the two components are metameric forms of the same organic substance, capable of changing one into the other when liquid. At sufficiently high temperatures the composition may move along some line like VW, the component A actually changing into B, with a definite equilibrium ratio between them for each temperature, but at any one time the two components, whether in equilibrium or not, act toward each other like the permanent components of fig. 2. We have, therefore, chemical

Fig. 4.



composition equilibria as well as the solubility equilibria of fig. 2. One of two things may then happen on cooling. If the chemical equilibrium between A and B is reached rapidly, the composition of the liquid will shift along the line VW, the line NP will be met at W and crystallization of B (pure or containing A) will begin. But the change of composition in the liquid which ordinarily would be produced by the crystallization alone will now not occur; if heat is not abstracted too fast A will change into B, as

[43] Wilder D. Bancroft, The Equilibria of Stereoisomers, J. Phys. Chem., 2, 143, 1898.

B leaves the solution, maintaining the chemical equilibrium, and all the material will crystallize out as B at the constant temperature of WY. If, on the other hand, the chemical equilibrium is reached slowly, the composition will not follow the equilibrium line for moderately rapid changes of temperature; the solubility line NP will be cut elsewhere than at W, as at W_1, and after that the crystallization will also alter the composition of the liquid, and will therefore proceed at a varying temperature from the varying liquid.

The "theory" under discussion is merely the corollary of the assumptions that within the solid crystals of inverting substances occur chemical changes like those of the organic liquids of fig. 3, and that the relation between two inverting solid forms is governed by solubility equilibria like those between the solid and liquid in fig. 3. B (fig. 4, heavy lines) now crystallizes out of the crystal A instead of out of a liquid. The crystals, however, are not necessarily supposed to be pure A and pure B, but, as appears from the figure, may be α, or A containing some B, and β, or B containing some A. Whether they are always so appears to be a point regarding which rival forms of the hypothesis differ.

Fig. 4, which is taken from Smits with a change of lettering, does not appear to give a logical account of the phenomena when the chemical equilibrium is not fully realized. (Dotted lines, V, W_1, X_1, etc.) For in that case, as has already been shown, the position and temperature of W_1 should not remain constant as the change proceeds, and do not remain constant in the metameric mixed liquids to which the solid inversions are supposed to be analogous.

This hypothesis is really rather modest; it attempts no ultimate explanations, but merely a simplification, by attributing to the same sort of machinery the observed changes in some liquids, the considerable abrupt changes in inverting solids, and gradual changes which may occur in those same solids. The proof of the validity of this simplifying view seems to require the demonstration: (1) that there are equilibrium changes in the solid like that indicated by the line VW, fig. 4; (2) that these are connected with changes in the inversion temperature such as are indicated by the line NP; and (3) that the change indicated by VW is chemically the same as one concerned in the inversion. Such demonstration is very difficult in view of the general sluggishness and irregularity of inversion in solids. Smits appears to be the only one who has made a serious attempt to provide it. The principal things he adduces seem to be the following: (1) The specific heats of solids usually change prior to melting, thus indicating a change in chemical composition in the solid, connected with the change of state, which is here a melting, not an inversion. This instance, however, appears to be the result of a misapprehension. Smits quotes Wigand[44] as saying that substances, especially metals, show an increase in specific heat just below meltings. But Wigand expressly states that this effect may be attributed merely to premature melting caused by impurity. This explanation, also offered by other writers, receives the strongest confirmation by the recent work of Dickinson and Osborne[45] on ice, which shows that adequate attention to purity banishes all perceptible effect of this character, even in that case where its independence of impurity had been supposed to be, perhaps, most fully established. (2) Smits also adduces the fact that inversions commonly come lower on rapid cooling or higher on rapid heating as a confirmation of the theory. It is so to this extent, that the theory is capable of giving an explanation of the fact. Fig. 4 was originally given by Smits to show this. The rapidly cooled material does not have time to reach the chemical equilibrium, and therefore reaches the solubility line at W_1; the inverting crystal has the composition W_1 instead of W. Unfortunately, mere sluggishness of transformation will also account for the only observed difference, which is the change in transformation temperature. If we could make the inversion come *higher* by rapid cooling the argument for the theory would be far stronger; hence the main interest centers around those cases where such a phenomenon is in question. There appear to be two such which are specially pertinent, but the case of the melting of sulphur may profitably be included also, since although this melting comes higher with rapid heating,

[44] A. Wigand, Neure Untersuchungen über spezifische Wärmen, Jahrbuch der Radioaktiviät und Elektronik, 10-75, 1913.

[45] H. C. Dickinson and N. S. Osborne, The specific heat and heat of fusion of ice, Am. Soc. Refrig. Engineers, 1, 32, 1915; J. Wash. Acad. Sci., 5, 338, 1915; Bull. Bur. Standards, 12, 49, 1915.

the effect is clearly not due to sluggishness. (3*a*) In sulphur the change in melting point is due to the presence of $S\mu$, a metameric form which can be separated out and recognized. Since the amount of $S\mu$ changes as the sulphur melts, the phenomena in that respect are of the same character as with the organic liquids of fig. 3, with the additional feature that it is now the solid state in which formation of a dissolved metamer occurs. But though the solid inversion temperature is also affected by the amount of $S\mu$ present, the $S\mu$ may then be considered to affect this temperature as any other impurity might, since the $S\mu$ is not supposed to be one of the metamers A or B, which are essential to the inversion. These metamers are as hypothetical in this case as in others. (3*b*) In mercuric iodide it has been claimed by Smits[46] that an inversion actually occurs sooner when approached rapidly. This is the inversion from the yellow to the red form on cooling. The explanation is as follows: The line VW, fig. 4, is supposed to run up toward the right. On sudden cooling the chemical equilibrium retains for a few seconds its high temperature value, and a composition represented by the point V_1 is cooled below the solubility line NP, and inverts at W′, although still above the regular inversion temperature of W. The chemical equilibrium might afterward be expected to change and the red form revert again to the yellow which is normal at that temperature, and this is said to actually happen in a few seconds. Tammann[47] disparages Smits' experimental result on mercuric iodide, though without attempting to test it—a somewhat remarkable proceeding for so simple an experiment. In collaboration with Dr. H. E. Merwin, of this laboratory, I have attempted to repeat the observations. We worked in front of a large window, on a bright day, with considerable variation of conditions, and with care as to the calibration of our thermometers. The material was from a C.P. lot, but was not specially analyzed. It was used both as fine powder and as small lumps formed by fusing that in the tubes. The external diameter of the tubes was from 1 to 3 mm. We found no sign of the premature inversion

[46] Both articles cited; also "A new theory of the phenomenon allotropy," K. Akad. Wetenschappen, Amsterdam, 1910, 768; and "On the system mercury-iodide," ibid., **19**, 703, 1916.
[47] Zs. phys. Chem., **83**, 733, op. cit.

described by Smits; our results also indicated that if this had taken place the re-inversion Smits mentions would not have, so there seems little likelihood that we overlooked such a thing. Tammann's suggestion as to an error in Smits' work from a momentary exposure to the air also appears to be quite off the target; we found the material too sluggish to be affected in this way. We also note that Smits' 1916 diagram[48] for this case is inconsistent with the result from 225° as given in both his record and his diagram[49] of 1910.

(*3c*) Smits claims that the remarkable behavior of cristobalite, discovered by Fenner, is a confirmation of the theory we are discussing. Here there is little question as to the facts: cristobalite formed at higher temperatures, say 1500°, inverts from β to α at a temperature 70° or so above the inversion of cristobalite formed near 1200°, and this α-β inversion temperature is permanent as long as no heating again to high temperature occurs. The question is as to the interpretation. It seems clear, in the first place, that the mere existence of different inversion temperatures in material of the same ultimate composition and crystalline form is evidence of a change with temperature of internal equilibrium in the solid which may well be of the sort for which Smits contends; and this tends to confirm and be confirmed by the evidence of sulphur and other substances. But proof of such changes, though necessary to establish Smits' theory, is not sufficient to do so, and Smits almost certainly sees in the behavior of cristobalite a more important argument for his theory than would come from merely demonstrating a change of internal equilibrium. He does not trouble himself to state this argument, apparently thinking it would be more obvious to his readers than one reader has found it to be, but he treats cristobalite in connection with mercury iodide, from which it seems fair to suppose that he considers cristobalite to present the same hypothetical internal changes as he has carefully described for mercury iodide; that is, that it shows an inversion, the β-α inversion which (1) is dependent on a considerable change in the ratio of two components A and B, which (2) occurs prematurely on cooling, which (3) so occurs because there is a

[48] K. Akad. Wetenschappen, articles cited.
[49] K. Akad. Wetenschappen, articles cited.

non-equilibrium ratio of A and B in the uninverted substance, and (4) occurs because this causes a solubility-equilibrium line NP to be cut in an unusual place. At any rate something of this sort must be the case if cristobalite is to bring to the theory anything beyond a trivial assistance. But the minute we examine the consequences of thus fitting Smits' theory to cristobalite, we find them to be really extraordinary. For we must then suppose: (1) That the change from A to B, whose progress is measured only in hours at temperatures nearly high enough to melt the substance, goes with almost instantaneous rapidity at a low temperature when combined with the production of a new crystalline form; and not only this, but (2) that the ratio of the A and B components before inversion, which is far from an equilibrium ratio, is nevertheless restored after the complete shaking up of the A-B composition involved in the inversion. Or, to express the matter in terms of Smits' theory, the composition, for a very sluggish change of chemical equilibrium, runs sharply along a non-equilibrium line, as W_2 X_2 (fig. 4), both going and coming, quite contrary to the behavior of the analogous liquids in such a case. This occurrence is not mathematically impossible, but the necessity of assuming it is anything but a point in favor of an unproved theory.

The fact that the expansion and specific heats of solids are very much less anomalous and irregular than those of liquids seems to show that molecular changes are at least of a different order of magnitude in solids. To the same effect is Bridgman's demonstration[50] that nuclei will not form and the reaction from existing nuclei will not even run appreciably until the difference in the free energy of the two forms exceeds a certain threshold value.

Bridgman,[51] who has investigated numerous inversions over wide pressure intervals, finds the greatest diversity among them. The high temperature form has in some cases a greater, in others a less volume; in some cases the higher, in others the lower specific heat; the denser form often has a smaller cohesion, etc. There is therefore no special significance in the fact that the specific heat of

[50] P. W. Bridgman, The Velocity of Polymorphic Changes between Solids, Proc. Am. Acad., 52, p. 86, 1916.
[51] Ibid., p. 172.

pseudo-wollastonite is less than that of the lower temperature form, wollastonite.

The inversions of silica, on the other hand, seem capable of challenging much that is now accepted. Bridgman,[52] for instance, speaks of the formation of crystals as always a process of building up from nuclei. But it seems incredible that in quartz, a substance whose very melting is extraordinarily sluggish, a rearrangement of this sort could, at relatively low temperatures, take place with almost instantaneous promptness. A further objection to the idea of growth from nuclei is found in the extension in temperature of the phenomenon. I have hitherto spoken of the phenomena *preceding the inversion,* but the evidence at present is very uncertain that the "inversion" is anything more than the final increment of these preceding phenomena, which extend over a temperature-range of at least 400°. Wright, in commenting upon the progress of these changes, speaks of a constantly increasing disorienting force which at last "the crystal forces can *no longer* withstand" (italics mine). Alongside of this view it seems desirable to put that of a gradual change, which while rapidly accelerated is nowhere sudden nor discontinuous. The question may perhaps be left open till more data are available.

The discrepancy between the expansion of quartz during the inversion interval, and the energy required to produce it (Table IX) is not at all disconcerting. The phenomena accompanying the melting of ice show that in a change of state there is no fixed relation between the volume changes and the work done by the attractive forces. Bridgman has shown that this fact is abundantly illustrated in inversions, and has accounted for it by pointing out that bringing the *centers of force* of atoms nearer together is a very different thing from bringing their *centers of figure* nearer together. But the discrepancy in quartz is, of course, another reason, and a very strong one, for considering the phenomena over a wide temperature range below 575° as belonging to a change of state. Even if there is a sudden change in quartz at the upper end of the long region, a change which would be the only "inversion" if an infinite rate of change with temperature is essential in our definition

[52] Ibid., p. 75.

of inversion,[53] nevertheless most of the real change occurring occurs elsewhere. Benedicks[54] has said that a part of the transformation may take place below the transition temperature; which also may be expressed by saying that a small quantity of the other form is produced and then dissolves in the first. But, he adds, "no real supposition is hereby made."

Dr. R. B. Sosman has called to my attention that a specific heat curve shaped like that of quartz below 575° is found below the A_2 change of iron. This change in iron is also accompanied by an unusual expansion, as in quartz. Now the iron change is known to be connected with magnetic phenomena, and the accompanying thermal phenomena are, consistently with magnetic theory, explained as the result of the mechanical work done in destroying the magnetic arrangement.[55] It seems plausible that this type of curve is one characterizing the fading out of an attractive force.

If the difference in total heat between quartz and silica glass from 0° to 700° is supposed to be due simply to the total thermal effect involved in the protracted inversion, that effect is given as 7·8 calories per gram, nearly as much as the 10 cal. of the wollastonite-pseudo-wollastonite inversion, and similarly the inversion heat α-β cristobalite above 0° is about 6 cal. Some values of the quartz inversion heat *at the inversion point*, 575°, which I formerly gave, are evidently meaningless.

Conclusions: 5. Effect of Chemical Composition.

The differences in specific heat just noticed between different crystalline forms of the same substance show that specific heat differences between substances of unlike composition need to be interpreted with caution. The substances may not be in comparable states. It seems desirable, however, to show more definitely what are the differences in mean atomic heat between different substances occurring in the present work; this is done in Table X by comparing the various substances with an arbitrary standard. This standard is very near the mean of all those in Table X, and is exactly the mean of diopside and albite, except at 700°, where a comparison

[53] Carl Benedicks, On Allotropy in general and that of Iron in particular, Jour. Iron and Steel Inst., 86, No. II, 243, 1912.

[54] Op. cit., p. 244.

[55] P. N. Beck, quoted p. 355, in A. Dumas, op. cit.

of all made it seem probable that albite is nearly 1 per mille in error. This table has already been used as evidence of the small part played by both rapidly-varying ("accidental") and slowly-varying ("concealed") errors, as well as systematic errors constant for the different substances.

The differences in Table X appear to suggest questions rather than conclusions beyond those already considered.

TABLE X.

Interval Atomic Heats of Silicates, compared by being given as differences from a fictitious standard silicate.

Silicate, minus standard.

	0–100°	0–300°	0–500°	0–700°	0–900°	0–1100°
$MgSiO_3$ Amphibole	·023	·036	·039	·039	·038	·043
$MgSiO_3$ Pyroxene	·036	·059	·084			
Diopside	·108	·109	·108	·109	·109	·107
$\frac{PW + Py}{2}$	·129	·115	·111			
P. Woll.	·223	·170	·137	·113	·093	·082
Woll.				·149	·139	·136
Anorthite	·012	(008)	*·013*	·001	·006	·019
Andesine	—·055		—·056	—·057	—·053	
$\frac{\text{Anor.} + \text{Alb.}}{2}$	—·048		—·048	—·056	—·052	
Albite	—·107	—·109	—·108	—·113	—·109	—·107
Microcline	—·096	—·114	—·112	—·112	—·116	—*·126*
Micro. glass	·006	*·003*	·013	·017	·021	·063
Standard alone	4·067	4·588	4·913	5·143	5·316	5·453

The three italized values differ more than 1 per mille from the probable smooth curve.

SUMMARY.

Specific heats of various silicates and forms of silica have been determined for upper temperatures from 100° to 1400°. The method was by dropping from furnaces into calorimeters. A rather unusual number of checks and precautions against error was employed, which are described in detail. Two apparently new methods are described for determining true or atomic heats from interval heats.

On the whole, the general temperature variation of the specific heats is one depending mainly upon the value of ν, an atomic vibration period, assignable to oxygen in combination.

Several forms of silica, whose expansion is very small, and which therefore practically give values of specific heat at constant volume, C_v, show that C_v for high temperatures appears to exceed the theoretical value 5·96.

Glasses show, in the main, a specific heat only slightly above the corresponding crystal forms, but with a tendency to increase at some rather high temperature.

In several sets of polymorphic forms with sluggish inversions there were differences of about 2 per cent between the two forms, but none of these forms showed any variation in specific heat near the inversion temperature.

In quartz, below the α-β inversion at 575°, the heat absorption is much less than corresponds to the abnormal expansion. If such anomalous absorption, unusual change of volume, and change of crystal properties are each or all together the sign of a change of state, then quartz undergoes a gradual change of state over an interval of 400° below what is commonly called its α-β inversion. Quartz, and probably other forms of silica, exhibit what appear to be two kinds of inversion, due to different mechanisms.

Some of these facts militate against certain hypotheses which make polymorphism the resultant of continuous polymeric or isomeric changes in the solid.

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Art. II.—*Specific Heat Determination at Higher Temperatures;* by Walter P. White.

This paper deals with some experimental details of the work described in the paper immediately preceding, and the two are presented separately mainly because they may tend to interest different classes of readers. The general methods used are described very briefly at the beginning of the preceding paper, and in more detail in some earlier papers;[1] the present material is essentially a report of further experience or progress.

The experimental procedure presents three features, the heating of the body and determination of its temperature; the transfer to the calorimeter; the measurement of the heat in the calorimeter. The temperature determination in the furnace, inherently the most difficult of the three, appears, as already said, to have been entirely satisfactory. The calorimetric precision was considerably in excess of requirements. The transfer, while far from being positively a failure, was, by comparison, the weakest link in the chain of operations.

I. *Furnace Temperature.*

1. *Platinum-wound furnace.*—In an earlier report[2] it was stated that the uniformity of furnace temperature increased as the temperature became higher. It has since been found that this result was exceptional and therefore misleading. Two effects were at work; first, a tendency, apparently characteristic of the type of platinum-wound furnace used, for the top to be colder than the bottom at higher temperatures, and second, a cooling of the bottom by a slight upward current of air through the furnace. These happened to neutralize each other at the higher temperatures observed. The considerable effect produced (15° difference over 6 cm. in the middle of the furnace at 500°) by a slight air-current

[1] Especially in: Walter P. White, Specific Heats of Silicates and Platinum, this Journal, 28, 334, 1909; Some Calorimetric Apparatus, Phys. Rev., 31, 671, 1910; Easy Calorimetric Methods of High Precision, J. Am. Chem. Soc., 36, 2313, 1914.

[2] Specific Heats, etc., loc. cit., page 335.

whose very existence was unsuspected for several years seems worthy of emphasis. With the air current shut off the irregularity increased with temperature.

Day and Sosman, who eliminated the major irregularity in their furnace by separately adjusted extra coils, found that the minor differences were then less at high temperatures, as might be expected in view of the greater activity of radiation and conduction.

The work done with the platinum-wound furnace was greatly facilitated by a temperature regulator.[3] Several hours were usually allowed for the charge to become heated with sufficient uniformity; without the regulator these would have been occupied by tedious and time-wasting hand regulation, with less accurate results.

2. *Lead-bath furnace.*—The satisfactory measurement of charge temperature, already reported at 700° and higher, was obtained by making the most of an only moderate uniformity in a simply arranged furnace. At lower temperatures a better furnace performance is possible. Uniformity to 0·1° has been obtained in electric furnaces by stirred baths[4] and also by auxiliary heating coils,[5] but with restrictions on manipulation coming in one case from arrangement of the apparatus and in the other from the attention required as well. In the lead-bath furnace used in this work a combination of the two methods gave the assurance of very great uniformity without demanding remarkable efficiency either in stirring or auxiliary coil regulation. The auxiliaries easily prevented large temperature differences, and thus the stirring was enabled to destroy the lesser irregularities.

Some trouble finally developed with this furnace, which is properly chargeable to the fact that the interior of the bath was not open to inspection. The cover, originally screwed in, had become welded in place. This defect has now been remedied by having the cover merely rest in place, with its rim dipping into a lead alloy seal.

3. An additional *steam heater* was made by modifying an apparatus of Regnault, which is inverted to discharge the heated body, and loses no water in the opera-

[3] A description of this regulator is in course of publication.

[4] A. L. Day and R. B. Sosman, The Nitrogen Thermometer Scale from 300° to 630° with a Direct Determination of the Boiling Point of Sulphur, this Journal, 33, 521, 1912.

[5] John B. Ferguson, Temperature Uniformity in an Electric Furnace, Phys. Rev., 12, 91, 1918.

tion. The original form (fig. 1), shown in several of the larger text-books, is simple and convenient, but its use has been limited by the fact that it soon boils dry. This difficulty, however, was simply overcome by having a condenser connected, which is removed just before the drop is made. An electric heating coil with flexible leads

Fig. 1.

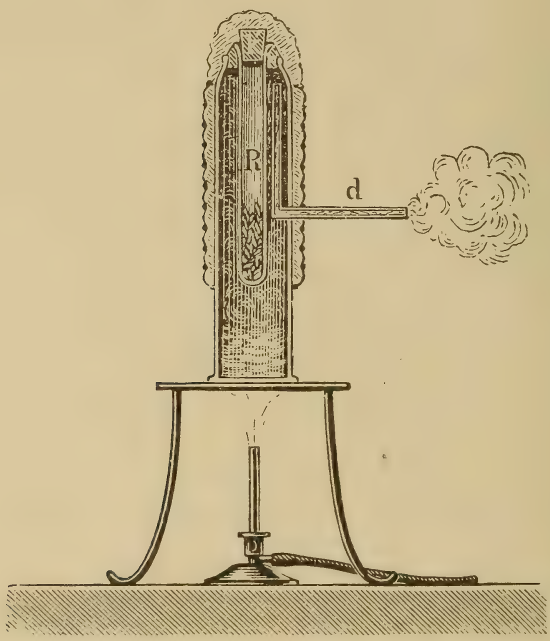

Fig. 1. Regnault's portable steam heater for specific heat work. The material under investigation in the bottom of the heating chamber, R, is discharged by inverting the apparatus.

enabled the apparatus (fig. 2) to be moved about without danger of premature cooling. The reversed outlet tube in our apparatus does not run inside the boiler like *d* in fig. 1. I have been unable to see any particular advantage in having it do so. The apparatus is in some respects inferior to our original heater, with automatic discharge, described in 1910, but is more portable, and easier to make and set up.

Experimenters have usually closed the upper and lower ends of their steam heaters with corks, or used some

Fig. 2.

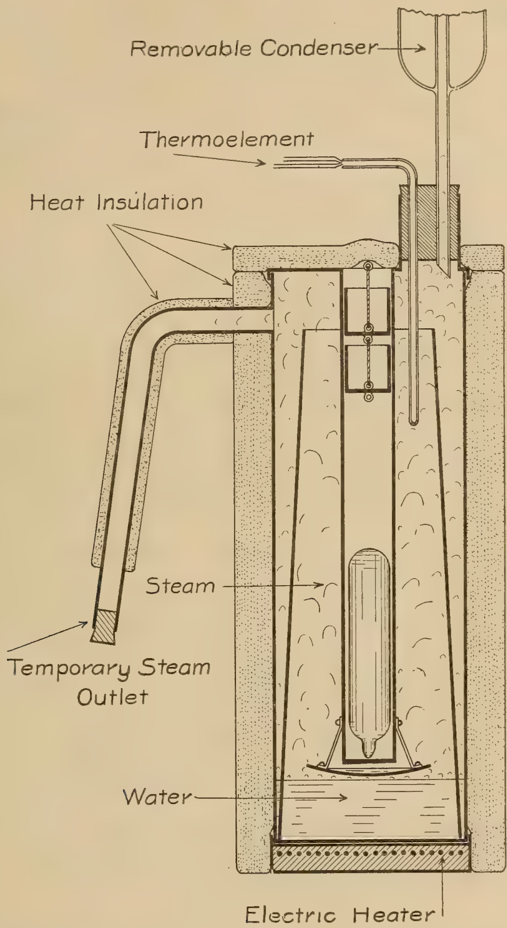

Fig. 2. Modified Regnault apparatus. One-fourth size. Just before discharging, the temporary outlet is opened, the condenser and thermoelement removed, the upper opening stoppered, and lastly, the heating chamber unstoppered. The flexible heater leads are not shown. The very shallow cup below the chamber fills with condensed water, and shields the chamber against superheating.

other arrangement which left the ends comparatively cold. Regnault gave attention to this point, and showed[6]

[6] V. Regnault, Bemerkungen über die zur Bestimmung der spezifischen Wärmer fester Körper angewendeten Verfahren, Pogg Ann., 120, 263, 1864.

that actual experiment indicated no appreciable irregularity within the used portions of the chamber. Since he treated as negligible discrepancies of 1 per cent,[7] his argument, while a sufficient justification of his practice, is not inconsistent with my own observation[8] that in working to 1 per thousand appreciable error may result if the ends of the chamber are not kept near 100°. In the 1910 heater steam actually flowed over the top of the chamber, and the bottom had several cork partitions. Cup-shaped copper partitions are much better than cork, and have proved perfectly satisfactory in the *top* of the modified Regnault heater also. A pair was far more than sufficient, since even the outer one was only 0·05° from the steam temperature. The 1910 steam heater also was improved by attaching a water condenser, and substituting a specially made electric heating plate for the flame first used. These changes, besides saving trouble, promoted speed; the electric heating could safely be set so as to keep the water just below boiling all night (without any need of running the condenser) ready to start operations almost instantly in the morning.

4. *Time of Heating Charges.*—The time required to bring any charge to uniform temperature of course varies according to fineness of grain, heat conductivity, volume specific heat, and especially the space between the container and the wall of the heating chamber. It is not altogether easy to determine, in advance of experiment, the resultant of all these factors; so it seems desirable to call attention to the probable necessity, in many cases, at least, of rather numerous determinations of this important quantity. Fortunately the determination is very easy to make, by thermoelectric means, as described in the previous paper.

II. Transferring the Charge to the Calorimeter.

1. *In the platinum-wound furnace.*—At first Harker's method of dropping the charge was used, in which a platinum suspending wire was fused by a strong electric current. Above 1000° great trouble arose from arcing

[7] Loc. cit., p. 265.
[8] Obtained by direct thermoelectric measurement of the temperature differences.

across the terminals after the wire was melted.[9] The difficulty could doubtless have been overcome by making the current fuse a length of copper wire outside the furnace at the same time as the supporting wire inside. It was preferred, however, to avoid the loss of time[10] and the expense involved in manipulating and using up the platinum wire, and even more to get rid of the effect on temperature distribution produced by the pedestal which was needed, when the platinum wires were used, to support the container and charge during the long heating. A mechanical drop was therefore installed, shown in fig. 3. It was made of Marquardt composition, which we had in the form of tubes and plates. Slots were cut in the right-hand tube with a dentist's grinding wheel, for the flat latch, L, to move in. The two tubes were held together by platinum wire. A *stout* platinum wire (about 1·2 mm.) pulled up at W to release the container, and was operated automatically as the wooden swinging shield under the furnace was swung to one side. The latch worked at 1500°, stood all the high temperature work, including 30 hours at 1400°, and was regularly withdrawn from the furnace at 900°, without perceptible alteration. (The work above 900° was so arranged that the furnace could be allowed to cool before it was necessary to withdraw the dropping mechanism.) It gave many defective drops, but these were mainly due to two things: (1) insufficient rigidity of the supports combined with a too expeditious swing of the wooden shield; (2) using a container whose diameter was too near that of the furnace tube. As the work progressed, defective drops became less frequent. There is no doubt, however, that with a little care the electric fusion could be made to give more accurately aimed drops than could be obtained with the latch. The relative advantages of the fusion method are of course greater where only a small amount of work is in view (since it is very easy to install), and also greater at lower temperatures, where finer wire can be employed, in support and in leads, and the pedestal can often be omitted.

[9] This difficulty was discussed in Some Calorimetric Apparatus, op. cit., page 677.

[10] With the latch, the container for the next heating could be placed in the hot furnace during the first 6 minutes of the calorimeter determination; the wire manipulation took too long to be sandwiched in in this way, but had to wait each time till the calorimeter work was done.

Above 1200° it was necessary to extend the equipotential shield[11] to the platinum container. This was done by means of a fine (0·1 mm.) wire, which pulled away as the container fell.

2. *In the metal-bath furnace.*—The iron dropping latch, used throughout in the iron furnace, was improved

FIG. 3.

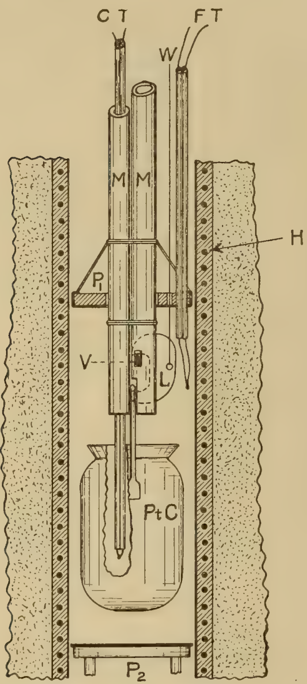

FIG. 3. Apparatus of Marquardt material and platinum for automatically dropping the platinum container, Pt.C. One-third size. L, latch; V, its fulcrum; MM, tubes, about ·8 mm. in diameter; W, wire, whose pull unlatches the bail of the container; CT, charge thermoelement; FT, furnace thermoelement; P_1, P_2, shielding partitions; H, furnace winding. The platinum tube around CT in the container is supposed to be cut away. L is 2·3 mm. thick. MM were covered with sheet platinum, which was part of the equipotential shield.

by arranging it as in fig. 4. The essential thing here is that the thrust upon the handle of the container when the latch, L, is withdrawn comes in the same horizontal

[11] Walter P. White, Leakage Prevention by Shielding, Especially in Potentiometer Systems, J. Am. Chem. Soc., 36, 2015, 1914.

plane as the surface on which the weight is supported. There is thus no tendency to tip the container, and the drop is straighter.

3. *In the steam heater.*—An automatic arrangement for discharging from the steam heater was described in 1910,[12] in which a heavy pendulum, released by the act of opening the calorimeter jacket, was pulled along by a cord attached to the container. The lowering of the con-

Fig. 4.

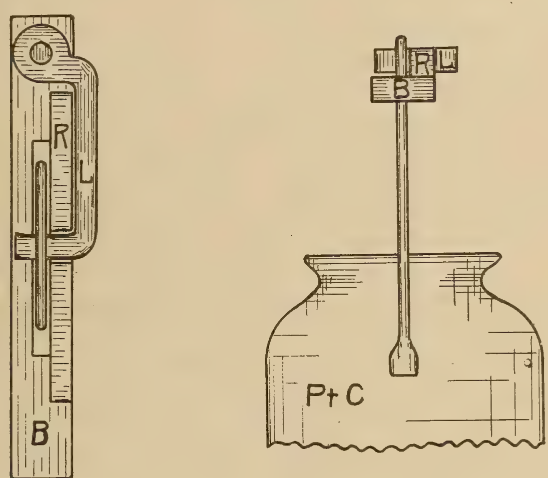

Fig. 4. Top and side views of the dropping latch of the iron furnace, one-half size. B, top of the frame. The latch L rotates counter-clockwise, pulling its bent end from under the bail of the container while the divided bar R holds the bail back. If the tops of L and R are in the same plane there is no tendency to tip the container.

tainer was thus almost unvarying, was rapid, and yet slowed up at the end, as the container reached the water in the calorimeter, so that splashing was avoided. At the end the container was released by automatic tongs, and sank by its own weight. This arrangement has proved to be all that could be desired, but the special pendulum first used has been advantageously replaced by a simple ball and cord. At the top this cord was looped over a bar; by sliding it along the bar the length of the swing could be quickly and easily regulated so as to

[12] Some Calorimetric Apparatus, op. cit., p. 683.

be the same for different loads in the container. An inverted cone on top of the container made that slide into the water with less disturbance and chance of spattering.

III. The Calorimetric Measurement.

The calorimeters had been carefully tested, in connection with an electric calibration, and proved very accurate under the conditions then prevailing. In the specific heat work the problem was complicated by the necessity of exposing the calorimeter to the air of the room for from 7 to 10 seconds at the time of the drop. This was the time required to remove the splash guard (a wide tube which prevented the water thrown up by the drop from getting on the outside of the calorimeter) and then to cover calorimeter and jacket. The error in this operation was diminished by two modifications of the apparatus as described in 1910. (1) In the central part of the splash guard tube pasteboard replaced the brass; the flow of heat between the room and the calorimeter rim was then much less rapid, and the calorimeter at a more uniform temperature at the instant of the drop. (2) The calorimeter cover rested in a horizontal pocket in the jacket cover, from which it was pushed by one hand (by means of a rod running through the far side of the pocket) ready to be seized by the other hand and put in place on the calorimeter. This arrangement saved time, and gave a definite known temperature of the cover. The hand did not touch the cover itself, but only a stem of negligible heat capacity and low conducting power.

The effect of the exposure to the air was studied by special experiments, with the smaller calorimeter, holding about 1500cc. With the air 4° colder, opening the jacket with the regular cover still on the calorimeter caused a temperature fall of 0·0003° per minute, or about one-fourth what would have occurred with the whole (closed) jacket 4° colder. This result is about what would be expected in view of the fact that the jacket, made to hold the larger calorimeter also, gave an unusually full exposure when open. It is also easy to see why the effect with the room warmer was very much less, and for a short opening, as 4 seconds, was about twice as great in proportion. With the calorimeter open the effect of evaporation strongly preponderated; it caused in one case a fall of 0·005° per minute with the room 3° warmer, and from 0·009° to 0·014° with the room 4° colder. The lead-bath furnace at 500° also affected the calorimeter noticeably, raising the temperature in one case nearly 0·002° per minute with the calorimeter closed, and 0·004 with it open. Here the greater absorption of radiation by the water overcame the evaporation. It follows from these data that exposure to air 4° cooler for from 7 to 10 seconds would cause a fall of nearly 0·002°, and from 0·0015° to 0·0021° were actually observed in 5 blank drops with cold furnace. Under the furnace at 500°, a rise of 0·0012° or more was observed in blank drops, which is a little more than would be expected. The *error* is only the variation in these effects, and apparently should generally be under 0·001°, which is only 0·3 per mille of the smallest heats with the furnaces, those at 300°. At 100° the results, as will presently appear, show that the exposure error was certainly not over 0·001°, and probably not over 0·0003°.

The thermometric sensitiveness employed in most of the work was that of 24 copper-constantan couples read to 0·1 microvolt or 0·0001°, three times as good as in the work of 1910. This was several times as good as the average final precision actually attained in the most favorable case. Nevertheless it seems to have been well worth while to employ such sensitiveness. It was of the very greatest advantage, in studying the efficiency of the installation and investigating the puzzling errors encountered, to be free from all apprehension of appreciable error in the temperature measurement, while the observations could hardly have been easier or more certain, even with considerably less sensitive apparatus of other types. The essentials of the thermoelectric method used have already been described.[13]

A surprising result appeared in connection with the time needed for the charge to come to equilibrium in the calorimeter. Ordinarily, in texts or articles on calorimetry, it is said that one must wait till the cooling is "regular" before taking the final reading of the transfer period. This rule seems inexact and may prove misleading, since the variation from "regular" cooling usually becomes imperceptible before a true equilibrium is

[13] Easy Calorimetric Methods of High Precision, loc. cit., p. 2327.

attained between charge and water. The logical and final test is to wait so long that longer waiting does not change the result, that is, to compute for the same experiment thermal leakage allowances ("cooling corrections") for experimental periods of increasing lengths until a constant result is reached.[14] By this means it was found that with our 70-gram charges some of the glasses required 20 minutes for equilibrium. Previously, however, in the attempt to get a simpler and more certain indication, direct measurements had been made, by means of a thermoelement, of the temperature at the middle of a cooling charge of glass lumps mingled with chemists' glass shot. These experiments indicated that in our work 9 minutes would be more than enough for equilibrium. It was through reliance on this conclusion that some of our earlier determinations attained only inferior precision, and had to be classed as merely "preliminary," while serious errors in much of the work would have resulted but for the cross-check with different cooling corrections. The error in the conclusion, once found, was easily accounted for by comparing one of our regular charges with a charge of glass shot, using the thermoelectric method. One cooled more than twice as fast as the other. The source of error, therefore, was the assumption that one charge of glass could be taken as a measure of others in the matter of cooling. This assumption was not unreasonable, since it is not clear even now why there should be any noticeable difference.[15] Inferences regarding conduction of heat seem to be remarkably risky; their uncertainty in the case of the attainment of equilibrium in the furnace has already been mentioned, and this, too, was responsible for the putting of some earlier determinations into the preliminary class.

IV. Probable Efficiency of the Dropping Process.

It has already been shown[16] that the discrepancies, or accidental errors, in the final results not infrequently

[14] Cf. C. Bohn, Noch einige Bemerkungen über die Bestimmung der spezifischen Wärme aus Mischversuchen, Pogg. Ann., 122, 296, 1864.

[15] The two charges were, on the whole, about equally fine-grained. Moreover, the thermal conductivity of water is not very different from that of glass.

[16] Preceding paper, pages 2 to 9.

approached 1 per thousand, and were, on the whole, the most serious errors encountered. A knowledge of the cause of these errors and of possible methods of prevention in other cases would therefore be a useful result of the present work. The variety of the observations was such that it seems possible to disentangle, to a considerable extent, the causes of these discrepancies.

It seems reasonably certain that the process of dropping the crucible was mainly responsible for them.

Their possible sources seem to be fully covered by the following five: (1) The temperature determination in the furnace; (2) the loss of heat in the drop; (3) the exposure of the calorimeter to the outer air during the drop; (4) the effect of external conditions (jacket or electrical measuring system) on the calorimeter after the drop; (5) internal effects (temperature change) in the calorimeter after the drop.

Of these sources of error, the external ones, (3) and (4), will be independent of the heat quantity measured, and will therefore be revealed when that is made very small; in the second place, error from temperature change in the calorimeter, (5), will be proportional at least roughly to the heat quantity, and so will error in the temperature measurement in the furnace, (1), since that affects the whole charge; such errors will therefore be revealed by varying the total heat; and finally, error coming from the dropping process, (2), will presumably vary with the temperature, but only on account of the container, and will be independent of the charge, since that loses no heat in the drop. The average discrepancies, in calories, of about 160 determinations are given in Table I. From them it appears: (*a*) The discrepancies at 100°, which include as many external sources of error as any of the determinations, are relatively small, and thus show that such errors are probably only a minor factor at all higher temperatures.[17] (*b*) Above 100°

[17] The discrepancies in dropping the container alone at 100° are much less than with the charges. It is probable that the better results with the container show the precision reached with the calorimeter, itself, since the lower temperatures of the charges were determined, by means of a small auxiliary mercury thermometer, with a precision which is now seen to be less than corresponds to that of the container results, though enough for the argument above and for the main objects of the investigation. At any rate, for the 8 container determinations the exposures to the air were so uniform that over 0·8 of the exposure effect canceled out, though the necessary conditions for this to occur again can not be exactly stated.

there is usually no perceptible difference in the amount of irregularity between empty and loaded container, though the quantity of heat was nearly or quite ten times as great in one case as in the other. This seems fairly

TABLE I.

Average accidental variation, in calories, of the heat determined at various temperatures.

With the empty containers the number of determinations in a series runs from 2 to 8, averaging 3·3. With the full charges most of the series were of 2 each.

	Empty Container	Charges		Empty Container	Charges
100°	0·028	0·2	700°	2·9	3·1
	0·3	0·5		1·0	4·6
		0·8		2·5	·8
		0·014		·4	·6
		0·9	Mean		·4
		0·5	total	——	——
		0·2	heat	1350	12600
		0·2			
Mean		0·2			
total	——	——			
heat	287	1160	900°	1·7	1·2
				3·	2·3
300°	1·9	1·1			3·7
	1·7	·7			5·5
	0·2	1·4			1·6
		1·6	Mean		2·9
Mean		·8	total	——	——
total	——	——	heat	1800	17250
heat	460	4580			
			1100°	5·9	·4
500°	2·2	1·5		·3	7·7
	2·1	1·6		1·0	4·4
	1·1	·8		7·5	9·5
	1·6	3·8	Mean		2·2
	2·9	2·6	total	——	——
	·6		heat	2200	22000
Mean	·5				
total	——	——	1300°	1·1	7·7
heat	940	8210		4·9	2·9

conclusive against the supposition that appreciable accidental errors often came from either the charge temperature measurement or the calorimetric determination. (3) The discrepancies do show a tendency to vary with the temperature of the drop, that is, with the heat of the container, and since they do not vary with anything else, and are too large to be the effect of external conditions, the loss from the container in dropping seems almost the only possible cause of most of the accidental errors.

The simple dropping method chosen thus appears to have been relatively unsatisfactory, though the experience of the present work seems to have been necessary to prove this, since the preliminary data gave a different indication. The heat given out by the empty container was so near that of platinum itself as to indicate that the whole drop loss was under 3 per mille[18] of the total heat of an average charge. Moreover, the steam produced in a drop was usually almost imperceptible. It was therefore reasonable to expect that the irregularity, which with the method used is evidently the only drop error, would always be well under 1 per mille.

But though the drop errors were unexpected and may be larger than some other methods might give, they are really small in consideration of the precision of most work in this field. They are large only in comparison with the performance secured in the furnaces and calorimeter.

Variation in the heat radiated to the calorimeter from the furnace evidently may contribute to the variation in the observed drop losses. The opened furnace was constant enough for this radiated heat to be easily measured.[19] It was about 1 calory per second at 1100°; 0·3 calory at 700°. The total time of exposure was probably never over a second, but a variation of all that would have produced scarcely 1/6 of the average heat variation observed. Hence the error was due to the losses, and thus almost certainly to irregularity in the splash—most of it, probably, through the resulting effect on the production of steam. The radiation time error is clearly quite accidental. It can be eliminated by an automatic shutter, and this might possibly be desirable in more accurate work.

Plato has shown how to prevent the escape of steam[20] by an arrangement subsequently described, without

[18] Put at 6 per mille in 1909 for a very wide container, giving a large splash. ''Specific Heat of Silicates, etc.,'' op. cit., p. 336.

[19] The change of a thermoelement in an empty platinum crucible was only 20° in the first 2 minutes after opening at 1100°.

[20] W. Plato, Erstarrungserscheinungen an Anorganischen Salzen und Salzgemischen, I, Zs. Phys. Chem., 55, 735, 1906.

credit to him, by Magnus.[21] The hot body falls into a deep cylinder, carrying that down with it below the surface of the water. The water closes over, so that a seal is in place before steam is formed at all. This method does not suppress the splash, but that also can easily be done. The splash consists of two parts: (1) a throwing of water aside as the falling body, here the whole cylinder, enters; and (2) an upward throwing of the water that closes over the body. The first can be suppressed by letting the body fall into a tube of wire gauze; the second, by putting around the top of the falling cylinder a rim of tinfoil, which collapses into a sort of cone as it is exposed to the pressure of the water. Even with this arrangement there is a little projection of spray by the bursting of the air bubbles that come up, but this can be dealt with, since it does harm only by getting on the outside of the calorimeter. Substitutes for the tinfoil rim are also evidently possible.

This device of Plato's seems to demand a charge rather smaller in comparison to the size of the calorimeter than we used, and therefore a smaller temperature rise, but the excess precision already attained makes it possible to deal satisfactorily with smaller intervals. Indeed, measurements even ten times as delicate as those in this work, namely to 0·000012°, have been made[22] thermoelectrically with almost as great relative precision by taking very great care of the surrounding temperatures. The exposure error, next in seriousness to the drop error itself, is diminished if the splash is eliminated, on account of the saving in time. Plato's device also demands a very accurate drop, so that to drop down a tube, as Plato did, seems essential. But this, though presenting some complications, may more than make up for them by simplifying the problem of starting the drop in the right direction.

The relatively large size of the charges, 50 to 80 grams, used in the present work seems to have been justified by the resulting diminution of the drop loss error. If the practical avoidance of this error enables smaller charges to be used, there will be a gain not only in cost of material but in uniformity of temperature in the fur-

[21] A. Magnus, Ueber die Bestimmungen spezifischer Wärmen, Ann. Phys., **31**, 601, 1910.

[22] In this laboratory by Mr. E. R. Edson of the Mellon Institute of Industrial Research.

nace and in the time required for heating. The charges used in the present work took hours to heat; frequently two determinations in a rather long day was the best that could be done with maximum precision. The fall tube also may make for a further economy of time. With that in use it would often be possible to put several charged containers in the furnace at once and drop them one by one. This could be done wherever the furnace is so uniform in temperature that a thermometer beside the charge is sufficient.

It is clear that many of the difficulties just discussed are avoided by dispensing with water as a calorimetric substance, and using instead a block of copper, as has been done by Magnus[23] and Bronsted.[24] This method seems promising even for highest precision, though for that improvements over the calorimeters thus far used seem needed. The aneroid is especially exacting in the matter of jacket temperature control.[25] Another drawback is the greater time required for the charge to give up its heat in the absence of water, but this may be set against the advantages, and is no disadvantage at all for charges consisting of a single lump, or for substances which may not be exposed to air or water.

Summary

This paper deals with the experimental technique of specific heat determination at temperatures up to 1400° by the "Method of Mixtures," and continues some earlier presentations. Modifications in furnaces and in methods of transferring to the calorimeter are described in detail. The variability of the heat losses attending the dropping of hot bodies into water proved to be surprisingly great; the prevention of such losses is probably advisable in accurate work, perhaps by the use of aneroid calorimeters.

Geophysical Laboratory,
Carnegie Institution of Washington,
June 28, 1918.

[23] A. Magnus, Specifische Wärmen Fester Körper bei hohen Temperaturen, Physik. Zs., **14**, 5, 1913; Die spezifische Wärme des Platins und des Diamanten bei hohen Temperaturen, Ann. Phys., **48**, 984, 1915.

[24] J. N. Brönsted, Untersuchungen über die specifische Wärme, Zs. Elektrochem., **18**, 714, 1912.

[25] Walter P. White, Calorimetric Methods and Devices, J. Am. Chem. Soc., 40, 1893, 1918.

Art. III.—*The Migration of the Headwaters Divide of Right Middle Creek, Floyd County, Kentucky;* by Willard Rouse Jillson.

The headwaters divides of many streams rising in the foothills of the Appalachian Mountains have experienced horizontal shifting or migration. That such movements have taken place in the eastern part of the Cumberland Plateau is apparent upon inspecting the Prestonsburg, Paintsville, and Salyersville, Kentucky, topographic sheets, the first two of which have recently been issued by the United States Geological Survey. Middle Creek in Floyd County, Kentucky, presents uncommonly plain

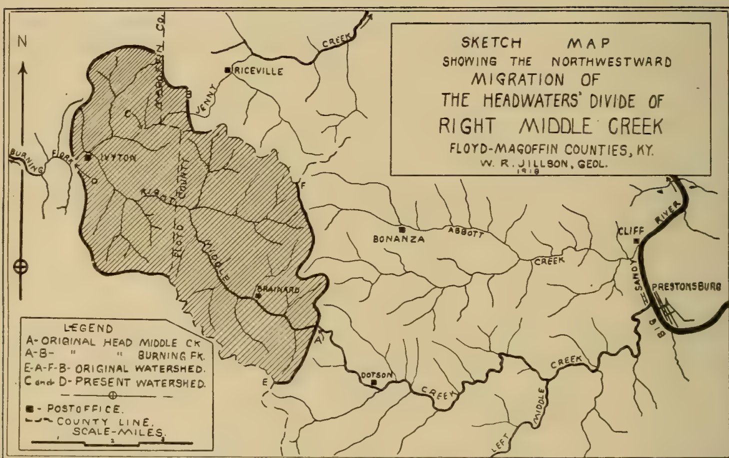

Fig. 1. Map of Right Middle Creek, showing watershed. (Reduced from Prestonsburg sheet, U. S. Geological Survey.)

evidence of migration, and the results of a study of the drainage basin of this stream are considered worthy of record.

As shown on the accompanying map Middle Creek is a large easterly flowing tributary of the Levisa Fork of the Big Sandy River, which it joins at the town site of Prestonsburg. About 3 miles from its mouth Middle Creek branches and the Right Fork of Middle Creek, or, as it is locally called, Right Middle Creek, extends westward about 14 miles.

The present watershed of the upper part of Right Middle Creek is indicated by the western, northern, and eastern edges of the shaded area. The lowest pass, or "gap," is found at a quarter of a mile west of Ivyton Magoffin County, at *D*, and is about 960 feet above sea level. The "gap" is flat and swampy on the Burning Fork side; but on the Ivyton side it is perfectly drained, and erosive forces are active. At *C*, within the shaded area, is another low pass. These two passes indicate points of movement of the shifting divides. The upper part of Right Middle Creek basin is bounded on the west by the basin of the Burning Fork of Licking River, on the north by the basin of Jenny Creek, a tributary of the Levisa Fork of the Big Sandy River, on the east by the basin of Abbott Creek, which is also tributary to the Big Sandy River.

From a combined study of the field geology, the drainage courses, and the topography, it is apparent that Right Middle Creek has shifted its divide 8 to 10 miles northwestward and has captured the headwaters of the Burning Fork of Licking River. The extent of the captured area is about 20 square miles and is indicated on the map by the shaded area. Apparently the original head of Right Middle Creek was along the line *E* to *A*. Capture resulted from a gradual pushing to the northwest of the Right Middle Creek-Burning Fork "gap" from *A* to the present location at *D*. The Burning Fork, already somewhat entrenched when the shifting began, offered in its own main channel the lowest point for capture by the advancing headwaters of Right Middle Creek. As a result, to-day the upper portion of Right Middle Creek is superimposed upon the old channel and basin of the Burning Fork. Field evidence is as follows:

1. The tributary streams within the shaded area flow northwestward at an acute angle against the main current of Right Middle Creek.

2. The valley of the Burning Fork of Licking River is a broad, open, flat basin, with low rounded hills and imperfect headwater drainage. The Burning Fork itself is a very small stream and out of proportion to the size of its valley. Aggradation is in progress.

3. The valley of Right Middle Creek from Ivyton to a point one mile below Brainard presents the physiographical opposite to the valley of the Burning Fork. The

Right Middle Creek valley is V-shaped and in some places the walls of the creek are nearly vertical. There is scarcely any "bottom land," the hills are high and steep, and the drainage is perfect. Erosive forces are actively engaged.

4. Between Ivyton and Brainard, Right Middle Creek is bordered by imperfect terraces developed on a strong sandstone member of the Pottsville series, through which the Right Middle Fork has cut. Probably this sandstone formed at one time the floor of the headwaters of the Burning Fork which were too feeble to cut through it and meandered back and forth across it carving out a wide, flat valley at a high elevation. Toward Brainard the terraces gradually become less distinct and finally disappear.

5. Within the shaded area the channel of Right Middle Creek is choked with gravel and bowlders. The stream is still degrading rapidly.

6. The topography of Middle Creek changes abruptly 1½ miles below Brainard. At *A* the valley broadens, the hills become lower, the wagon road comes up out of the creek to find bottom land on either side, and the stream meanders back and forth in a slightly aggraded valley floor of sandy loam.

7. From *A* to the mouth of the stream, all tributaries come into the main channel at an acute angle with the current. The hills have an older, rounded-off, and worn-down appearance, and the broadened, level, slightly aggraded floor indicates an excess of eroded material from the headwaters. No trace of terracing remains.

Migration has also taken place near the headwaters of Jenny Creek. From Riceville southwestward Jenny Creek has cut through a thick sandstone member of the Pottsville and has developed a box canyon known locally as "The Narrows Fork." By so doing Jenny Creek tapped and appropriated one of the minor tributaries of the former head of the Burning Fork of Licking River. This captured tributary is seen on the map just to the east of the "gap" at *C* within the shaded area. According to field observation the "gap" at *C* is now shifting very slowly as a balance in elevations of the headwaters of the two competing creeks has almost been reached. Jenny Creek carries about the same amount of water as Right Middle Creek and has a lower average elevation.

The question therefore arises, Why did not Jenny Creek capture the head tributaries of the Burning Fork? The answer involves a consideration of local structures as given below.

The physical factors favoring migration in this region are as follows:

1. *Difference in elevation.* Right Middle Creek is a tributary of the Levisa Fork of the Big Sandy River. At its mouth, Middle Creek has an elevation of about 580 feet at low water. The elevation at the mouth of Burning Fork is about 880 feet at low water. This difference of 330 feet is slightly increased when a comparison is made, as between the headwater tributaries of the Licking River where they adjoin the tributaries of Right Middle Creek. It was this difference in elevation which gave the first ''push'' to the northwestward migration of the divide between Burning Fork and Right Middle Creek.

2. *Difference in structure.* But equally as important as the difference in altitude of the main channels of these two competing drainage systems were the structural and lithological features of the area, which, perhaps, may be considered the real cause of the rapid shifting of the Middle Creek-Burning Fork divide. The slight difference in the structure and lithology also may explain why Jenny Creek possessing the advantage of a somewhat lower stream channel could not overtake Right Middle Creek in the race for the headwaters of the Burning Fork.

The village of Ivyton is near the center of a region of local uplift—a structural dome. This dome sends off rather high limbs to the west, to the north, and to the southwest. A somewhat lower limb extends east, and it is up this limb that the headwaters of Jenny Creek progressed westward. But the lowest and steepest dipping limb extends to the southeast, almost in the course of Right Middle Creek, and there is a structural drop in this direction of over 100 feet in a very short distance. The strong sandstone member of the Pottsville series, through which both Right Middle Creek and Jenny Creek have had to cut, has a somewhat softer texture in the lower courses of Middle Creek than on Jenny Creek. In these two factors, then, all others being excluded, lies the key to the situation. Right Middle Creek with a somewhat softer rock to cut and a much steeper structural limb to ascend was more favorably situated than Jenny Creek, although Jenny Creek possessed the initial advantage of a somewhat lower channel. Right Middle Creek, a veritable giant, has removed a mountain 10 miles long, has captured the headwaters of its indolent neighbor, the Burning Fork, and as a penalty for the theft must for the rest of geologic time run backwards and "uphill" throughout its upper course.

The migration of the Burning Fork divide, or "gap," is still in active progress, though it is probable that now having reached the top of the Ivyton structure the rate of the recession will decrease materially. After progressing a little farther northwestward down the fixed course of the Burning Fork, the Right Middle Creek "gap" will soon come to a more or less stationary position, because the "gap" will have passed over the crest of the Ivyton structure, where the factor of reverse dip may be expected to operate negatively upon further northwestward recession. The influence of this reverse dip may reasonably become so strong as to counteract the positive forces still operating which favor migration and are still maintained by the difference in the initial surficial elevation of the waters of this locality which are tributary to the Big Sandy and Licking Rivers.

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Art. IV.—*A Cretaceous Hymenæa from Alabama;* by Edward W. Berry.

The leguminous genus Hymenæa of Linné is one of those rather numerous genera now confined to the American tropics that have a geological history extending back to the middle Cretaceous. At present it contains about a dozen existing species of trees, and probably others await discovery in the botanically little explored parts of the American tropics. They have coriaceous bifoliate leaves, red wood, a resinous gum, and as previously stated are confined to the American equatorial region where *Hymenæa courbaril* and probably other species of the genus, known as locust or copal trees, yield the oleoresin known as animé or copal,[1] much used in the manufacture of varnish and to a considerable extent in perfumery.

The materials for reconstructing the geological history of the genus are as yet too meager to warrant such an attempt and we particularly need some knowledge of its distribution during Tertiary times. Remarkably enough, no less than four species have already been described from the early Upper Cretaceous, and although all of these are not above suspicion, authentic forms are found at that early date in both North America and Europe. Where the genus originated and to what an extent it colonized the old world in former times we do not know, nor when or why it became extinct in the Eastern Hemisphere.

The accepted tradition for many plant genera and one that has a large measure of probability in numerous instances, places their origin in the far north, from which region they spread southward over the land masses of the Northern Hemisphere, and beyond, where land bridges were available. In cases where a genus appeared simultaneously on both sides of the Atlantic, or in Europe, Asia and North America, as a considerable number of genera did during the Cretaceous, such a northern origin is a permissible theory. Hymenæa has not been found, however, in the extensive Upper Cretaceous or early Tertiary floras of Greenland or other northern

[1] Similar but not the same as Zanzibar copal, which is obtained from trees belonging to the allied genus Trachylobium.

lands, nor if it once inhabited Asia is it easy to understand why it left no descendants in the Oriental tropics.

About one per cent of the sea drift stranded on Turks Island consists, according to Guppy, of the buoyant pods of *Hymenæa courbaril,* whose widespread occurrence in the Antilles may be thus explained. So far as I know, no fossil pods recognized as those of Hymenæa have been described, the records being based entirely upon occurrences of the leaves. Although the bifoliate habit which characterizes the leaves of Hymenæa is shared by forms belonging to other genera of the leguminous alliance, such as Bauhinia, Leucæna, Cassia, Acacia, Cynometra, Inga, etc., all have an ensemble of habit, form and venation that permit them to be differentiated—at least in typical cases. I regard as such a typical case the following new species based upon materials collected by me in the clays of the Tuscaloosa formation at Shirleys Mill in Fayette County, Alabama, and which I consider to represent the late Cenomanian or early Turonian of the European section. This new species may be described as follows:

Hymenæa fayettensis sp. nov.

Leaves with a short stout petiole, bifoliate, consisting of two ovate-lanceolate, entire margined leaflets. Leaflets sessile, with a markedly inequilateral, cuneate or slightly decurrent base, but not noticeable inequilateral above the base. Length 6·5 cm. to 8 cm. Maximum width, in the lower half of the leaflets, 2 cm. to 3 cm. Tips extended, bluntly pointed. Midribs stout proximad, becoming thin distad. Secondaries thin, numerous, camptodrome; seven or eight sub-opposite to alternate pairs in each leaflet, branching from the midrib at angles ranging from 30 to 50 degrees, curving upward, the proximal ones quite ascending, while the angles of divergence become progressively greater distad. Tertiaries numerous, very fine, transverse and more or less immersed in the leaf substance. Texture sub-coriaceous, but less so than in most of the recent species.

This is a well-defined species of this interesting genus of Cæsalpiniaceæ and quite distinct from previously described forms. It is most similar to *Hymenæa primigenia* Saporta, described by Saporta[2] and Velenovsky[3]

[2] Saporta, Monde des Plantes, 1879, p. 199, fig. 2.

[3] Velenovsky, Fl. Böhm. Kreideform., pt. 3, 1884, p. 9, pl. 5, fig. 4; pl. 6, figs. 1-4.

from the Cenomanian of Bohemia, and recorded by Hollick[4] from the Magothy formation of Marthas Vineyard. The latter determination may well be questioned. In *Hymenæa primigenia* the leaflets are petiolate, somewhat variable in form, larger, and frequently have crenate-dentate margins. The other previously known American Cretaceous species is *Hymenæa dakotana* described by Lesquereux[5] from the Dakota sandstone of Kansas, and recorded by Newberry[6] from the Raritan

formation (probably upper Raritan) of New Jersey, by Hollick[7] from Long Island and Marthas Vineyard, and by the present writer[8] from the Magothy formation of New Jersey. This widespread species is usually represented by what are regarded as detached leaflets which are not certainly identifiable. These are not unlike those of *Hymenæa fayettensis,* but in general the former are much smaller and more inequilateral, with shorter tips

[4] Hollick, Mon. U. S. Geol. Surv., vol. 50, p. 84, pl. 32, figs. 8, 9, 1907.
[5] Lesquereux, ibid., vol. 17, p. 145, pl. 55, figs. 2, 3; pl. 56, figs. 1, 2; pl. 62, fig. 2, 1892.
[6] Newberry, ibid., vol. 26, p. 90, pl. 41, fig. 14, 1896.
[7] Hollick, op. cit., p. 83, pl. 32, figs. 5-7.
[8] Berry, Ann. Rept. State Geol. (N. J.) for 1905 (1906), p. 138, pl. 22, figs. 1, 2.

and with petiolules of considerable length. The two are perfectly distinct.

For the sake of completeness the remaining known fossil species of Hymenæa may be enumerated. These are *Hymenæa elongata* Velenovsky[9] and *Hymenæa inaequalis* Velenovsky[10] from the Cenomanian of Bohemia, the former also recorded from the Emscherian of that country;[11] *Hymenæa fenzlii,* a doubtful determination by Ettinghausen[12] of leaves from the Tortonian of Croatia: and finally the form from the Tortonian of Baden which Heer described as *Bauhinia germanica*[13] and which appears to be more like Hymenæa.

[9] Velenovsky, Fl. Böhm. Kreideform., pt. 3, 1884, p. 10, pl. 5, figs. 3, 5.
[10] Velenovsky, ibid., p. 9, pl. 6, figs. 5, 6.
[11] Fric, Archiv. Naturwiss. Landes. Böhm., vol. 10, no. 4, 1897, p. 79, tf. 114.
[12] Ettingshausen, Beitr. z. Kennt. Fl. v. Radoboj, 1870, p. 68, pl. 2, figs. 5, 6.
[13] Heer, Fl. Tert. Helv., vol. 3, p. 109, pl. 134, fig. 21, 1859.

SCIENTIFIC INTELLIGENCE.

I. Chemistry and Physics.

1. *The Potash Deposits of Alsace.*—It is well known that the iron-ore deposits of the field of Briey in Lorraine have supplied the larger part of the iron of Germany in recent times, but it does not appear to be so well known that Alsace contains another enormously important natural treasure in the potash deposits near Mulhausen in Alsace. In an address delivered in London just a week before the armistice of November 11, 1918, President Paul Kestner of the Société de Chemie Industrielle described these potash deposits as containing about 1,500,000,000 tons of salts with an average contents of 22 per cent K_2O, richer than any other deposits, easily mined, and capable of supplying the world's demand for potash for many years. He believes that the existence of these potash deposits and the iron-fields already referred to has been the principal reason for Germany's desperate struggle to keep Alsace-Lorraine at all costs. Several German writers are quoted as stating the necessity of retaining this territory on account of these deposits.

As these provinces have now been recovered by France it appears that the German Potash Syndicate will no longer control the world's principal potash supplies as a monopoly, and that this will be a benefit to the general food-supply, since by far the larger part of the potash salts are used as fertilizers for crops. —*Jour. Soc. Chem. Industry,* **37,** (T) 291. H. L. W.

2. *The Atomic Weight of Carbon.*—An elaborate series of determinations of the normal density of ethylene gas, C_2H_4, has been carried out by T. Batuecas under the direction of Professor Guye at Geneva. The gas was prepared from alcohol by several different methods and the agreements of the results were remarkably close. The mean of 21 measurements gave 1·2603 ± 0·0001 g. as the weight of a liter under normal conditions. From this result the molecular weight of the gas and the consequent atomic weight of carbon were calculated by the usual physico-chemical methods, either that of molecular volumes according to Leduc, that of limiting densities according to Rayleigh and Berthelot, or that of Guye based upon the critical constants. The results thus obtained were 11·996, 11·999 and 12·005 for the atomic weight of carbon, which agree closely with the value calculated by Clarke and by Guye, and with the value 12·00 for a long time accepted in the international table. It is considered inopportune that a change in this atomic weight to 12·005 was made by the international committee in 1917.—*Jour. Chem.-Phys.*, **16**, 322. H. L. W.

3. *The Acidimetry of Colored Solutions.*—Having occasion to titrate alkaloidal solutions containing much coloring matter, Alfred Tingle, of Toronto, was unable to apply the method proposed by A. H. Allen, consisting in dissolving the base and impurity in an immiscible solvent and then adding standard acid until methyl orange in the aqueous layer showed an acid reaction, since the coloring-matter interfered even with this method. but he was able to overcome the difficulty in finding the neutral point by titrating directly and using a pocket spectroscope for finding the neutral point. A direct vision diffraction instrument gave satisfactory results when applied to five different common indicators. Blank experiments are necessary in order to find the end-points of most indicators. Usually the breadth of an absorption band is changed when the solution becomes alkaline. The concentration of most indicators is desirably greater when used with the spectroscope than when used ordinarily. The observations may be made through a conical flask or a vial with flat sides, but the layer of liquid must not be too great to prevent the admission of a satisfactory amount of light. It appears that this method will be useful in many practical cases.—*Jour. Amer. Chem. Soc.*, **40**, 873. H. L. W.

4. *The Determination of Nitrites.*—M. F. Dienert has devised a method for this purpose for use in cases where the amount of nitrite present is larger than convenient for the application of the usual colorimetric tests. The method is based upon the liberation of iodine by the well-known reaction expressed by the equation

$$NaNO_2 + 2HI = NaI + I + NO + H_2O$$

and then measuring the liberated iodine by means of arsenious acid solution. As the nitric oxide produced immediately reacts with oxygen, thus forming more nitrous acid, it is essential that the first part of the process should be performed in absence of air. This is accomplished by bubbling carbon dioxide through a first flask containing 2 g. of KI in 50 cc. of water, then through a second flask containing 10 cc. of normal H_2SO_4 and finally through a third connected flask containing the nitrite to be determined. After all the air has been displaced, the tube of the first flask is lowered and the solution in it is driven over into the second flask by the current of carbon dioxide; then in the same way the liquid in the second flask is passed into the third one, then without the introduction of air, 10 cc. of 20 per cent ammonium carbonate solution are put into the last flask and the titration is made with N/70 arsenious acid. The author shows that the results are very accurate, and evidently the method will be a useful one.—*Comptes Rendus,* **167**, 366. H. L. W.

5. *The Volumetric Estimation of Zinc by Acidimetric Titration.*—To apply this method of R. HOWDEN the zinc should be present as chloride and the solution should be free from ammonium salts, as well as from the salts of other heavy metals. A sulphuric acid solution does not give good results. The free acid is driven off by evaporation to small volume, then the liquid is diluted to 20 cc., a drop of methyl orange solution is added and the liquid is carefully neutralized with decinormal caustic soda. As zinc chloride is neutral to methyl orange, this is easily done. A few drops of phenolphthalein solution are added and the acid in combination with the zinc is titrated with the caustic soda solution. Towards the end of the titration the liquid should be heated to boiling, and the end of the process is indicated by the persistence of a pink color after boiling. The alkali may be standardized by means of pure zinc. The precipitate of zinc hydroxide does not interfere, the end-point is perfectly sharp, and experiments have shown that perfectly concordant results can be obtained.—*Chem. News,* **117**, 322. H. L. W.

6. *Diffusion of Light by Gases.*—In a recent paper by CH. FABRY it is shown that a number of important optical phenomena, occurring in nature, may be explained on the hypothesis that they are due primarily to the diffusion or scattering of light by the molecules of gases in a highly attenuated state. In order to distinguish between the scattering of light by particles of appreciable size on the one hand, and by gaseous molecules on the other, advantage is taken of the following differentiating characteristics. (*a*) Light diffused by a gas is polarized while that scattered by particles which are large in comparison with the wave-length is not polarized. (*b*) The distribution of intensity in the spectra of the diffused light will not be the same for systems of large and of small particles when the spectrum of the incident light embraces a wide range of wave-lengths

(such as the solar spectrum) and when it is kept, of course, invariable in the two cases. As Lord Rayleigh has shown, the coefficient of diffusion varies inversely as the fourth power of the wave-length, for scattering by gas molecules. In this case, the shorter wave-lengths will predominate in the diffused light. For relatively large particles the composition of the scattered light will depend upon the specific properties of the material of the particles. In general, the violet radiations will be absorbed to a greater degree, and hence less diffused, than the red rays. In this case spectrophotometric observations on the scattered light would furnish valuable information concerning the nature and identification of the diffusing matter. Considerations of the kind just outlined enabled Fabry to derive suitable formulae and to obtain, with their aid, the following interesting theoretical results.

Consider a cubic meter of air, under standard conditions of pressure and temperature, when illuminated by the sun on a clear day in summer. In a direction at right angles to the incident beam the intensity of the diffused light is found by computation to be 0·062 "candle." A volume of 16 cubic meters of air would give one candle. The mean spherical intensity is about 0·08 candle per cubic meter. If the air in a hall, having a volume of 1000 cubic meters, could conserve the luminosity that it has in full sunlight it would give an intensity of 80 candles.

Comets exhibit two spectra, one of bright lines, and another of the continuous type which is supposed to be scattered sunlight. Assuming the latter to be due to gaseous molecules it is shown that the density of the tail of the comet would be of the order 10^{-11}, even when the tail has a thickness as small as ten times the diameter of the earth. The density just given is about the same as that of the residual gas in the highest vacua obtained by experimental processes.

If the light of the nocturnal sky were due to diffusion of sunlight by hydrogen gas then the density would have to be of the order 10^{-14}. This is an extremely high degree of rarefaction for, under the circumstances, one gram of hydrogen would fill a cube measuring ten kilometers along an edge. The mean free path of a molecule would be 1600 kilometers, and a cubic millimeter would contain only 300 molecules.

The density of hydrogen in the solar corona would decrease very rapidly from $6{\cdot}5 \times 10^{-9}$ near the surface to 10^{-10} at a distance from the surface equal to the sun's radius. Accordingly, it is not difficult to see how comets may pass through this attenuated atmosphere without suffering appreciable perturbations.

The last section of the paper deals with the influence of the Doppler-Fizeau effect called into play by the rapid motion of gaseous molecules. It is shown that fine dark lines would be filled in, and thus obliterated, by the combined effects of diffusion of light and of molecular agitation. This is the first satisfactory explanation of the observed fact that the Fraunhofer lines are entirely absent from the continuous spectrum of the solar corona. —*Jour. d. Phys.*, **7**, 89, 1917. H. S. U.

7. *Direct-Reading Density Balance for Solids.*—When great precision is not required, the density of a given liquid may be obtained at once and without calculation from the scale reading of a suitable hydrometer. On the other hand, the evaluation of the density of a solid by the ordinary method of hydrostatic weighing is a much slower process since it involves the experimental determination of two numbers and the calculation of the ratio of these numbers. The disadvantages of the latter method are entirely avoided by employing a balance of the form devised by Jules Gasnault. The sphere of applicability of this balance is the precise analogue of that of the hydrometer for, with a fixed calibration, it gives direct-readings for solids having densities lying between certain limits. Just as a set of hydrometers is required for liquids having a wide range of densities so also in the case of the new balance different scales and other modifications would have to be introduced to cover extended intervals of density.

The balance in question and the manner of using it may be briefly described as follows: An assay balance has the right-hand portion, say, of the beam prolonged by a rod of some light metal such as aluminium. A portion of this extension to the right of the right-hand scale-pan is graduated in such a way as to indicate densities directly. The specimen of solid (which must sink in the liquid employed) is first placed in the right-hand pan in air. It is counterpoised by an equivalent tare placed in the left-hand pan. The tare is conveniently made up from a cheap set of weights, the smallest weight having a mass of one gram. The fine adjustment is effected by sliding a rider along the left-hand segment of the balance beam. The moment μ of all the vertical forces due to the parts of the tare is then (approximately) equal to $V.D.a$, where $V =$ volume of solid, $D =$ density of specimen, and $a =$ horizontal distance from the central knife edges to the knife edges supporting the right scale-pan. The solid under investigation is next suspended by a fine wire of negligible mass from the prolongation of the beam. This wire has an open loop at the upper end so that it can be slid along the beam extension. The solid is immersed in an appropriate, inactive liquid contained in a rectangular trough the long axis of which is roughly parallel to that of the beam. The adjustment consists, therefore, in displacing the loop along the beam-extension until the beam is again horizontal (as it was both before and after the specimen and tare were counterpoised). The moments now satisfy the condition $\mu = V\ (D - d)\ b$, where

d = density of liquid, and b = horizontal distance from the central knife edges to the plane of the loop. Consequently

$$V.D.a = V\ (D-d)\ b \text{ or } D = [b/(b-a)]d.$$

By taking values of D which increase in arithmetical progression and $d = 1$ (for water, say) the scale can be graduated from the values of b derived from the last equation. After the beam-extension has been thus calibrated the unknown density of a given solid may be read off directly from the scale. Obviously, the scale divisions will be smaller near one end of the range of feasible densities than the other. In general, however, the same lack of uniformity affects hydrometers. The average time required for the determination of the density of a single sample is said to be about two minutes. For lack of space the preceding account is intended to be suggestive rather than complete.—*Jour. d. Phys.*, 6, 291, 1916. H. S. U.

8. *Influence of the Finite Volume of Molecules on the Equation of State.*—The fact that the simple equation $pv = NK\theta$ does not represent accurately the behavior of real gases is explained on the grounds that the theoretical derivation of the ideal gas equation takes into account neither the forces of cohesion between the particles nor the finiteness of the volume of the molecules. Although the equation of van der Waals involves both of these factors, nevertheless it does not represent the observed phenomena to a sufficiently high degree of accuracy. "In all subsequent modifications of this equation (Clausius, Dieterici, or D. Berthelot), the changes which have been proposed all relate to the influence of the cohesive forces; the part of the argument dealing with the finiteness of the molecular volumes is generally left untouched." Accordingly the authors of the last sentence, MEGH NAD SHAHA and SATYENDRA NATH BASU, have published a paper in which an attempt is made to correct for the volume of the molecules.

Boltzmann's equation $S = K \log W + C$ is taken as fundamental. S = entropy, K = Boltzmann's gas-constant, and W = probability of the state. Neglecting (for the time being) the influence of internal forces, it is shown that the probability that a number N of molecules, originally confined within the volume v and possessing finite volumes, shall be contained in a volume V is given by

$$W = \frac{V}{v} \cdot \frac{V-\beta}{v-\beta} \cdot \frac{V-2\beta}{v-2\beta} \cdots\cdots \frac{V-(N-1)\beta}{v-(N-1)\beta},$$

where $\beta = 8 \times$ (volume of a single molecule). Combining the preceding equations with the constant-energy relation

$$\frac{\partial S}{\partial V} = \frac{p}{\theta}$$

it follows that

$$p = -\frac{R\theta}{2b}\log\frac{V-2\beta}{V}$$

where $R = N\ K$. Finally (after Dieterici) the influence of the internal forces is taken into account by introducing the Napierian base to the power $-a/R\theta v$. Accordingly, the critical volume v' and the gas-constant K are given respectively by

$$v' = \frac{2\mathrm{e}}{\mathrm{e}-1}b = 3{\cdot}166b$$

and

$$K = \frac{R\theta'}{p'v'} = 3{\cdot}513.$$

The equation of van der Waals leads to $v' = 3b$ and $K = 8/3 = 2{\cdot}67$, and that of Dieterici to $v' = 2b$ and $K = \mathrm{e}^2/2 = 3{\cdot}695$. For the simpler gases, the value of K deduced by the authors is in better accord with the experimental data than Dieterici's value $\mathrm{e}^2/2$. For oxygen, nitrogen, argon, and xenon the experimental values of K are 3·346, 3·53, 3·424, and 3·605, respectively. The limiting volume b equals $v'/2$ according to Dieterici's equation, and $v'/3{\cdot}16$ according to the formula of the present paper. The latter ratio is in better agreement with $v'/4$ which is the approximate value obtained by extrapolation of the Cailletet-Mathias mean density line to $\theta = 0°$ absolute.—*Phil. Mag.*, **36,** 199, 1918. H. S. U.

II. Geology and Natural History.

1. *Geology and paleontology of the Raton Mesa and other regions in Colorado and New Mexico. Part I. Geology of the Raton Mesa and other regions in Colorado and New Mexico;* by W. T. Lee. *Part II. Fossil floras of the Vermejo and Raton formations of Colorado and New Mexico;* by F. H. Knowlton. U. S. Geol. Surv., Prof. Paper 101, 450 pp., 103 pls., 16 text figs., 1917.—This very important memoir not only establishes in detail the geology and paleontology of the area investigated, but is the most comprehensive work so far published toward the solution of what strata in the Rocky Mountains shall be referred to the Cretaceous and to the Eocene, and as to which one of the several unconformities shall be taken as the dividing line between the Mesozoic and Cenozoic eras. There is also a great deal of valuable invertebrate paleontology by Doctor Stanton scattered throughout the first half of the volume.

Lee is disposed to give full value to the physical phenomena and all the more so when, as in this case, the evidence of the plants and dinosaurs leads to opposite chronogenetic references. He therefore depends most on diastrophism and says that the Cretaceous "was a period of inaction" or "quiescence" while the Cenozoic was one of violent crustal movements, "and of consequent changes in climate and life." Accordingly, "in the area described in this paper the first unconformity above rocks of undoubted Cretaceous age marks the proper Cretaceous-Tertiary boundary." In this respect he "differs from some geologists, who seem to place emphasis on the culmination rather than on the inception of orogenic movement." It is true that in the area studied the thin Cretaceous deposits indicate a time of "quiescence," but in western Wyoming and Montana, where the equivalent formations are thick with the thickness and coarseness of the rocks increasing upward in the section along with the obliteration of the Cretaceous sea, this evidence tends to show that earth movement had already begun long before the close of the Cretaceous. The unconformity represents a "lost interval" whose duration is not known, but some portion of it Lee holds must be of Tertiary time, and "Tertiary rocks may yet be found that are older than those of the Raton formation." "The unconformity seems to represent all of Laramie time and perhaps some of late Montana time, for rocks of Montana age have been eroded away." The differential uplift and erosion he thinks must have been more than 4,000 feet.

Then Lee goes on to point out that this diastrophism "resulted in the withdrawal of the Cretaceous sea and the upheaval of mountains in its place." Also that these movements "naturally caused great changes in climate, and therefore in plant and animal life." We shall see later on, however, that there was no appreciable change in the climate nor among the dinosaurs at the time of this earliest earth movement, here classified as of Cenozoic time, and yet the flora of the Raton was decidedly different from the older one, in fact, so much so that Knowlton easily distinguishes the floras of the Vermejo from those of the Raton. It was not the climate (temperature and moisture) that brought about this change, as the floras are of swamp habitats and mild temperatures, nor the physiography, for the dinosaurs are at their best in formations here classified by Lee as of early Eocene time.

The Vermejo formation of late Cretaceous time, and in the main of fresh-water origin, has a flora of Montana age. It is a distinct and older flora than that of the Laramie of the Denver basin. On the other hand, the invertebrates found in the Vermejo of the Canon City field are approximately equivalent in age to those of the Fox Hills of the Denver basin.

The Vermejo and the Raton are superposed formations and are separated by the unconformity described above. The Vermejo and Trinidad formations, which are older than the Laramie, have a flora of 108 species, and of these 61 are here described as new. To attain these results, Knowlton had to revise all the related floras, because many of the old species were insufficiently known as to their characters and geologic position, and in addition previous authors more often misidentified their specimens.

Of the Vermejo flora, but 4 species continued to live in Raton time, and 12 of its genera here fail of representation. Not only this, but the former flora is strikingly different in composition. In the Raton, the palms are abundant, but they are rare in the Vermejo, while the conifers, common in genera and species in the latter formation, are unrepresented in the former. The plantains, common in the Raton, are doubtfully present in the Vermejo, while the magnolias, exceedingly common in the former flora, are absent in the latter one. Accordingly, Knowlton concludes that the Vermejo flora "is distinctly Montana in aspect" and "distinctly different" from that of the younger Laramie one. Compared with the Raton flora, he says "there is no real relationship between them."

The Raton flora has its closest affinity with the Denver flora, which also lies above the unconformity, there being 34 species in common. "Put in another way it means that 43 per cent of the Raton flora having an outside distribution is found also in the Denver: and as the total published Denver flora embraces 98 species, it follows that more than one third of these occur in the Raton formation." With the Wilcox formation of the Atlantic and Gulf Eocene (a strand flora that has 330 known forms), there are 29 species in common, while 38 "are either identical with or very closely related to Wilcox species." On the other hand, "of the 80 Wilcox species having outside distribution about 45 are common to the Raton, Denver, or Fort Union, and not one is known from the Cretaceous anywhere." Accordingly Knowlton correlates the Raton with the Wilcox, while E. W. Berry regards it as "of Eocene age and slightly older than the Wilcox." To refresh the reader's memory, it should be said that the Wilcox is underlain by the Midway formation and overlain by the Claiborne near the top of the Eocene. Finally Knowlton concludes that the Raton, Arapahoe, Denver, and Dawson "are Tertiary (Eocene) in age." The climate of the Raton flora with its figs, cinnamons, breadfruit trees, magnolias, and sweet-gums, "was at least warm temperate [and moist], perhaps not unlike that now prevailing in South Carolina and Georgia. In fact, there is no evidence that the physical and climatic conditions had changed from those of Vermejo time."

To emphasize the importance of the unconformity in the Rocky Mountains between the Mesozoic and Tertiary formations, Knowlton states: A restudy of these floras shows that there are about 350 known species of plants in the higher Cretaceous, while in the succeeding Eocene floras there are more than 700 known forms." Of all these species, he says but "about 21 or 22 species are known to cross the line of this unconformity throughout the whole areal extent, from New Mexico on the south to the Canadian border on the north."

The reader should also be reminded that in most of these Eocene formations of the Rocky Mountains occur dinosaur bones of unmistakable Cretaceous types. In other words, that while the moist and warm climate is said to have prevailed, the dinosaurs, supposed to be more sensitive to environmental change, did not die out or change markedly, while the plants underwent not only a specific but as well a distinct generic change! How these two sets of facts are to be harmonized is as yet not at all clear. Seemingly the dinosaur evidence still negates the interpretation placed on the importance of the unconformity between the Vermejo and Raton and related formations. On the other hand, the student of marine invertebrates is also puzzled to see why the earliest Eocene floras of the Rocky Mountain area, with their Cretaceous dinosaurs, are not markedly those of the oldest Tertiary but are decidedly those of the Middle Eocene or Wilcox time. In this connection the student will not fail to notice that there is a very long time break between the Cretaceous and the Midway of the Atlantic-Gulf area. Not a single marine invertebrate other than Protozoa is known to cross this stratigraphic line, and these animals are supposed to be less subject in their evolution to climatic change than are the land-living ones. Yet the highly specialized dinosaurs of the Cretaceous are said to have continued alive into the Middle Eocene with not more than specific change. These are some of the facts that still fail of being harmonized into an agreeable chronogenesis, an agreement as to when the Mesozoic closed and the Tertiary began in North America.

The paleobotanists have seemingly gone as far toward the solution of this vexed problem as their material permits, and it amounts to more than 1000 species from a continent-wide area. On the other hand, one wonders if a restudy of the dinosaurs in the light of the present far more detailed stratigraphy would show that our biologic and geologic knowledge of them is faulty and that they too have undergone a specific and generic evolution comparable to that of the plants. That the dinosaurs may have lived on into Eocene time in the Cretaceous of the Rocky Mountain area is understandable when we are told by the paleobotanists that there was no appreciable climatic change during the close of the Mesozoic and early in Tertiary time. Yet the flora changed completely and it is in this that our difficulties lie. The climatic and as well the physiographic change came after Raton-Denver-Fort Union, etc. time, as is seen in the presence of the tillites in southwestern Colorado, and with the introduction of this change the dinosaurs vanished. Finally, we need more light as to the length of the "lost interval" between the Cretaceous and the Midway of the Atlantic border, and if possible, correlations based on animal remains between the older Tertiary of the Atlantic-Gulf area and those of the Cenozoic of the Paris basin.

The latter comparison might then bring into close association the chronogenetic evidence to be derived from our earliest Eocene mammal faunas. CHARLES SCHUCHERT.

2. *Geology of Missouri;* by E. B. BRANSON. Univ. of Missouri Bulletin, vol. **19**, No. 15, 172 pp., 5 pls., 59 text figs., 1918. —This good and up-to-date report is written for the educated man, for those in search of useful natural resources, and for geologists who want quickly to get at the broader and more general stratigraphy of the state. There are also many little maps in the report giving the outcrops of the thicker formations in generalized form, along with the paleogeography for the state at the time of the deposit illustrated. As the type is small, there is a great deal more information in the report than the number of pages indicates.

In reading the work one soon comes to realize how different the stratigraphic interpretation of to-day is compared with that of twenty years ago. Then there were universal seas, slowly retreating from the North American continent: now the formations are seen to be local, the sequence much broken and the seas periodic in their advance over and retreat from the continent. Under these circumstances the ancient geography looms larger, and efforts are being made by many to visualize this paleogeography. This Missouri report is one that should be in the hands of all working and teaching geologists. C. S.

3. *Early Mesozoic physiography of the southern Rocky Mountains;* by WILLIS T. LEE. Smithson. Misc. Coll., vol. 69, No. 4, 41 pp., 4 pls., 1918.—The principle of paleophysiography is here used in connection with that of diastrophism in determining the chronogenesis of Triassic and Jurassic time in the Rocky Mountain area. To determine the physiography of Triassic time, the author takes up a rapid study of Pennsylvania-Permian time and finds that there was an "ancestral Rocky Mountains" in the southern part of the United States. In late Triassic times other mountains were raised along the Pacific coast and a shallow basin like that of the present Mississippi valley was formed to the east of them. Some of the debris of these western mountains was laid down in the shallow valley as desert sands in Arizona, Utah, and western Colorado. Finally, early in Jurassic time the peneplain that had long been developing—the La Plata peneplain—was completed, and later invaded, first in the south by the La Plata desert sands and from the northwest by the Jurassic sea. On these grounds, the author is disposed to regard the marine deposits as of very late Jurassic age, recognizing, however, that the ammonites are not in harmony with his views.

The paper is strikingly original, and whether one agrees with the author's conclusions in regard to the age of the marine Jurassic deposits (Sundance) or not, it is a praiseworthy application of an old principle in the elucidation of medieval geologic history. C. S.

4. *Notes on the geology of the Glass Mountains;* by J. A. UDDEN, and *Geologic exploration of the southeastern Front Range of Trans-Pecos Texas;* by C. L. BAKER and W. F. BOWMAN. Univ. of Texas Bull. No. 1753, 177 pp., 12 pls., 1 map, Sept. 20, 1917 [July 1918].—During the past several years, evidence has been coming forward that there is a distinct and clearly separable Permian system in America, with the clearest testimony in the southwestern portion of the United States. In this report are described the many formations, along with their structure, that compose the Pennsylvanian and Permian systems of the Trans-Pecos area of Texas. Baker and Bowman also point out a time of mountain making, one in the midst of the rock sequence, that seemingly will divide the series into two systems, the Pennsylvanian with a thickness here of about 4800 feet and the Permian with 9640 feet of strata. It is further interesting to note that in this series of strata there are many species of new ammonids that will soon be described by Doctor E. Boese. C. S.

5. *The geology of Vancouver and vicinity;* by EDWARD MOORE JACKSON BURWASH. Pp. 106, 24 text figs., 3 maps, Chicago, 1918 (University of Chicago Press, $1.50).—In this valuable publication are described the geography, physiography, and geology of an area of about 70 by 80 miles around the city of Vancouver, British Columbia. Much attention is given to the igneous masses and their effect as mineralizers upon the rocks intruded. The work is profusely illustrated. C. S.

6. *Geology of the northern end of the Tampico embayment area;* by E. T. DUMBLE. Proc. Calif. Acad. Sci., 4th ser., **8**, No. 4, pp. 113-156, pls. 3-6, 1918.—Since 1890, northwestern Mexico has been a field much exploited for petroleum. Due to the work of the author and others, the geology of this area is now well known in its broader outlines, and it is here described. The formations treated are those of late Mesozoic and Cenozoic times. C. S.

7. *Bidrag til Finmarkens geologi;* by OLAF HOLTEDAHL. Norges Geol. Unders., No. 84, 314 pp., 21 pls., 38 text figs., 2 geological maps, 1918.—In this book the author describes the geology of the most northern district of Norway, and on pages 299-314 the information is presented in condensed form in English. Dahll's Gaisa system is abandoned, as it contains "the most heterogeneous things," while the Raipas has been much restricted. To the south is the old pre-Cambrian nucleus and upon its ancient peneplaned surface was laid down the marine Lower Cambrian. These strata, 230 meters thick, are still generally unfolded, and also the later Ordovician sandstones, which are over 2000 m. thick and are followed by more than 4000 m. of dolomites. At a later date came the great Caledonian overthrusts. The tillites described by Reusch in 1890 and generally assumed to be of Cambrian age are shown by Holtedahl to be

of either middle or upper Ordovician time. As this and other information is of the greatest interest to American geologists, the author will present it himself in a paper soon to appear in this Journal. C. S.

8. *Notes on Operculina-rocks from Japan, with remarks on "Nummulites" cumingi Carpenter;* by HISAKATSU YABE. Sci. Repts., Tohoku Imperial Univ., Japan, 2d ser. (Geology), vol. **4**, No. 3, pp. 105-126, pl. 17, 1918.—This good article also describes the geographical and geological distribution of the foraminifer *Operculina.* C. S.

9. *Papers from the Department of Marine Biology of the Carnegie Institution of Washington.* Vol. **9**, 362 pp., with 105 plates and maps, 4to. Washington, 1918 (Carnegie Institution).—The ten papers which this bulky volume comprises relate mainly to corals and the formation of coral islands

The Ecology of the Murray Island Coral Reef (pp. 1-48; pls. 1-19) by ALFRED G. MAYER is a study of the principal conditions influencing the growth and distribution of corals near the northern end of the Great Barrier Reef of Queensland, Australia. Some forty species of corals occur upon this reef, and the factors which determine the distribution of the various species were found to be, in order of their importance, temperature, silt, effects of moving water, and struggle between species. Many experiments are described by which the vitality of the different species was tested.

To determine the rate of growth the writer carefully measured some of the identical coral heads at Thursday Island which had been measured and photographed by Saville-Kent twenty-three years earlier. The results show that while large reef corals may increase nearly two inches in diameter per year, other forms may entirely cease growing after reaching a certain size. The average yearly growth of about one inch agrees fairly closely with the measurements obtained by Gardiner on species in the Indian Ocean and is considerably greater than the rate of growth of the Florida reef corals as carefully measured by Vaughan.

Three papers are by THOMAS WAYLAND VAUGHAN. The first consists of an annotated list of shoal-water corals from Murray, Cocos-Keeling, and Fanning Islands, beautifully illustrated by 74 large plates. The second is a description of the shoal-water bottom samples from Murray Island, Australia, and comparisons of them with samples from Florida and the Bahamas. The relative importance of the various groups of organisms in the formation of shoal water deposits is explained, with a discussion of the physical agencies concerned in limestone formation. The third summarizes the data from long periods of observation of the temperature of the Florida coral reef tract.

JOSEPH A. CUSHMAN lists the foraminifera of Murray Island, with figures of new species, and MARSHALL A. HOWE the calcareous algæ; while a list of the diatoms is contributed by Albert Mann.

Daily determinations of the salinity of the ocean water at Fowey Rocks, Florida, are tabulated by Richard B. Dole and Alfred A. Chambers. Roger C. Wells describes the solubility of calcite in sea-water.

The final paper, by L. R. Casey, discusses the Gorgonaceæ as a factor in the formation of coral reefs and shows that over large areas in the region of the Tortugas Islands this group of corals is far the most important element in the formation of reef limestones. He estimates that each acre of the reef is covered by an average of over five tons of living gorgonians, about one-fifth of which are killed annually. This means a yearly contribution of about one ton of limestone, as spicules, per acre.

The entire volume constitutes a most important contribution to our knowledge of coral islands and reefs and the organic and physical agencies concerned in their formation. W. R. C.

10. *Forced Movements, Tropisms, and Animal Conduct;* by Jacques Loeb. Pp. 209, 42 figs. Philadelphia and London, 1918 (J. B. Lippincott Co.).—In this first volume of a series of Monographs on Experimental Biology to be written by American investigators the author elaborates a theory which he proposed many years ago to account for the movements of animals on a purely chemico-physical basis. He aims to show that the conduct of animals and plants depends upon movements forced upon them as a result of reactions to stimuli of the various forms of energy and that by the quantitative methods of the physicist the nature of the response to these stimuli is often mathematically predictable. The symmetry of the animal body, with its paired sense organs in the higher forms, causes the animal to respond to stimuli in a purely mechanical way regardless of whether or not such actions are purposeful. The effects of each of the forms of energy which may act on the organism are explained, with a brief discussion of instincts, memory images and tropisms, leading to the conclusion that the direction of motion is forced upon the organism, and that what passes for free will is essentially a combination of tropistic reactions and memory images.

The book provides many interesting examples of animal behavior which can be explained without the aid of vitalism, and while the reader may not accept the author's extreme mechanistic theory he cannot fail to derive a stimulus for further inquiries concerning the nature of the vital energy. W. R. C.

11. *The Human Skeleton; An Interpretation;* by Herbert Eugene Walter. Pp. xv, 214, with 175 illustrations. New York, 1918 (The Macmillan Co.).—The evidence of man's lowly ancestry as indicated by his framework is cleverly summarized in this entertaining book for the general reader. In

the author's skillful hand what would commonly pass for an insignificant structural detail or minor imperfection becomes not only a vivid witness of an adaptation from an ancestral structure but a clue as to what it may in later generations become.

The title is the only dry part of the book, and the sympathetic reader will doubtless agree with the author that "the human skeleton, so often associated unthinkingly with the gruesome symbolism of death, is actually a very wonderful and animated piece of architecture, full of beauty and inspiration for one who looks upon it with a seeing eye and considers its agelong evolution with a comprehending and sympathetic mind."

W. R. C.

12. *Botanical Abstracts,* vol. **1**, No. 1, September, 1918.—This new monthly periodical intends to furnish "abstracts and citations of publications in the international field of botany in its broadest sense." Paleobotany is included, along with botanical education. There will be two volumes per year, each with about 300 pages, and the price in the United States is $6.00 a year. The editor-in-chief is Professor Burton E. Livingston, who is assisted by a board of fifteen men. The abstracts are classified under headings and the authors follow alphabetically. In genetics the editor does not limit himself to botany, but includes papers treating of animals.

III. Miscellaneous Scientific Intelligence.

1. *My Reminiscences;* by Raphael Pumpelly. Vols. I and II, pp. 844, many illustrations, 1918 (Henry Holt and Co.).—For profit and amusement during the evenings of this winter, this book is recommended. It abounds in humor, good stories, and anecdotes, and in descriptions of most trying situations and tender family cares. How the author built the first smelter of ores in Arizona in 1860, and was chased by the Apaches over the deserts into California; how he introduced the use of gunpowder in mining operations in Japan in 1862; how he was among the first to locate the iron mines of the Menominee and Gogebic iron ranges—all is told in a fascinating way. With Pumpelly the reader travels intimately all over the northern hemisphere and is introduced to the conditions of the wilderness and the civilized areas not only in America, but in Japan, China, Siberia, Turkestan, Egypt, and Corsica, as well. Student days at the mining school of Freiberg, Germany, between 1856 and 1859, when Professor Cotta was there, are full of interest to all teachers of geology and to mining engineers. Born at Owego, New York, in 1837, Pumpelly produces these two volumes in 1918, in the spirit of a young man. Get acquainted with him, and let him tell you the story of his pet Corsican mouflon! C. S.

2. *Publications of the Carnegie Institution of Washington.*—Recent publications of the Carnegie Institution are the following (see earlier, vol. **45**, p. 483):

No. 213. Papers from the Department of Marine Biology of the Carnegie Institution of Washington. ALFRED G. MAYER, Director. Volume IX. Pp. 362; with plates and maps. This important quarto volume is noticed on an earlier page in this number.

No. 227. Contributions to Embryology. Vol. VII, Nos. 20, 21, 22, 23. 4to. Pp. 134; 16 pls., 9 figs.

No. 245. Interpolation tables or multiplication tables of decimal fractions; by HENRY B. HEDRICK. Pp. ix, 139.

No. 246. Albany Zone Catalogues for the epoch 1900; prepared at the Dudley Observatory, Albany, N. Y.; by LEWIS BOSS. These include catalogue of 8276 stars between 20° and 41° of south declination. Pp. xxviii, 249; catalogue of 2800 stars between 2° of south and 1° of north declination; by ARTHUR J. ROY; etc.

No. 253. Dictionary and Grammar of the Language of SA'A and Ulawa, Solomon Islands, with appendices; by WALTER G. IVENS. Pp. 249, 11 pls. and frontispiece.

No. 260. Studies on solution in its relation to light absorption, conductivity, viscosity, and hydrolysis. A report upon a number of experimental investigations carried out in the laboratory of the late Professor HARRY C. JONES; compiled by PAUL B. DAVIS. Pp. 144.

No. 261. Food ingestion and energy transformations, with special reference to the stimulating effect of nutrients; by FRANCIS G. BENEDICT and THORNE M. CARPENTER. Pp. 355.

No. 271. Contributions to Embryology. Vol. VIII, Nos. 24, 25, 26. 4to. Pp. 198; 10 pls., 21 figs.

3. *Carnegie Foundation for the Advancement of Teaching;* by HENRY S. PRITCHETT, President. Bulletin No. XII; prepared by CLYDE FURST and I. L. KANDEL. Pp. xi, 85. New York City (576 Fifth Avenue).—This bulletin deals with pensions for public school teachers, a subject to which the Foundation has given close study for a number of years. It shows that the great majority of the systems in use are socially unjust and financially unsound. It is gratifying to learn, however, that reforms are being instituted, conspicuously in Massachusetts, New York City, Illinois, and Pennsylvania. There is also presented, as an improvement upon any pensions for teachers now in existence, a suggested system of retiring allowances for teachers in the State of Vermont, based upon the most complete actuarial and financial data ever collected for such a purpose.

Obituary.

Charles Richard Van Hise, College president and geologist, died on November 19, 1918, of meningitis following an operation on his nose. He leaves a wife and three daughters. Van Hise was born at Fulton, Wisconsin, in 1857, and his three degrees in course were taken at his alma mater, the University of Wisconsin, over which he has presided since 1903. He was honored with the LL.D. degree by Chicago, Yale, Harvard, Williams, and Dartmouth. For twenty years, most of his life has been devoted to research and teaching in geology, along with the geologic development of the Lake Superior iron areas. In North America he has long been the leader in pre-Cambrian geology, more especially in the Lake Superior region, and his bibliography has more than eighty titles, many of which are thick volumes.

Van Hise is probably best known among geologists for his far-reaching Treatise on Metamorphism, though some hold that his most original and valuable work is his Principles of North American Pre-Cambrian Geology. As a member of the National Conservation Commission since 1908, he has been most active in conserving the natural resources of our country, and his book The Conservation of the Natural Resources of the United States, will long be a standard of reference. He also is the author of Conservation and Control; a Solution of the Trust Problem of the United States. In 1912 he was chairman of the arbitration board to adjust the labor disputes between the Brotherhood of Locomotive Engineers and the eastern railways. Later he reported for the Government in regard to the probable future movements of the Panama slides. During the great war he was, among other things, a member of the advisory board to the U. S. Food Administration. He had recently returned from a visit to Great Britain and France, made by invitation of the Ministry of Information of the British Government; on November 8 he delivered a memorable address on "A League of Free Nations."

Pumpelly has recently said that Van Hise was the best of fellow travellers, and that he was "charged with mental lightning." In the National Academy he was an active member, and one whose judgment was highly valued.

Professor Pierre de Peyster Ricketts, for many years a member of the Columbia University faculty in the departments of assaying and analytical chemistry, died on November 20 in his seventy-first year.

Professor George F. Atkinson, since 1896 the head of the department of botany at Cornell University, died on November 14 at the age of fifty-four years.

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FOURTH SERIES

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[FOURTH SERIES.]

Art. V.—*On the Paleozoic Formations of Finmarken in Northern Norway;* by Olaf Holtedahl.

Far beyond the Arctic Circle, between latitudes 69° and 71° N., lies the Norwegian district of Finmarken. It is the most northern prominence of the Scandinavian peninsula. The present Finmarken is only a part of the old Finmork (the home of the Finns or Lapps) which originally also embraced the land to the east.

Except in the most western part of Finmarken, where there is a continuation of the wild and rocky land of the Norwegian mountain zone farther to the south, most of this district is relatively low, from 300 to 500 meters above sea-level. The most typical landscape is the undulating plain, with here and there deeply incised river valleys. In the valleys birches are common, along with a few pines, but on the high plains grow only dwarf bushes and mosses.

Though a good many geologists have travelled in Finmarken and many geological details have been published, yet very little has been known as to the general geological structure and age of the rocks. Tellef Dahll in 1867 tried to put the different rocks into order and divided the sedimentary series, whose dominating rocks are sandstones, into an older *Raipas* and a younger *Gaisa* system; the former having dolomites as a typical member.

As to the age of these series, which are very unlike anything known from more southern parts of the Scandinavian Peninsula, opinions have been very divergent. The earlier investigators have generally thought them to be of fairly recent date, belonging to the Devonian or still younger formations, while in more recent time these "sandstone formations of Finmarken" have commonly been regarded as being older, possibly a northern parallel to the arkoses and sandstones of the "Sparagmite division" of southern Norway, a thick series of rock coming, in as far as we yet know, conformably below the Lower Cambrian *Holmia*-shale.

A rock of Finmarken that has gained a wide reputation is the tillite, found in 1890 by Reusch at different places in the Varangerfjord. The age of this tillite, found in Dahll's Gaisa beds, is generally stated in text-books to be Cambrian; this fixing of the age, however, had no real basis since no fossils had been found and the relation of the formations to those of the more southern parts of the Scandinavian Peninsula were not determined.

During four short summer seasons (1914-1917) the writer has worked for the Geological Survey of Norway in this northern land and has obtained results that may also be of interest to American stratigraphers.[1]

Table of Finmarken Formations.[2]

Late Silurian time.
- Overthrusted, metamorphosed rocks and intrusive masses of the Caledonian deformation.

Possible late or middle Ordovician time.
- Tillite-bearing sandstone series. *Bossekop series* of the Alten district. Thickness 200-500 meters. The *Bossekop and Mortensnes tillite* has a thickness of about 10 meters, the *Bigganjargga tillite* of 2-3 meters.
- Unconformable contact.

Lower and basal Ordovician time.
- Sandstones and shales with dolomites:
  - *Varanger series.* Thickness over 3000 meters. Above are impure and interbedded dolomites, grey and red sandstones. Then a sandstone succession of about 2000 meters in thickness. Below, dark shales and thin-bedded sandstones. The *Raipas series* of the Alten district, containing large masses of lava and tuff, is thought to be the equivalent of the Varanger series.

[1] A complete account in the Norwegian language (with a short summary in English) has appeared in a paper entitled "Bidrag til Finmarkens geologi," Norges Geologiske Undersökelse, No. 84.

[2] As to Dahll's terms *Raipas* and *Gaisa*, the former has been retained for the volcanic sandstone-shale-dolomite series of the Alten district, while the latter could not be maintained as it was found to contain very heterogeneous things.

FIG. 1.

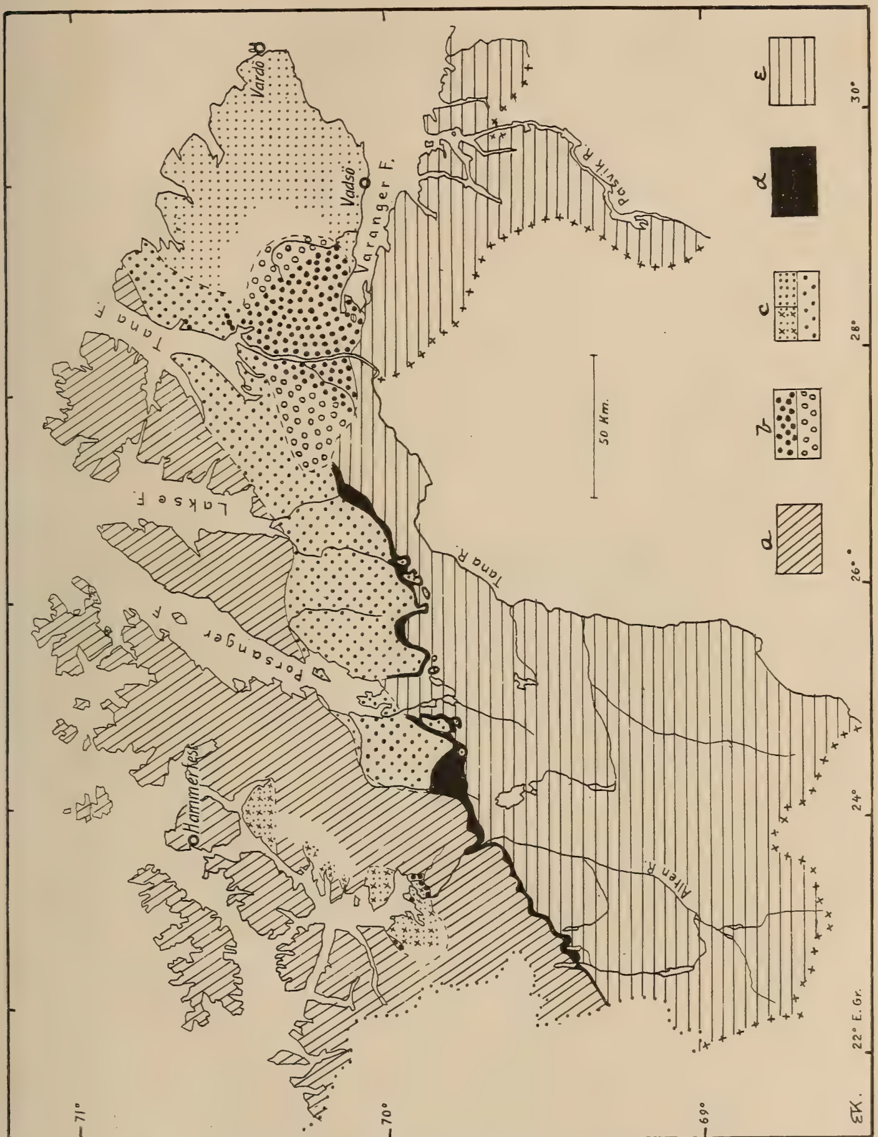

FIG. 1.—Geological map of Finmarken. *a,* metamorphic and intrusive overthrusted rocks of the Caledonian deformation. *b,* above, the tillite-bearing sandstones; below, the probable further distribution. *c,* the older dolomites and sandstones; above, the younger or Varanger series; in the west with volcanic rocks (Raipas); below, the older or Porsanger series. *d,* Lower Cambrian series of shale and sandstone with *Platysolenites.* *e,* pre-Cambrian rocks.

Porsanger series. Thickness between 500 and 1000 meters. Above is the Porsanger dolomite with intraformational conglomerates, about 100 meters thick. Below is the Porsanger sandstone, terminating upwards in shales.

Conformable contact.

Lower Cambrian time.

Dividals series or *Hyolithus zone.* Thickness about 240 meters. A series of shales and sandstones with *Platysolenites* and other fossils.

Great unconformity.

Pre-Cambrian peneplained floor. A complex of ancient rocks.

The distribution of the various formations is given in the map, fig. 1. The object of the present article is to tell about the relatively unaltered sedimentary series, and therefore the pre-Cambrian formations, and the metamorphic rocks of the Caledonian deformation, are not to be considered.

Lower Cambrian Shale and Sandstone Series with Platysolenites.

Lying unconformably upon the generally highly metamorphosed pre-Cambrian, which consists of hornblende schists, quartzites, gneiss, and granite, different in different districts, is found a not very thick series of Lower Cambrian green and reddish shale, alternating with sandstone beds. The thickness of this, the Dividals series, is about 240 meters. That is a very characteristic series, which the writer after having seen it inside the Altenfjord in 1914 announced in a preliminary paper[3] as being a continuation of the ''Hyolithus zone'' of the Swedish geologists, the ''Dividals series'' of K. Pettersen, who for many years worked on the geology of the Tromsö district, the Norwegian area to the southwest of Finmarken. In this series are known Lower Cambrian fossils, the bulk of which were found recently in the well known sections of Torneträsk of northern Sweden.[4] Fossils of this time have also since been found at different localities in Finmarken. A species of *Obolus* in badly preserved specimens was found in 1915 by the writer in a section on the Alten River (fig. 2) and in 1917 *Platysolenites antiquissimus* Eichwald was found at two different places farther to the east, south of the Porsanger-

[3] Norges Geologiske Undersökelse, Aarbok, 1915.

[4] See Guide Book No. 6, XI, Internat. Geol. Congress, Stockholm.

fjord, by J. Braastad, mining engineer, and by the writer. This fossil occurs about 120 meters above the pre-Cambrian rocks. The exact zoologic position of *Platysolenites* is, however, not yet determined, as nothing other than the slender crinoid-stem-like cylinders have been found. On the other hand, it seems fairly certain that it represents the stem, or possibly the arms, of a cystid. At any rate, in the whole of the Scandinavian Baltic

Fig. 2.

Fig. 2.—Canyon of the Alten River, 30 km. from the sea. Altitude from river to plain, 400 m. Photograph by Kr. Nissen.

region it is an excellent guide fossil to the oldest known fossiliferous zone, or the Lower Cambrian.

To the southwest of Finmarken, in the district of Tromsö Th. Vogt found in 1915 in the "Hyolithus zone," besides *Platysolenites,* other Lower Cambrian fossils, chiefly trilobites.

The Lower Cambrian series, except in its uppermost part, is almost undeformed and rests on the even or peneplained surface of the pre-Cambrian, a surface that now dips slightly toward the N. N. W., due to the Caledonian deformation. In the western part of Finmarken, the unaltered Cambrian, having here a thickness of 150 meters, is covered by the metamorphic thrust rocks of the West Scandinavian mountain range, just as it is further south along the eastern part of this range, while to the east we find the practically undisturbed stratigraphical sequence; and here one has the opportunity of studying the younger beds, which are of the type not known further south, that is, the *Finmarken facies.* I divide this younger series, consisting chiefly of sandstone or sandy shales, into two main divisions, an older dolomite-sandstone series, and a younger sandstone with tillites.

Older, Dolomite-bearing Sandstone Division of Finmarken.

Resting apparently conformably upon the Lower Cambrian series is a compact, very light-colored sandstone, consisting chiefly of quartz, yet with some grains of feldspar which are changed into kaolin. This rock belongs to a very thick sandstone series, which I have named the *Porsanger sandstone,* as it is well seen at the inner portion of the Porsangerfjord. The total thickness is at least 500 meters and probably more. Not all of this thickness is, however, compact sandstone, for especially in one horizon (probably 300 to 400 meters above the base) occur thinner bedded and darker sandstones, together with dark grey sandy shale. The surfaces of the thin-bedded sandstones have, through a thickness of many meters, exceedingly fine interference ripple-marks.[5]

In the upper part of the Porsanger series occur interbedded thick zones of sandy, often reddish brown shale, and finally the series is terminated by a reddish brown and green shale zone, with only thin beds of sandstone, having a thickness of from 50 to 100 meters. Above this shale comes the *Porsanger dolomite,* a compact, light-colored dolomite that weathers whitish as a rule. The thickness of this dolomite is difficult to fix, due to tectonic deformations which have strongly folded it and in places thinned it considerably. I consider the thickness, however, to have been at least 100 meters.

This dolomite shows many interesting features. Some of the zones are much silicified, with fine-grained quartz

[5] Compare Kindle, Geol. Survey Canada, Mus. Bull. 25, 1917.

in layers or in irregular masses. Nodules of dark colored silica are frequently seen, with the characteristic appearance of chert. Exceedingly common are intraformational dolomite-conglomerates, the larger fragments with their edges generally fairly well-rounded. Of very great interest also is the occurrence of nicely laminated dolomite, restricted to a thickness of several meters.

FIG. 3.

FIG. 3.—Vertical and horizontal section through stromatolite material of the *Gymnosolen* type. Natural size.

The laminæ are concentrically arranged, sometimes only slightly convex, sometimes more so, sometimes with a tubular or cylindrical appearance (fig. 3). This is the *Cryptozoon* structure of American stratigraphers, and will be more fully treated further on. Between such laminated layers occur sometimes innumerable small oolite-like, irregularly built grains.

Over the Porsanger dolomite follow, in the Porsanger district, the metamorphic thrust rocks, and accordingly the originally higher sequence can not be followed further here.

Younger beds, of the Varanger series, are found on the Varanger Peninsula further east, where we have, especially on the north side of the fjord, excellent sections

Fig. 4.

Fig. 4.—Cliff of Varanger series of alternating beds of red and ripple-marked sandstone and yellow-weathering impure dolomite. North coast, between the Tanafjord and Vardö.

through a sedimentary series of quite remarkable thickness. To the west occurs here a series of dark shales or slates with thin layers of quartzitic sandstone. They rest upon a light-colored sandstone which I believe overlies the Porsanger dolomite. Even if this sequence is not yet determined, we know that the dark shale must be younger than the Porsanger series, as the latter is met with in the most western part of the Varanger Peninsula, at the Tanafjord, where this series does not have such shale deposits. Above the shale follows a sandstone of about 2000 meters thickness, which I have studied very little. Still higher appears a thick series of thin-bedded, impure, light colored, yellow-weathering dolomite or dolomitic limestone alternating with red sandstones with the greatest abundance of ripple-marks (fig. 4). Above the ripple-marked strata comes another sandstone, reddish and grey, with layers of compact shale, and finally another series of yellow-weathering dolomite and red

Fig. 5.

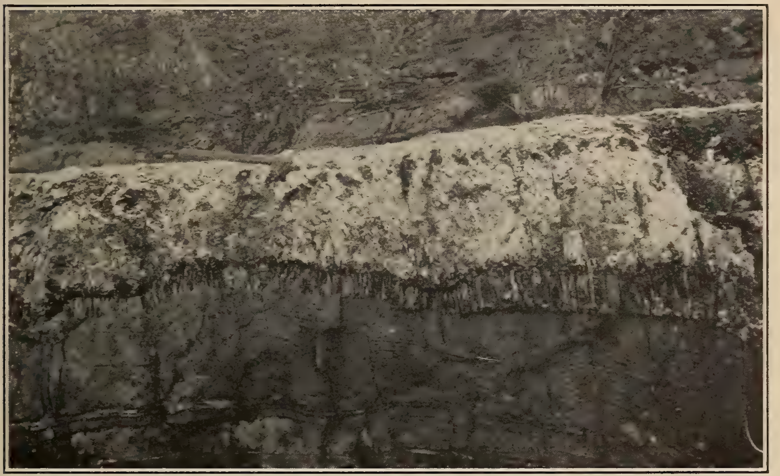

Fig. 5.—Stromatolite dolomite with silicified tubes. Raipas Mountain, at inner end of the Altenfjord.

sandstone, exceedingly like the previous one. At the base of this last mentioned series occurs a thin horizon of dark shale with thin layers and nodules of dark impure limestone. In one of these layers occur concretionary structures. These are made up of concentrically arranged lamellæ of dark limestone of coarser or finer grain, often containing clastic quartz particles and oolites. Oolites, more or less silicified, are also seen in somewhat higher horizons of this dolomitic series.

The total thickness of the different formations exposed on the north side of the Varanger Peninsula and constituting the Varanger series, certainly much exceeds 3000 meters, while the Porsanger series probably has nearly 1000 meters, making together at least 4000 meters of sediments.

In my opinion the Raipas series of the Alten district of western Finmarken, exposed in a "window" through the overlying metamorphic thrust rocks, is an equivalent of the Varanger series. The sedimentary rocks of the Raipas are dark shales, several horizons of dolomite and a sandstone. In the dolomite are found concentric structures of different types, here strongly silicified. Through an incomplete silicification of a layer having tubular laminated structures the curious subcylindrical tubes seen in fig. 5 have originated. The Raipas sandstone has in some layers a peculiar conglomeratic character,

Fig. 6.

Fig. 6.—Conglomeratic sandstone from the older division. North side of the Varangerfjord.

showing a concretionary or ball-like structure, found also in the upper sandstone of the Varanger series (fig. 6). Microscopical examination shows that the conglomeratic sandstone must be of the nature of an intraformational conglomerate. This for the reason that the sandstone of the groundmass and the included pieces (phenoclasts) has been and still is carbonaceous; and where parts of the quartz and feldspar grains have been dissolved or corroded, the dissolution and replacement by dolomite material have gone on concentrically in a regular manner in the round inclusions, when the material was homogeneous. In places with distinct bedding, the process of replacement is more complete in some layers than in others.

The Raipas series is marked especially by the presence of thick masses of volcanic material, tuffs and lava beds. The fact that these are not known from the Varanger Peninsula, 200 kilometers to the northeast, does not in my opinion contradict a contemporaneity of the series in the two districts. The volcanic activity seems to have been confined to the western district.

Remarks on the Cryptozoon-like structures.—These concretionary masses are found in Raipasfjeld in Alten, at the Porsangerfjord, and on the north side of the Varanger Peninsula in the Syltefjord. They are especially well developed in the Porsanger dolomite, where a rock several meters thick is made up of them. We find here different types. One (fig. 3) is identical with the *Gymnosolen ramsayi* described by Steinmann from pieces of dolomite brought by W. Ramsay from the western shore of the Kanin Peninsula on the arctic coast of Russia,[6] east of the White Sea. This type seems to be very much like forms of *Cryptozoon minnesotense* of Winchell,[7] which is described as consisting of subcylindrical and upwardly directed cones from 1 to 2 inches in diameter, giving the appearance of a succession of cups, or cones, piled on top of each other. In addition to this type, we have, however, many others, which are more hemispheric in structure, the convexity varying in all sorts of ways, till we meet a type of rock that in vertical section appears as a very slightly curving set of laminæ. In the author's opinion it seems impossible to distinguish between these types of structures, as all sorts of transitional forms occur, and therefore he also thinks that the many "species" of *Cryptozoon* described from North America can not be maintained in a critical revision. I can not regard these structures as real fossils which deserve generic and specific names. In a paper by Kalkowsky, "Oolith and Stromatolith in norddeutschen Buntsandstein,"[8] we have been made acquainted with a designation that serves very well for all of them, viz., *stromatolites,* a term that includes these laminated, concentrically built

[6] Fennia, 31, 1911.
[7] Geol. Nat. Hist. Survey Minnesota, 14th Ann. Rept., 1886, pp. 313-314.
[8] Zs. d. d. geol. Gesellsch., 60, 1908.

structures, occurring in limestones and dolomites. In fact, some of the stromatolites from the Triassic figured by Kalkowsky are extraordinarily similar to the *Gymnosolen* structure and thus probably also to *Cryptozoon minnesotense.* Walcott's *Collenia* from the Algonkian should likewise be considered as a stromatolitic structure.

As to the nature of these structures, I can not agree with Steinmann, who regards *Gymnosolen* as a cœlenterate, probably some sort of a coral; or with Grabau and Shimer, who in their "North American Index Fossils," 1, page 46, place *Cryptozoon* among the Stromatoporoidea; or with Wieland, who thinks *Cryptozoon bassleri* is nearly related to *Lithothamnium.*[9] The laminated structure without any indication of a radial one, and with inclusions of oolite and clastic mineral particles, can, in the writer's opinion, only mean that it is in the main to be regarded as a chemical precipitation, one, however, that probably came into existence through the organic processes of living organisms. I consider this type of rock to belong to what Andrée in "Ueber Sedimentbildung am Meeresboden"[10] calls "physiologischer Fällungskalk." It is natural to think of primitive plants, marine algæ, as the most active organisms in these respects, and we have here a strong hint in the known calcium carbonate-precipitating activity of fresh-water algæ, most conspicuously seen in hot water springs, where the calcareous deposits may be very like the stromatolites. This indirect activity of algæ has recently been emphasized by Walcott,[11] who reports the inclusions of cells of blue-green algæ in the Algonkian *Gamasia,* a form, however, very different from the *Cryptozoon*-like *Collenia.* We may also be reminded of Walcott's announcement of having found bacteria in Algonkian limestone,[12] and the well known statements of Drew that fine calcareous muds are precipitated by denitrifying bacteria in the Gulf of Mexico.

Even if the stromatolites most strongly resemble calcareous sediments that have been precipitated by plants in fresh-water lakes and hot springs, it seems difficult to assume with Walcott that all the limestones and dolo-

[9] Bull. Amer. Mus. Nat. Hist., vol. 33, 1914

[10] Geol. Rundschau, 7, p. 282, 1916.

[11] Algonkian algal flora, Smithson. Misc. Coll., 64, 1914.

[12] Proc. Nat. Acad. Sci., 1, 1915.

mites containing the algal deposits have also been formed in fresh water. Their exceedingly wide distribution in space and time, the huge thickness of the limestones with *Cryptozoon* structures, and above all the fact that marine fossils occur in the Ozarkian-Canadian *Cryptozoon*-bearing rocks of North America can only be explained by the assumption that these basins of deposits have also been a part of the world-wide oceans.

Fig. 7.

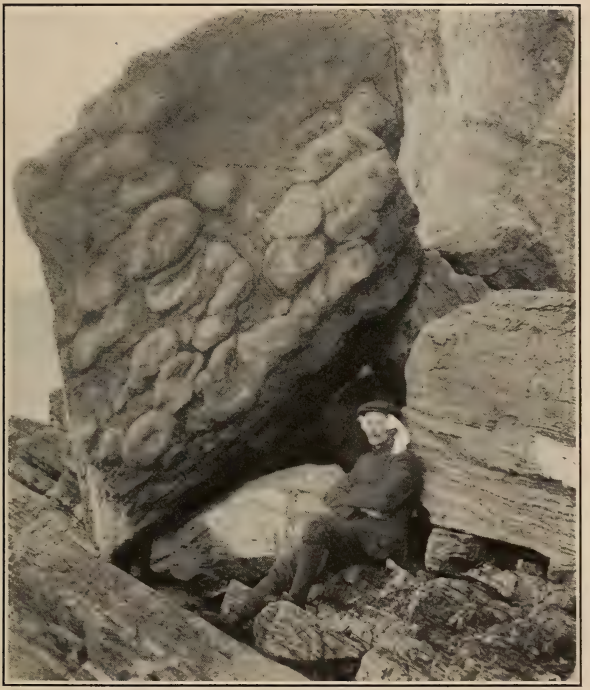

Fig. 7.—Bed of stromatolite in dark limestone. North side of Varanger Peninsula.

The fact that oolites so commonly occur with stromatolites strongly supports the view that we have here to do with chemical precipitations. The irregular small concretions found associated with the stromatolites of the Porsanger dolomite may also be regarded as oolites (''oolitoids'') which, probably through not having been able to roll freely on the bottom, have had the precipitated material irregularly distributed on their surface. These bodies in fact seem to represent a structure intermediate between oolite and stromatolite.

Of considerable interest is the fact that while most of the stromatolites of Finmarken are found in dolomite, one zone (see fig. 7) occurs in a rock that according to an analysis made contains 87·6 per cent $CaCO_3$ and only 0·57 per cent $MgCO_3$, thus indicating that the usual high content of magnesia is due to a secondary process, a dolomitization which probably took place very soon after their deposition.

Age of the Porsanger and Varanger series.—As to the age of this older dolomite-bearing sandstone division of Finmarken, it is certainly younger than the Lower Cambrian shale and sandstone with *Platysolenites,* because the Porsanger sandstone is found to lie on that zone. Further, it must be older than the time of Caledonian mountain-making, as the dolomite-bearing sandstones are overlaid by the thrusted mylonitic rocks of the Caledonian deformation. The chief period of the Caledonian deformation in this part of the world probably occurred considerably earlier than the accepted contact zone that bounds the Silurian-Devonian, for in the island of Hitteren off the Norwegian coast,[13] southwest of Trondhjem, and in Spitzbergen,[14] Downtonian unmetamorphosed sandstones occur unconformably above the deeply eroded remnants of the Caledonian mountain range.

It is now known that in the Tromsö district to the southwest of Finmarken (and likewise in the Swedish district farther south) there occurs above the green and red shales of the Lower Cambrian (Hyolithus zone) and below the mylonitic rocks, a series of black shales of considerable thickness. As suggested especially by Th. Vogt, it is very probable that this series corresponds to the Middle, possibly also to the Upper Cambrian black shales of southern Scandinavia. This series of black shales is not present in Finmarken, as here the Porsanger sandstone lies directly upon the Lower Cambrian green and red shales and sandstones. Therefore a break seems to exist here. Now if we consider the stratigraphical sequences in the different Scandinavian-Baltic Cambro-Silurian districts, we meet a striking fact, also found

[13] According to the investigations of Reusch.
[14] According to the investigations of Hoel and the writer.

elsewhere. This is the extremely well-marked *transgression* at the very boundary between the Cambrian and Ordovician. The *Dictyograptus* shale and corresponding sediments overlap in different areas upon various older strata; in Dalarne in central Sweden the transgression is over pre-Cambrian rocks, in Oeland over Middle Cambrian, in Estland over Lower Cambrian. We have in this fact a strong indication of the probable age of the Porsanger series. If we assume it to be basal Ordovician, we have here, in a relatively eastern part of northern Fennoskandia, exactly the same stratigraphical succession as that of the eastern part of south Fennoskandia, in Estland, where the "Unguliten sand" lies upon Lower Cambrian clay and sand which has, among other fossils, *Platysolenites.* The elevation of the northern land which has given rise to the enormous sandstone masses of Finmarken may, in fact, have been one of the causes of the early Ordovician transgression.

It is furthermore of considerable interest in correlation to note that even if the stromatolites can not be considered as actual fossils, they represent a very characteristic type of rock which in various regions seems to be nearly as good as guide fossils; for instance, the widely distributed cryptozoons of North America, which are exceedingly typical for the limestone-dolomite facies of the Cambro-Ordovician transition zone and the basal Ordovician, the Ozarkian and Canadian of American stratigraphers. Another interesting fact is that I have seen the *Cryptozoon* structure in limestone of Ozarkian age, collected by the Second Arctic Norwegian Expedition in the "Fram" on the south coast of Ellesmereland.[15] What without doubt is a stromatolitic structure is further mentioned from a sedimentary series, containing dolomite, limestone, sandstones and shales of Cambro-Silurian age, occurring in northeastern Greenland.[16] In fact, a few fragmentary fossils found here—Nathorst mentions orthocerids, a small *Orthis,* small gastropods—may very well belong to a low Ordovician zone.

Stromatolites also occur in dolomite in the so-called Heclahook system of Spitzbergen, and even though no

[15] Holtedahl, O., Summary of geological results, No. 36 of Rept. Second Norweg. Arctic Exped., "Fram," Kristiania, 1917.

[16] Nathorst, A. G., Bidrag till Nordöstra Grönlands geologi, Geol. Fören Stockholm Förh., 23, 1901.

fossils are found here, the system is known to be unconformably overlaid by the Downtonian sandstone series. I have seen a good deal of the Heclahook limestones and dolomites, and some of them are remarkably like those of Finmarken.

Rocks similar to those of the Heclahook of Spitzbergen are further known in Bear Island, midway between Spitzbergen and Norway, and here in one horizon fragmentary fossils have been found by the Swedish explorers Nathorst and Andersson.[17] Through the kindness of the director of the zoo-paleontological department of the Swedish State Museum, Professor G. Holm, I have had the opportunity of studying these fossils, which have proved to be of a quite decidedly American character, and to belong to Black River time. Besides several bryozoans and cephalopods and a *Rafinesquina,* which could not be specifically determined, there occur species of so decidedly an American character as *Gonioceras occidentale* Hall, *Actinoceras bigsbyi* Hall, and *Tetradium* cf. *syringoporoides* Ulrich. Thus the American Black River faunal element has spread very far into northern European waters.[18]

The dolomite with *Gymnosolen* from the Kanin Peninsula of northern Russia east of the White Sea is so extremely like the corresponding rock from the Porsanger series that their contemporaneity can not be doubted.

Not only the stromatolites, but many other characters of the Finmarken dolomite as well are typical of the calcareous rocks of most of the above mentioned regions. Oolites, intraformational conglomerates, and nodules and layers of chert (or chert-like quartz) are characteristic features of the Ozarkian-Canadian limestones and dolomites of North America, and are also known in those of

[17] Andersson, J. G., Stratigraphie und Tektonik d. Bären Insel, Bull. Geol. Inst. Upsala, 4, 1900.

Lindström, G., A species of *Tetradium* from Beeren Eiland, Öfvers. Kgl. Sv. Vet. Akad. Förh., 1899.

[18] After the present article was written, the author spent some time during the summer of 1918 on Bear Island, and succeeded in finding a still lower fossiliferous horizon. It is separated from the Tetradium limestone by several hundred meters of dolomites and dolomitic limestones. This older fauna is also very distinctly American in type; the age may be fixed as Canadian. The fossils are silicified, and the especially common ones are cephalopods (including *Piloceras*), gastropods, and *Calathium.* Yet older dolomites have very distinct stromatolites, besides oolites. The Heclahook system of Bear Island is thus found to comprise basal, lower, and early middle Ordovician zones, and the same is without doubt true for the Heclahook formation of Spitzbergen.

Greenland and Spitzbergen. Oolites and intraformational conglomerates (the latter in great thickness) are likewise found in the basal Ordovician of Ellesmereland.

When we furthermore recall that the dolomite-bearing sandstones of Finmarken are on the confines of the Arctic Ocean and nearest to the American Arctic occurrences, the assumption is very probable that all belong to an *American* or *Arctic-American facies.* Still another important fact pointing toward the same conclusion is that the only place in northwestern Europe where rocks occur showing a likeness to the dolomites of Finmarken is in the extreme northwest of Scotland. Here occurs a sedimentary series of basal Ordovician age, and, according to the contained fossils, decidedly of the American facies. This Durness dolomite is clearly separable from the underlying Lower Cambrian sandstones by a marked faunal break. An unconformity has also been observed by Grabau.[19] Here again we have a stratigraphic sequence identical with that of middle and eastern Finmarken. Not only this, but in the Durness dolomites there also occur chert, oolites, and intraformational conglomerates. Certain concretionary structures mentioned[20] may be of a stromatolitic nature.

A sedimentary series like that of the dolomite-bearing sandstone of Finmarken is not known anywhere in southern Scandinavia. On the other hand, in the highly metamorphic and very thick sedimentary series of the western part of northern Scandinavia, thick dolomites and limestone are very characteristic, and in this occurrence we have a somewhat similar correspondence.

From the statements just presented, it is seen that there are many facts pointing toward the existence of an ancient narrow barrier of land crossing the Scandinavian peninsula. To the north and northwest of this barrier occurs the thick dolomite-bearing series with the Arctic-American facies, and on the other or southeastern side occur shales and nodular limestones only a few meters in thickness, the latter being the *Dictyograptus* and *Ceratopyge* divisions of southern Scandinavia. This postulated barrier (see map, fig. 8) is therefore the continuation of the one generally assumed to exist between

[19] Bull. Geol. Soc. America, 27, p. 563, 1916.
[20] Geological structure of the northwest highlands of Scotland, Mem. Geol. Survey Gt. Britain, p. 424, 1907.

the corresponding different facies of the British Isles and of eastern North America.

There is reason to believe that the upper part of the very thick dolomite-bearing division of Finmarken

FIG. 8.

FIG. 8.—Paleogeography of early Ordovician time. Black squares indicate occurrences of dolomite and limestone of Ozarkian-Canadian age, and of American-Arctic facies. Vertical lines, areas of probable further extension. Horizontal lines, areas of Atlantic-European facies with *Dictyograptus*. Between the broken lines occur the assumed land-masses.

reaches as high into the Ordovician as the *Tetragraptus* (*Phyllograptus*) horizon correlated with the British Arenig. It is also of considerable interest to point out that this time in Scotland was one of extreme volcanic activity, which may correspond with the Raipas eruptions. Recently Carstens has shown that eruptions took place in the Trondhjem district in central Norway in early Cambro-Ordovician time, and these may very well be correlated with those of the Raipas.

The land barrier above pointed out appears to have continued into Black River time, as is indicated by the fossils of Bear Island, but it may have had a somewhat different situation. While the Bear Island fauna is of a decidedly American character, it is a well known fact that the Middle Ordovician faunas of the southern Scandinavian Baltic region (except the graptolites and bryozoans) do not show American relations at all. The same may be said of a northern fauna of about the same or probably of a somewhat younger age than the one from Bear Island, found by Nansen at the south side of Yugor Strait (Nova Zembla) and described by Kiaer.[21] While in my opinion the stromatolite-bearing dolomite of the Kanin Peninsula is indicative of the earliest American Ordovician facies, yet that of Yugor Strait shows that this Arctic Russian district belongs to the Scandinavian Baltic faunal province of Middle Ordovician time.

Younger, Tillite-bearing Sandstone of Finmarken.

Unconformably above the dolomite-bearing division comes a younger series, without dolomites but with tillites. The unconformity between them is not very strongly marked in eastern Finmarken, though in places it is readily seen, e. g., at the inner end of the Varangerfjord. In western Finmarken it is much more marked, indicating that the Raipas series was folded before the tillite-bearing division (the Bossekop series) was deposited. The presence of this folding was one of the reasons why, in my preliminary paper,[22] written when I had seen only this western part of Finmarken, I was led to conclude that the Raipas formation was of young pre-Cambrian age, since such a pre-Caledonian folding was not previously known in the Cambro-Silurian of the Scandinavian peninsula.

Preceding the deposition of the tillite-bearing division, we have in eastern Finmarken the origin of a big fault. This is especially distinct at the inner end of the Varangerfjord, and it is without doubt continued along the north coast of the Kola Peninsula, where Ramsay long ago assumed a fault line, dividing the pre-Cambrian

[21] The Lower Silurian at Khabarova. Norweg. North Polar Exped., 4, Kristiania, 1904.

[22] Norges Geol. Undersökelse, Aarbok, 1915.

gneiss-granite district to the south from the small occurrences of sedimentary beds to the north, in the Fisherman Peninsula and the island of Kildin. Contrary to the opinion of Ramsay, I hold that these sediments are younger than the dislocation, and that they probably are contemporaneous with the tillite-bearing division of Finmarken, since in places they are observed to lie upon the old granite floor. The fault may be seen in connection with the downwarping of the crust in the postulated geosyncline to the north, where the older series was deposited (see fig. 8).

The basal rocks of the tillite-bearing division of Finmarken in the Varanger district are mostly very light colored, whitish grey sandstones, resting upon the very uneven, yet well-rounded hilly surface of the old granite and gneiss. A little above the base comes the local tillite of Bigganjargga, 2 to 3 meters thick, with a grey colored groundmass, and resting on the nicely striated and polished surface of the conformably underlying sandstone. Above the typical tillite, which is found in two places about 8 kilometers apart, are observed coarse, only slightly bedded conglomerates, which may very well be of fluvio-glacial origin. Besides the facts mentioned, the very common erosion-channels also tell of purely continental deposition.

While these basal sandstones and conglomerates have a very restricted distribution, higher up occurs a more widespread zone with mostly reddish brown shales and sandstones, above which follows conformably the reddish brown tillite of Mortensnes. Still higher are grey and greenish shales, which finally contain sandstone beds. About 200 meters above the tillite, red quartzitic sandstones are the dominating rocks. The greatest observed thickness of this younger division is 400 to 500 meters. The reddish brown tillite is widely distributed, and maintains a thickness of about 10 meters. It is also seen at the Tanafjord, but here with less thickness and smaller bowlders. This wide distribution, and the occurrence between conformably lying shaly sediments without any distinct boundary below and above, are seemingly only to be explained by assuming a deposition from drifting icebergs.

Where the continental ice was situated is very easily determined; first, we know that there was a high southern land at this time (see fig. 9), and secondly, the rock nature of the bowlders of the different conglomerates is to a large degree like that of the pre-Cambrian ones now exposed in this district. We also find in the different conglomerates an abundance of sedimentary rocks, especially quartzitic sandstone, and furthermore, very commonly there are dolomitic rocks with the characters of the older series, and with cherts, oolites, and stroma-

Fig. 9.

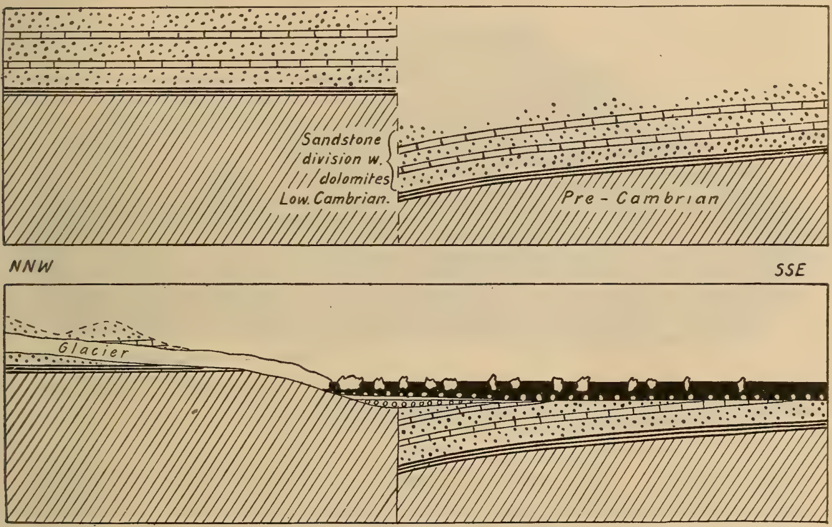

Fig. 9.—Above, hypothetic section through the inner end of the Varangerfjord, showing the geologic structure after the fault had appeared. Below, the assumed conditions at the time of the deposition of the reddish brown tillite.

tolites. These sedimentary rocks had their home above the pre-Cambrian to the south, where they are now totally removed.

In western Finmarken, in the Bossekop series, occurs a reddish brown rock with all the characters of the Mortensnes tillite. It is found as a zone in a sequence of light-colored quartzitic sandstones with minor intercalations of brown shales, nearly 200 meters thick. As in the Mortensnes tillite, here in the west also are found bowlders with distinct glacial striæ (fig. 10). These striæ in some bowlders are seen to have been deformed by later crustal movements, those of the Caledonian mountain-making.

As to the very important question of the age of this younger tillite-bearing sandstone of Finmarken, it is still very difficult to give any exact information, as no fossils are found. If my interpretation of the age of the older division is correct, it must be placed somewhere between the Lower Ordovician and the higher Silurian. It is distinctly older than the Caledonian deformation, because in places the rocks are highly folded, and in western Finmarken they are overlain by thrusted mylonitic rocks. The most probable supposition is, in the writer's opinion, that the time is of Middle or possibly Upper Ordovician age.

FIG. 10.

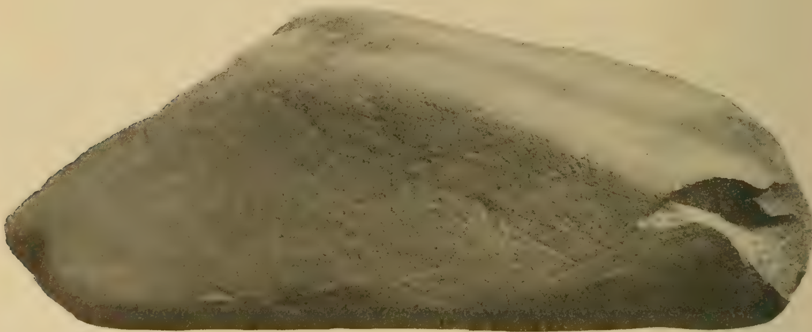

FIG. 10.—Glaciated quartzite bowlder, from the tillite at the inner end of the Altenfjord. Entire surface also with fine slickensided strata due to the Caledonian deformation. One half natural size.

The investigations of Wiman in Jemtland, Sweden, have shown that a dislocation there preceded the deposition of the *Orthoceras* limestone, which in places rests on the pre-Cambrian and whose conglomeratic basal layers contain pieces of Cambrian shales. This deformation of the crust might have been contemporaneous with the one preceding the deposition of the tillite-bearing division of Finmarken. In parts of Jemtland we find, furthermore, thick series of quartzites that are in part probably of Middle and Upper Ordovician age, and that may have been derived from a land-mass which then lay to the northwest and which may have continued northward into the southern part of Finmarken and the Kola Peninsula.

In the Trondhjem district of central Norway occurs the so called Hovind group, in which are found fossils of Upper Ordovician age; this is a series characterized to a large degree by very coarse sediments, sandstones and coarse conglomerates, indicating deformation of the crust in the preceding time. This Hovind group comes above the effusive rocks, which I consider to be contemporaneous with the Raipas of western Finmarken.

I may in this connection also be permitted to point out the occurrence of coarse bowlder conglomerates in the Girvan-Ballantræ region of Scotland, the Kirkland and Benan conglomerates of Llandeilo age. These conglomerates likewise tell of considerable crustal deformations, which have brought about the denudation of the Arenig rocks now found as pieces in the conglomerate.

It seems of course a little remarkable at first to assume for the tillites of Finmarken an Ordovician age. Still, I can not see that it is contradicted by any of the known facts. Our knowledge of the late Paleozoic shows that it is very difficult to trace the existence of continental ice masses in the marine sediments. Furthermore, it must be strongly emphasized that this glaciation of Finmarken was probably a purely *local* one. In my opinion it was brought into existence by the rising of a high land to the south of the Varangerfjord, a land about the size of which we know nothing with certainty, as its age can not yet be fixed. As the Cambro-Ordovician sequence of the Baltic region indicates fairly quiet conditions, it is reasonable to believe that the land had its higher part in the north, i. e., in Finmarken, which is also a probable assumption since the great fault runs here. If we assume a landmass of the width of the Scandinavian peninsula, high and rugged toward the Arctic Ocean, with a gentle slope toward the south, and a distinctly insular climate with much moisture on the north side, these conditions might very well bring into existence glaciers reaching down to the northern sea. On the other hand, Estland and southern Scandinavia may, under these assumptions, have had a rather warm climate. In fact, even on the north side the conditions might not have been at all severe. In South America at present glaciers creep down to the Pacific Ocean at so low a latitude as 46·5° S., the mean temperature of the year being here 8-10° C., the same as that of southern New York, and yet the inland has mountains not much higher than those of Norway to-day.

University of Kristiania, May, 1918.

Art. VI.—*Tectonic Adjustment of a Rotating Straticulate Spheroid;* by Charles Keyes.

Notwithstanding the fact that with reference to strains of deformation the behavior of the earth as a whole is that of a body having the rigidity of steel, the translocation of matter within is mainly analogous to that taking place in a highly viscous liquid. With the exception of the thin outer crust all internal change of mass position is necessarily by normal flow movement. Only in this exterior film where the load pressure is less than that of the crushing strength of rock and where rocks of different strengths alternate, do folding without rupture and faulting without flexing take place. It is the finely straticulate character of this surface zone that enables deformative effects to be quantitatively measured. To this layered cuticle are of course the chief investigations of the geologist confined.

Geologically the zone of rock-flowage does not really begin at a definite theoretical depth as usually postulated—at the distance from the surface where the strongest rocks commence to be crushed, or at a level of 5 or 6 kilometers down. The controlling factor of rock-flow is not so much any absolute load of superincumbent material as it is the lithological or textural nature of a given rock prism. Although the crushing strength of the toughest granite is a column 10 kilometers or so in height, perfect slipping of component particles over one another, which is in all essential respects true rock-flow, occurs in such formations as shales within a few hundreds of meters of the earth's surface. For this reason it is that thick sections in which the rocks are chiefly argillaceous, as in the Appalachian region for instance, give rise to a characteristic type of orographic structure which is dominantly flexing. When the rock column is principally composed of hard and brittle materials tectonic adjustment is an entirely distinct kind of orogeny. There is marked rupture or faulting of the layers. The mountain ranges of the Great Basin and the Mexican tableland well illustrate such phases. In a somewhat different way and without attempt at any explanation of the fact this great generalization was put forth many years ago by the late Major J. W. Powell of Washington.

As is well known the property by which clays or shales slip with greater ease in some directions than in others is due primarily to the micaceous or lamellar character of the components. Whether the shale beds be thick or thin the superior proneness to glide in a direction parallel to the original bedding planes persists. This ready movement in shales is essentially identical with the "flow" of crystalline rocks at great depths and under great pressure. It is strictly intermolar motion. It takes place not alone in thick beds of shale but in the thin partings between brittle formations. It is apparent in the thinnest film separating limestone and sandstone beds. The evidences of intermolar movement are particularly noticeable in sections in which there are great successions of thin limestone and shale layers. The Coal Measures in Kansas, Iowa, or Maryland afford illuminating examples.

Experimentally the straticulate structures and the deformative conditions in nature are capable of very close if not exact reproduction in the arts. Modern newspaper rolls as they leave the mill display some especially instructive tectonic potentialities. Compared with the enormously thick Appalachian section of alternating limestones and shales the paper itself is analogous to the rigid layers and the films between to the shale partings. The chief distinction between the phenomenon in nature and in the arts is that the paper is relatively enormously tough and hence cannot readily respond to rupture strains as do rock-layers. The rollpaper is not tightly wound, but the winding process is done under a certain measureable tension, which is retained to a very marked degree long after the roll is released from the spindle. This actual or potential stress is perhaps never entirely relieved until the roll is finally used on the printing press.

Contrary to expectations, the unwinding of the paper roll on the press, or its slower revolution in its wrapper, does not uniformly relieve the original stresses. Because of slight local differences in the texture of the paper, in thickness of the sheet, in direction of revolution, or in drying out of the original moist condition, the layers of paper locally buckle. Ordinarily this yielding would take place outwardly but the strong firmly glued wrapper prevents relief in that direction. The result is that there is a notable flexing inward, a folding so sharp at times that if the paper were not so tough, but brittle instead, rupture or, to use the strictly geological term, typical faulting would ensue.

Structures thus artificially produced in miniature simulate in all essential particulars those familiar flexures which distinguish the great mountain ranges of the globe. Several of the results are reproduced in the accompanying cuts which are pen tracings of photographs. They are not especially selected as isolated examples but are normal recurring figures. Reproduced a thousand times they seem to be the necessary consequence of diminishing tangential stresses. The formation of a simple continental geoanticline is most remarkable (fig. 1). With its elevated margins and its interior basin there is exact counterpart of North America bordered on either ocean by lofty mountain ranges.

By the use of layered materials not so tough as paper the characteristic faulting phenomena could be no doubt also developed. Were the straticulate shell of the roll or spheroid so constructed as to provide a texture and arrangement of the component layers more nearly corresponding to the conditions found in nature, major orographic structures would result as perfect as any displayed anywhere in the world. This is readily accomplished by a little prior calculation of relative rigidity and viscosity values of the materials and by the exercise in the experiments of a little ingenuity in the selection and arrangement of the layered masses. Under these circumstances one would expect structural replicas of all of the great wrinkles. However, the main interest in the experimental results lies in another direction.

In the mountain-flexing experiments of Reyer, Cadell, Willis, and Poulcke the theme is approached from the direction of a contracting crust due to a cooling globe. In the later attack on the problem secular refrigeration of the earth is not considered. Buckling of this outer rock-shell is regarded as initiated through the cumulative effects of the retardation of the earth's rotation. In a revolving sphere the radius of molar equilibrium is not a straight line but a curve, which as the rate of revolution diminishes approaches nearer and nearer a true radius and a straight line. The lagging of the outermost

FIG. 1.

FIG. 1. Continental geoanticline, with orographic borders. Dotted line is circumference of sphere.

FIG. 2.

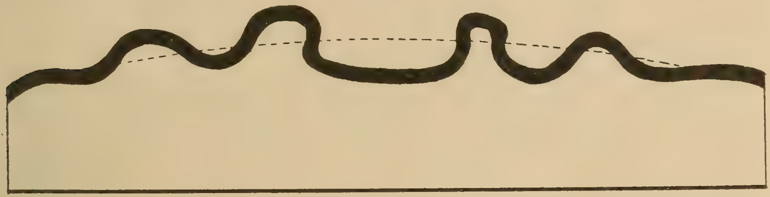

FIG. 2. Cordilleran anticlinorium, with unfolded center.

FIG. 3.

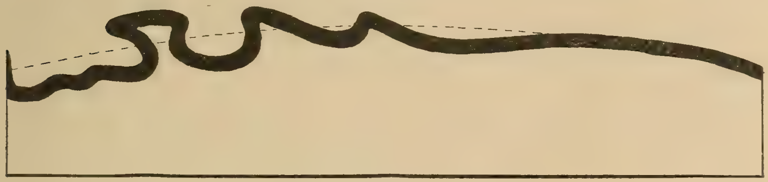

FIG. 3. Orographic flexure, with overturned fold.

FIG. 4.

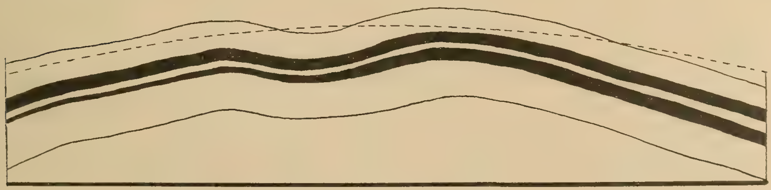

FIG. 4. Synclinal flexure—warped surface basin.

FIG. 5.

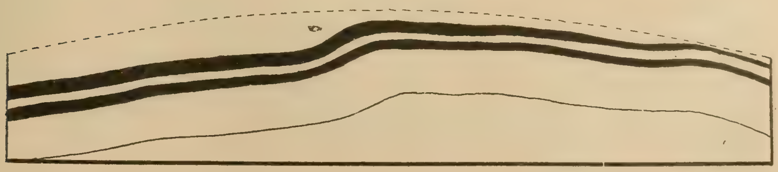

FIG. 5. Monoclinal flexure; normal orographic ridge.

film of the earth in the same way that there is holding back of the atmospheric shell which gives rise to wind pressure appears to induce phenomena which have been mistaken for compressive stresses that in days gone by seemed easiest ascribed to the contraction of a cooling globe.

The geotectonic effects of rotary retardation seemingly afford for the first time a satisfactory explanation of some of those anomalous and puzzling features which have always been associated with those curious mountain ranges of the Great Basin of western America wherein some of them appear to have been upraised through faulting in such a manner that the tumbled mountain blocks have been aptly likened to floating ice-cakes in a river at time of the spring break-up.

Finally with the force and rate of retardation and the amount of orographic shortening capable of mathematical expression a ready means is provided for gauging in units of human time the age of every mountain uplift, for determining very exactly in like terms the periodicity of every diastrophic movement, and for evaluating in years the span of every era, period, epoch and stage of the statigraphic record since the beginning of life on our globe.

Des Moines, Iowa.

ART. VII.—*The Taconic System Resurrected;* by CHARLES SCHUCHERT.

In the Centennial number of this Journal, July, 1918, the writer made the following statements:

"The Taconic system was first announced by Ebenezer Emmons in 1841, and clearly defined in 1842" (p. 75). . . . "It appears that everywhere in America the Lower Cambrian formations are separated by a land interval of long duration from those of Middle Cambrian time. These formations therefore unite into a natural system of rocks or a period of time. Between Middle and Upper Cambrian time, however, there appears to be a complete transition in the Cordilleran trough, binding these two series of deposits into one natural or diastrophic system. The Middle and Upper Cambrian series can be continued for the present under the term Cambrian system, a term, however, that is by no means in good standing for these formations" (pp. 77-78).

What the writer now wishes to set forth can not be clearly understood without further statements that he made at the same time in connection with the Silurian controversy. These are:

"Just as in America the base of the Paleozoic was involved in a protracted controversy, so in England the Cambrian-Silurian succession was a subject of long debate between Sedgwick and Murchison, and among the succeeding geologists of Europe. The history of the solution is clearly and justly stated in the Journal by James D. Dana under the title 'Sedgwick and Murchison: Cambrian and Silurian' (**39**, 167, 1890), and by Sir Archibald Geikie in his Text-book of Geology, 1903" (p. 78). . . .

"We have arrived at a time when our knowledge of the stratigraphic and faunal sequence, plus the orogenic record as recognized in the principle of diastrophism, should be reflected in the terminology of the geologic time-table. It would be easy to offer a satisfactory nomenclature if we were not bound by the law of priority in publication, and if no one had the geologic chronology of his own time ingrained in his memory. In addition, the endless literature, with its accepted nomenclature, bars our way. Therefore, with a view of creating the least change in geologic nomenclature, and of doing the greatest justice to our predecessors that the present conditions of our knowledge will allow, the following scheme is offered:

"Silurian period. Llandovery to top of Ludlow in Europe. Alexandrian-Cataract-Medina to top of Manlius in America.

"Champlain (1842) or Ordovician (1879) period. Arenig to top of Caradoc in Europe. Beekmantown to top of Richmondian in America.

"Cambrian period. In the Atlantic realm, begins with the Paradoxides, and in the Pacific, with the Bathyuriscus and Ogygopsis faunas. The close is involved in Ulrich's provisionally defined Ozarkian system. When the latter is established, the Ozarkian period will hold the time between the Ordovician and the Cambrian.

"Taconic period. For the world-wide Olenellus or Mesonacidæ faunas" (pp. 82-83).

In the English weekly, *Nature,* for September 19, 1918, the Centennial number is noticed, and among other comments we read the following: "The essay on 'The Progress of Historical Geology in North America,' by Charles Schuchert, contains important remarks in stratigraphy, and the following classification is proposed for the older Paleozoic systems:—Taconic (Olenellus beds), Cambrian, Champlain or Ordovician, and Silurian. The author does not seem aware of Charles Lapworth's support and revival of the term Taconic in 1891" (p. 50). This was agreeable news to the writer, and as American stratigraphers will want this important information, originally published in the *Geological Magazine* for December, 1891, pages 529-536, under the title "On *Olenellus callavei* and its geological relationships," it is here republished for more accessible reference.

The Lower Cambrian trilobite *Olenellus* (= *Callavia callavei*) occurs "near the base of the Comley sandstone (Hollybush) series of central Shropshire . . . at the foot of the hill of Little Caradoc, near Church Stretton. In this district the *Olenellus*-bearing sandstone *passes down* into olive-green felspathic flags, grits, and concretionary shales, and the base of the entire Comley Sandstone series is formed of the well-known Caradoc or Wrekin Quartzite, which reposes unconformably upon the volcanic Uriconian Group of Callaway. The *Olenellus*-bearing beds are *overlain* at once by conglomerates,[1] and gritty and quartzose strata, containing abundant fragments of igneous rocks, concretions of carbonate of copper, calcareous bands,[2] and limy nodules; and these in turn pass up into flaggy shales and quartzose grits, forming the highest visible parts of the Comley series.

[1] This important statement should be carefully noted.
[2] With *Paradoxides groomei* Lapworth.

"*Olenellus callavei* appears to be strictly confined to that part of the Comley series which lies below the conglomerate bands mentioned above; and its associates include *Kutorgina cingulata, Linnarssonia sagittalis, Hyolithellus* (compare *H. micans,* Walcott) and *Elliptocephalus,* sp.

"We possess in the foregoing facts sufficient paleontological evidence to establish the Lower Cambrian age of that part of the Comley series which contains the genus *Olenellus;* and we have now obtained stratigraphical and paleontological proof that it is succeeded at once by the so-called Middle Cambrian or *Paradoxidian.* Further, as Dr. Callaway originally pointed out some years ago, the Hollybush (or Comley Sandstone) series is followed in turn by the Shineton Shales, which contain locally a fauna of highest Cambrian age. In these central Shropshire rocks, therefore, the Comley and Shineton groups, which constitute an integral part in this district of Murchison's original *Lower Silurian,* and have a collective thickness of perhaps less than 3000 feet, we have apparently a condensed epitome of the entire Cambrian system as at present generally defined.

"Here, as elsewhere, we find the Cambrian divisible into three sections—an Upper Cambrian above, marked by the presence of the genus *Olenus* (Olenidian); a Middle Cambrian group with *Paradoxides* (Menevian or Paradoxidian); and finally a Lower Cambrian (*Olenellus* zone) or basal group (possibly of somewhat different systematic importance), distinguished by the presence of *Olenellus.* No one has yet, so far as I know, suggested any general title for the basal division of the Cambrian. Recollecting, however, that the very first discovered species of the genus *Olenellus* was named and figured[3] by the American geologist, Dr. Emmons, as early as 1846 from the rocks of his Taconic or Taconian system; and was claimed by him as early as 1853 as coming from strata older than any of the fossil-bearing Silurian (including the Primordial zone) then discovered; while even at the present day the genus holds its own as marking a distinct and identifiable life-zone in the strata of Emmons' typical Taconic area; it would be very convenient if geologists and paleontologists generally would agree in calling it the Taconian" (pp. 532-533).

[3] As *Elliptocephala asaphoides,* Emmons, Taconic System, 1846, p. 213, figs. 1-3.

In summing up, Lapworth says: "The students of these old rocks (however much they may conscientiously differ in the provisional nomenclature in which they clothe their facts) have now all more or less attained to the conviction that we are at last reaching a satisfactory homotaxial base to the Paleozoic rock-series. We now see that the Lower Paleozoic cycle of formations (the Protozoic or Protogean) or the Silurian of Murchison's 'Siluria' and Barrande's 'Système' has proved itself to be a geological cycle of the first order. We agree, in principle, that it is made up (like each of the succeeding great cycles) of three sub-equal groups or systems—an Upper system (the *Silurian* proper, or *Salopian*), a Middle system (the *Ordovician*), and a Lower system (the *Cambrian*). This lower system, like each of the two systems above it, has now shown itself divisible in its turn into three sections—an Upper Cambrian (*Olenidian*), a Middle Cambrian (*Paradoxidian*) and a Lower Cambrian (*Taconian*). Underneath this Cambrian lie sometimes conformably, sometimes unconformably, the strata of the mysterious cycles of the Pre-Cambrian (or Archean)" (p. 535).

ART. IV.—*Botanical Research in the United Kingdom during the War;* by PROF. F. O. BOWER, F.R.S.[1]

The absence of most of the younger botanists at the war, and the death of some, has naturally restricted the output of botanical research in Britain. But it has by no means stopped it, as the continuous publication of the leading Journals, notwithstanding difficulties of printing, paper, and illustrations, fully shows. The Annals of Botany, for instance, has shrunk. Comparing the volume of 1917 with that of 1914, it is less by about 1/3 of its pages, and about ½ of its figures. But already one botanist, twice wounded, and invalided out of the Army, has returned to his laboratory, and is publishing his results. There is also the steady flow of memoirs from other sources; substantial treatises are also appearing. For instance, Professor West's volume on Fresh Water Algæ (1916) inaugurates a new Series of Cambridge Botanical Handbooks designed for specialists, and very luxuriously produced. The Cambridge Press has also published the third volume of Professor Seward's great work on Fossil Plants, dealing with primitive seed-bearing plants (1917).[2] The concluding volume, which will contain a survey of the successive floras of the world, is promised shortly.

Of morphological discoveries since the outbreak of war the most important relate to the Psilotales and kindred forms:—plants which by their early occurrence and their characters were already recognized as likely to give the key to the morphology of primitive vascular plants. In 1914, the living Psilotaceæ were the only remaining Pteridophytes of which the sexual generation was not known. Prof. Lawson on his appointment to the chair in Sydney set himself to fill this gap. He has discovered the prothalli of both genera, and described them with ample illustration in the Transactions of the Royal Society of Edinburgh (1917). They are both saprophytes, and show general resemblance to those of the Ophioglossaceæ. Thus the period of the war has filled the last conspicuous gap in knowledge of the life histories

[1] EDIT. NOTE.—This paper was received some months since but seems worthy of publication even at this comparatively late date.
[2] Noticed in vol. 46, p. 475.

of the pteridophyte. A second, and still more important, discovery relates also to plants of bilotaceous affinity, but known only as very early fossils. The Lower Devonian Flora which gives the earliest record of vascular plants, includes fossils referred to *Psilophyton* and other genera, Remains of these chiefly in the form of impressions had already been described by Dawson, and others: recently (1916) Halle has accurately depicted many specimens from Roragen, including a remarkably mosslike capsule, which he named *Sporogonites.* But in all these the actual form and detailed structure were wanting. It was then a matter of peculiar interest when in blocks of chert referable to lower Devonian age, from the farm in Rhynie in Aberdeenshire, fossil plants were discovered in masses, standing as they died, with their form and structure very perfectly preserved. Drs. Kidston and Lang have monographed[3] the first of these plants under the name of *Rhynia Gwynne-Vaughani.* Its details are as well known from their description as some modern plant might be, though it is one of the earliest vascular plants in point of date. The description of others will soon follow. *Rhynia* is a rootless and leafless sporophyte, with branched cylindrical stems attached to the soil by branched underground rhizomes, bearing rhozoids. Epidermis with stomata, cortex and stele were all found perfectly preserved, while large distal sporangia contained many spores, of one kind only. For this plant a new phylum of organisms, the Philophytonales, has been established with near relations to the living Psilotaceæ.

The importance of much singularly detailed knowledge of a plant from the earliest known flora of vascular plants cannot be overestimated. It will be enhanced as other forms are detected and described from the same source. A new chapter in the morphology of the earliest land-plants is opening before us. The third year of the great war will undoubtedly be recognized as an era in the history of morphology. The new facts verify in a very remarkable way the brilliant speculations of the late Prof. Lignier of Caen. At the same time they arouse a special interest in the embryology of the living Psilotaceæ. We may anticipate that this will very soon be satisfied by Prof. Lawson. We are, through these dis-

[3] Trans. Roy. Soc. Edinburgh, 1917.

coveries, nearer than ever before to some rational view of the origin of a land-flora on a basis of observation, and in this the Bryophytes will assuredly take a natural place.

The comparative anatomy of the vascular system has been enriched by the last papers left complete on the death of Gwynne-Vaughan in 1915, from natural causes. Careful analysis of the structure of these rare ferns, *Stromatopteris* and *Platyzoma,* have been published by J. K. Thompson. The morphology of the leaf has been illuminated by comparative study of the juvenile leaves of rare fern-types, by F. O. Bower: and he has added three more memoirs during the war to his Comparative Studies in the Phylogeny of the Filicales.

A striking discovery has been made of obligate symboisis in the common heather, by Dr. M. C. Rayner.[4] The Heath family is well known to have a fungus living in the cortical cells of the root, forming the association known as mycorhiza. Miss Rayner has demonstrated by pure cultures, following lines already pursued by Prof. Bernard of Poitiers for the orchids, that the common heather cannot form roots without the presence of the appropriate fungus. Sterilized seedlings do not progress beyond the first stages. The infection normally takes place from the tissue of the ovary and seed-coat. The fungus lives in the growing tissues, and continues to grow through them to the ovary and seed-coat, from which it passes on germination to the new germ. The condition of dependence is similar to that in a lichen, and in both cases the proof of the dependence is given experimentally by successful synthesis. It is a beautiful demonstration of a state intermediate between immunity on the one hand and mortal parasitic attack on the other; a state of mutual tolerance, which finds its parallel in some infections of the animal body.

Plant-Physiology has been very active during the war, and often in lines that will have practical applications. A book entitled "Some recent researches on Plant-Physiology" by Dr. W. R. F. Atkins of Dublin, contains an account of comprehensive experiments on the saps of plants, by delicate measurements of their freezing point. This well-known physical method was used to obtain knowledge of the sugar and salt content of very small

[4] Annals of Botany, 1915.

quantities of expressed cell-sap. Such small amounts as are available could not be investigated before, and important data have been obtained bearing on the synthesis of sugar in plants, and on problems of the ascent of sap. Some of these were obtained in conjunction with Prof. H. H. Dixon, and are related to his fundamental work on the mechanism by which water is lifted to the tops of the tallest trees. On the other hand, Miss M. Delf has published a thorough experimental study of the rate at which water can pass through protoplasm, into or out of the cell, and the variation of this permeability with temperature.

Several instalments of researches on the permeability of protoplasm by Messrs. Styles and Jorgensen have recently appeared, which dispose of the view that this is simply determined by physical relations of surface tension. And the same authors have published a critical account of recent work on "Carbon-Assimilation," in which for the first time the many researches on the photosynthetic activity of green leaves are carefully correlated and evulated.

Miss Wheldale has brought together into book-form the scattered literature on the anthocyan pigments of plants. It contains also the author's own work on the inheritance of such flower-colors in certain plants. This is the first case in which the mendelian laws of heredity have been applied to the carrying over of actual chemical substance from generation to generation.

Fundamental researches have been published by Dr. F. Kidd on the effect of carbon-dioxide on vitality and respiration. It is shown that this product of respiration, if it accumulates in tissues, inhibits the further activity of respiration, and sends the plant into a dormant state. This seems to be the essential factor in the automatic arrest of growth in seeds. The gas can also be used to keep moist seeds in a dormant state though alive.

Under the physiological direction of Prof. V. H. Blackman, the Board of Agriculture has subsidized large-scale experiments on "Electro-Culture" of growing crops with a view to determining what is the exact cause of the increased yield that is found in some cases very strikingly, but in other cases is not produced.

An elaborate series of investigations on the sugars and starches formed in leaves of growing crops have been made by Messrs. Davis and Daish of Rothamsted. Much progress has been made towards accurate determination of these substances when several are present. And this is necessary for exact knowledge of the formation of these food substances from inorganic material by the green leaf.

During the war Dr. Willis has advanced his theory of "Age and Area" of Species. It was first founded on the facts of spread of the species in the flora of Ceylon and with special reference to those which are endemic. His point is that natural selection has little to do with the geographical distribution of species, and that the area occupied at any given time in any country depends mainly upon the age of the species in that country, but not on its absolute age. This thesis has been found applicable also to other areas, and Dr. Willis has already analyzed the New Zealand and Hawaiian floras with like results.

Mr. A. E. Carey and Prof. Oliver have a book ready for publication on "Tidal Lands" which will collate many isolated facts relating to the maintenance of coastal and riparian frontages. Besides its use to land owners and public bodies it will also serve as a handbook for studies in intricate questions of coastal engineering, and of applied botany. The effect of such studies may be very far-reaching.

In the sphere of economics one of the most important innovations is the cultivation of the oil palm (*Elaeis guineensis* in the Seychelles. Hitherto the natural wild produce from W. Africa has been used. Systematic cultivation of it in suitable soil in the Seychelles has already given good results, and great hopes are entertained of the establishment of this as a new and paying tropical crop. In British East Africa the cultivation of flax had been introduced with promising results. Not only is an increased fiber-production foreshadowed, but also increase in oil-supply, with the various secondary results of oil-cake and soap.

Though their staffs have been depleted, the great systematic centers of Kew, South Kensington and Edinburgh have kept their routine work alive, and given much advice and assistance to Government. Advance has been made in the revision of the flora of Jamaica, and in the flora of tropical Africa; while the collections of Miss

Gibbs from British North Borneo and of Mr. Ridley from Dutch New Guinea have been published. The working out of Mr. Compton's collection from New Caledonia has also been well advanced though now interrupted by his duty in the war.

There is thus evidence of progress in Britain during the war in many different lines of botanical enquiry, and in some cases of discoveries of the first importance. But in addition to what is published in the Journals much work relating directly to the war is being carried through by botanists. Naturally this cannot be referred to except in quite general terms. But the fact makes it all the more satisfactory that so much other work has been completed, which has no relation to the present struggle.

Among biological treatises published in Britain since the outbreak of war perhaps the widest in its scope is that on "Growth and Form" by Prof. D'Arcy Thompson. It deals with problems both in the vegetable and animal kingdoms filling in the "No Man's Land" between these sciences, physics and mathematics, with frequent allusion also to philosophical writings. It is a positive and constructive addition to biological literature.

ART. V.—*An Electron Theory of Passivity;* by REGINALD S. DEAN.

Starting from Drude's electron theory of metals it is possible to derive a relation giving the contact potential in terms of certain characteristic constants and the electron numbers of the concerned metals. This has been done by Langmuir[1] who gives the formula

$$V_1 - V_2 = P_2 - P_1 + \frac{N_1}{N_2}$$

where P_1 and P_2 represent the so-called electron affinities and N_1 and N_2 the electron concentrations of the concerned metals.

The contact potential is only a constant therefore if N_1 and N_2 are constants; if this is not the case the expression only holds if N_1 and N_2 represent the electron numbers of the surface layer. If it were possible to maintain a surface layer with a greater or less electron concentration than the mass of the metal we should then have a condition of abnormal contact potential. In case the surface were less concentrated in electrons than the main body of the metal, we should have a condition of ennobling. Such a surface condition would explain many of the peculiarities of the so-called passive metals.

The production of passivity by oxidizing agents and anodic polarization can be explained in this way since oxidation is in effect the removal of electrons.

The various phenomena of ennobling characteristic of passive surfaces are all to be explained from raised contact potential or the closely connected electrode potential.

The low photo-electric emission of passive iron as observed by Allen[2] is in direct accord with a surface layer lower in electrons.

There remain, however, three things which must be accounted for to make an electron theory of passivity probable: (1) the maintenance of an electron deficient surface; (2) the characteristic occurrence of passivity in the metals of the iron group; (3) the effect of magnetism on passivity.

[1] I. Langmuir, Trans. Amer. Electrochem. Soc., p. 144, 1916.
[2] H. S. Allen, Proc. Roy. Soc. London, 88, 70, 1913.

Let us commence by analyzing mathematically the conditions affecting the surface concentration of electrons.

If a conductor A,B, with difference of potential E between A and B, moves in a magnetic field of intensity F, its velocity normal to A,B will be given by

$$V = \frac{kE}{\mu F} \tag{1}$$

where k is a constant and μ the permeability of the medium. Now without interfering with our analysis we may replace the conductor A,B with a stream of electrons with velocity v, in which case V will be given by

$$V' = \frac{kv^2}{\mu F} \tag{2}$$

Further, the ends of A,B may be joined and all the electrons removed but one and equation (2) will still hold. We have then our ideal case of one electron moving in its orbit with velocity v. Its velocity normal to the plane of its orbit will be given by (2). The irregular motions of electrons within a metal can be resolved into a series of harmonic motions to which this mathematical analysis can be applied. If now we consider the surface of a conductor we find that the electrons on reaching the second medium, say air, would have a velocity of

$$V' = V\frac{\mu}{\mu'}, \tag{3}$$

where V is the velocity in the conductor and μ the permeability of the conductor and μ' the permeability of the second medium. Electrons whose velocity in the conductor was greater than $\frac{V_e\mu'}{\mu}$, where V_e is the velocity of escape, will therefore escape. Considering then a layer at the interface the number of electrons N coming through the lower boundary will be given by

$$N = d_1 V \tag{4}$$

where d^1 is the electron density and V the velocity. The number leaving the upper boundary will be given by

$$N' = d_2 V' \tag{5}$$

but $N = N'$

hence

$$d_2 = d_1\frac{V}{V'} = d_1\frac{\mu'}{\mu} \tag{6}$$

that is the electron density at the surface is less than that of the interior and is given by (6). This of course is only true for paramagnetic metals and the more paramagnetic the substance the greater the passivity, which at once explains the extraordinary tendency to passivation found in the iron group.

So far we have considered only a constant magnetic field; if we examine equation (2) it will be seen that V is inversely proportional to F, hence it is apparent that if a magnetic field be applied to a conductor, V will be lowered, causing the number of electrons with greater velocities than V_e to be smaller and hence the passivity produced by any given set of conditions will be less in a magnetic field than without or the force necessary to produce a given degree of passivity will be proportional to F. However if a conductor be once passivated no effect of changing the magnetic field should be anticipated. This is practically the effect found by Nichols and Franklin[3] and by Byers[4] and his collaborators.

[3] Nichols and Franklin, this Journal, (3) 31, 272, 1886; (3) 34, 419, 1887.
[4] Byers and Darrin, Journ. Amer. Chem. Soc., 32, 550, 1910.

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ART. VI.—*Two New Zircon Minerals—Orvillite and Oliveiraite;* by T. H. LEE, F.C.S., Lond., N. Am. C. Soc.

[Translated by J. C. Branner from the Revista da Sociedade Brasileira de Sciencias, No. 1, Rio de Janeiro, 1917, pp. 31-38.]

I. ORVILLITE.

Year before last there came to the Serviço Geologico e Mineralogico do Brazil a number of specimens of a zirconiferous rock from the region of Caldas, in the State of Minas Giraes. Several of them were almost entirely of the oxide of zirconium known as baddeleyite (brazilite of Hussak), and some of them contained 92% of the oxide of zirconium.

When Orville A. Derby, the lamented director of the survey, received this material he began a study of it with a view to proposing the name "caldasite" for the rock itself, so that the name baddeleyite would be restricted to the crystalline oxide of zirconium, and thus preventing the use of the name of the mineral for that of the rock. And as it is typical of the region of Caldas, its origin would thus be indicated.

Among the many varieties of this rock are some that have cavities filled with small crystals of silicate of zirconium (zirconite). By making analyses of this material I have verified the existence of the new silicate here described. It is of an unusually simple composition for one of the rare earths.

The first analysis made gave the following results, which are the average of two closely agreeing determinations:

Combined water	1·56
Alumina	0·15
Zirconia	71·88
Titanic acid	0.62
Ferrous oxide	0·43
Silica	25·31
	99·95

These results show that the material corresponds, in molecular composition, to a mixture of two or more compounds.

Taking into account the insolubility of zirconite ($ZrO_2.SiO_2$) the only silicate of zirconium thus far known by wet analysis, and verified by several determinations of materials that may be considered as absolutely pure, Derby suggested the possibility of making a separation of the component minerals in case they were different.

For this purpose a few grams of the substance were treated for some hours with a mixture of hydrofluoric and hydrochloric acids. The only visible effect produced was an alteration of the color of the fragments of the material which changed from a dark gray to a yellowish white, but preserving perfectly their original angular appearance. The acid solution, however, showed with turmeric paper the characteristic reaction for zirconium, and the residue was easily broken up under slight pressure of a platinum spatula.

Filtering and washing in a funnel coated with Canada balsam, the dry residue was examined under a microscope ($\times$ 400) and found to consist of microcrystalline aggregates radiating from centers and apparently homogeneous.

The homogeneity was confirmed by the analysis and the residue had the exact composition of zirconite ($ZrO_2.SiO_2$). The quantity, however, which was 41% of the original rock, corresponded to one-half of the silica contained in it.

It was evident that it was not a simple mixture of zirconite with an excess of zirconia (baddeleyite or brazilite) but two silicates, one of them insoluble in the humid reagents, and the other readily soluble.[1]

At this point the investigation had to be suspended for some time to await the arrival of new material.

It is noteworthy that this first analytical work had suggested the following composition of the Caldas rock:

Zirconite ($ZrO_2.SiO_2$)	41	(det.)
Silicate, new? ($3ZrO_2.2SiO_2$)	56	
Impurities	3	
	100	

[1] Thin sections do not show the least sign of the presence of amorphous or crystalline silica.

A second specimen had this composition:

Zirconia (ZrO_2)	85·01
Ferric oxide (Fe_2O_3)	3·57
Titanic acid (TiO_2)	1·52
Silica (SiO_2)	9·63
	99·73

Later, when the Geological Service had new material, Dr. Derby by using a needle and a microscope succeeded in separating a little more than 600 milligrams of the visible homogeneous materials. Of this two parallel analyses were made which showed beyond question that the material was homogeneous, and that it was a new silicate with the following composition:

Zirconia	68·04
Silica	25·45
Volatile matter and combined water	6·35
	.99·72

Dividing these percentages by the molecular weights we have the molecular factors:

Zirconia	0·5565
Silica	0·4220
Water	0·3516

Dividing the molecular factors of the zirconia and of the water by the silica we have:

Zirconia	1·319
Silica	1·000
Water	0·833

Multiplying by three we have:

Zirconia	3·957
Silica	3·000
Water	2·499

Equal to

$$4ZrO_2.3SiO_2.2{\cdot}5H_2O$$

or

$$8ZrO_2.6SiO_2.5H_2O.$$

It seems possible that the high molecular weight and the consequent constitutional complexity corresponding to this formula may be responsible for the facility with which the mixture of hydrofluoric and hydrochloric acids attacks and dissolves it.

Inasmuch as the identification of this new mineral species was due entirely to the efforts and labors of Dr. Derby, I have the honor to propose for it the name of *Orvillite.*

II. Oliveiraite.

My attention was called to the mineral euxenite in June, 1910, by a specimen given me for analysis by my colleague Jorge de Araujo Ferraz. There was very little of the material however. About a year later there was a discussion in one of our periodicals in regard to a new element derived from a mineral which, thanks to the studies of our learned Professor Paes Leme of our museum, was shown to be not a new element, but an oxide of the rare earths composing the mineral euxenite.

In August, 1913, by order of Dr. O. A. Derby, then director of the Serviço Geologico, I had the pleasure of receiving a large number of specimens of this material from my colleague who visited the place at which they occur on the fazenda Santa Clara, Tocantins station, on the Leopoldina railway in the municipality of Pomba, State of Minas Geraes. I made several analyses of the material, and the results were always in approximate agreement with those made at the Escola de Minas, and with one made at the Royal Polytechnic School at Turin and shown me by my colleague Ferraz. Thanks to the efforts of Professor Paes Leme I obtained a small bit of material from an uncertain locality in Espirito Santo from which it was said the new element had been obtained.

In order to have a clear idea of the similarity of the materials from the two different places I give here the results of the analyses:

Euxenite.

	Espirito Santo		Pomba, Minas
Tantalic acid	3·20	....	1·46
Columbic acid	28·70	....	36·39
Titanic acid	23·70	....	25·00
Oxide of cerium	....	....	·46
Oxide yttrium (group)	23·12	....	23·08
Oxide zirconium	4·23	....	....
Oxide uranium	7·50	....	10·06
Oxide lead	·14	....	·14
Oxide tin (traces)	....	....	....
Oxide iron	3·12	....	....
Combined water	6·41	....	2·41
	100·12	....	99·00

At first, as is shown by the anaylsis of the euxenite from Pomba, the zirconia was not determined by me, but was included with the columbic acid.

Upon reexamining the material and also what the same collector brought in March, 1914, I verified the existence of a new mineral, a hydrated titanate of zirconium.

Having separated the mineral I submitted it to Dr. E. Rimann, at that time the petrographer of the Geological Service, who made this note:

"It shows no distinct crystalline structure, but is amorphous; its color in thin fragments is a yellowish green and shows in places multiple twinning and a fibro-radial structure approximating radio-spherulitic. Its optical characters correspond more or less with those produced in amorphous minerals in general by high pressure, a correspondence increased by the fact that the double refraction and the fibro-radial structure are strictly limited to the highly sheltered area of the mineral. Neither crystalline faces nor cleavage can be seen."

Where the mineral is entirely free from foreign bodies it is of a greenish yellow color. A quantity of it separated under the microscope by Derby gave the following results when analyzed:

Zirconia, ZrO_2	63·36
Anhydrous titanic acid, TiO_2	29·92
Combined water	6·48
	99·76

Dividing these percentages by the proper molecular weight we have:

Zirconia	0·517
Titanic acid	0·373
Water	0·360

Dividing the molecular proportions by the zirconia we have:

Zirconia	1·000
Titanic acid	·7215
Water	·6963

Multiplying by three we have:

Zirconia	3·00
Titanic acid	2·16
Water	2·09

or

$$3ZrO_2\ 2TiO_2\ 2H_2O.$$

I propose for this new mineral the name of *oliveiraite* in honor of the veteran geologist Dr. Francisco de Paula Oliveira, who has been so long associated with Dr. Orville Derby in the work upon the geology of this country. The presence of the oxide of zirconium in euxenite explains the origin of the new mineral as a secondary product of it.

Almost all of the crystals of euxenite are covered with a yellow crust that has the following approximate composition:

Columbic acid, Cb_2O_5 Including tantalic acid, Ta_2O_5	52·51
Titanic acid, TiO_2	25·00
Rare earths, R_2O_3	7·40
Oxide of uranium, UO_3[2]	4·93
Combined water	11·14
	100·98

[2] On decomposition the uranium is present in the form of the oxide UO_3, and in the unaltered mineral in the form of UO_2.

It is clear that in the process of decomposition the euxenite has lost a part of the rare earths, oxide of uranium, and titanic acid, but little or none of the earthy acids (Cb_2O_5-Ta_2O_5).

Considering again the molecular relations of these two minerals, it is to be noted that in the relation between zirconia and silica in the first case, and between the zirconia and titanic acid in the second, there is a small excess of acid in each.

In orvillite for example, in place of the relation $4ZrO_2.O_2 : 3SiO_2$ it is $3{\cdot}96\ ZrO_2 : 3SiO_2$.

In oliveiraite, in place of $3ZrO_2 : 1TiO_2$, we have $3ZrO_2 : 2{\cdot}16TiO_2$.

This curious fact is notable in the minerals of zirconium. In Dana's great work there are given twelve analyses of zirconite, and in all of them the zirconia is low in relation to the silica, the mean being $ZrO_2 : SiO_2 = 1 : 1{\cdot}024$, in place of $ZrO_2 : SiO_2 = 1 : 1$, or an excess of silica of 0·024 molecule for molecule.

In the case of orvillite this excess is 0·01 molecule for molecule, and in that of oliveiraite 0·08 molecule for molecule.

ART VII.—*Further Notes on the Dustfall of March 9, 1918;* by A. N. WINCHELL and E. R. MILLER.

Replies to an inquiry addressed to the Section Directors of the Climatological Service of the Weather Bureau in the following states were uniformly to the effect that none of their cooperative observers reported dustfalls in the storm of March 7-11, 1918, viz.: Colorado, Idaho, Illinois, Indiana, Iowa, Kansas, Michigan, Minnesota, Montana, Nebraska, New York, North Dakota, Pennsylvania, South Dakota, Utah, Wyoming.

The Section Director for Wisconsin reports that "none of the observers mention the phenomenon in any way. Someone, I can not remember whom, told me that after that snow melted he found his front porch covered with red sand or soil."

The Section Director for Ohio reports the following notes by cooperative observers:

Tiffin, Seneca Co., March 12, Sun very red all day.
Wauseon, Fulton Co., March 12, very hazy and smoky.
Pataskala, Licking Co., March 12, very smoky.
Plattsburg, Clark Co., very dark sky on 12th.
Wilmington, Clinton Co., March 12th, heavy smoke or hazy all day.

At his own station, Columbus, on March 12th, "A peculiar reddish deposit was observed this morning in the central and northern parts of Columbus. It apparently came down with the rain of the early morning, and when the moisture evaporated it was quite evident on the windows of the buildings, and parts painted a light color."

The Section Director for New England reports the following notes by cooperative observers:

Alstead Center, N. H., March 14, 1918. "Sleet and rain mixed, making a crust about $\frac{1}{4}$ inch. In the morning it was of a reddish brown color and confined to the crust. On melting in white dish it left a sediment that was too fine to catch in cotton cloth, and was without grit, and felt smooth and oily. It covered seven miles square."

Woodstock, Vt., March 14, 1918. "Snow was yellow and pink."

Since the publication of the October number of this Journal a sample of dust has been received from Prof.

G. F. Wright of Oberlin, Ohio. He writes that it was collected from a protected roof in Oberlin, where it fell on March 12, 1918. This dustfall was preceded by a darkened sky, and produced a visible discoloration on the roofs. A microscopic examination of it shows that it is strikingly similar in composition and size to the dust which fell in Madison; it consists of the same minerals, the same spores and other organic fragments, and also the same diatoms, although the last named seem to be decidedly rarer than in the dust which fell in Wisconsin.

University of Wisconsin, Madison.

SCIENTIFIC INTELLIGENCE.

I. Chemistry and Physics.

1. *The Atomic Weight of Argon.*—A. Leduc has determined the density and compressibility of argon, using a sample of the gas which had been almost completely freed from helium and neon by fractional distillation at low temperatures after absorption by charcoal, and which was further purified by appropriate processes for removing small amounts of nitrogen oxygen, moisture, etc., until its specific gravity became constant. The density 1·3787, compared with air, was found, while Ramsay and Travers had found 1·379. The author could not claim from the accuracy of his results that his density was different from the other.

The compressibility of the argon was found to be 0·9990 as compared with an ideal gas, while that of oxygen is 0·9992. From these data, the molecular weight of oxygen, 32, and the specific gravity of the latter, the molecular weight of argon, which is the same as its atomic weight, was calculated as follows:

$$32 \times \frac{9990}{9992} \times \frac{1\cdot 3787}{1\cdot 1053} = 39\cdot 91$$

The last figure is uncertain, so that the accepted atomic weight 39·9 is confirmed. This confirmation is important because the atomic weight is exceptional in being larger than that of potassium (39·10), the element which follows it in the Periodic Table. *Comptes Rendus,* **167,** 70. H. L. W.

2. *The Emanation Method for the Determination of Thorium.*—G. H. Cartledge has applied this method to the analysis of monazite sands, the source of commercial thorium compounds. The emanation method is well known in its application to the determination of small amounts of radium, but thorium cannot be dealt with in just the same way as radium on account of the very short period, 54 seconds, of the thorium emanation. However, the author has been able to apply the method by passing

a current of air at a uniform rate through a definite volume of thorium solution and then through the ionization chamber and comparing the effects of known amounts of thorium upon the electroscope with the effects of the thorium in the samples to be analyzed. For details of the apparatus and the precautions necessary for preparing "radiochemically complete" solutions of monazite the original article must be referred to, but it is stated that an accuracy within 1·5 per cent of the total thorium is attainable by this method, and hence it appears to be a practically useful process. *Jour. Amer. Chem. Soc.*, **41**, 42.

H. L. W.

3. *Coal and its Scientific Uses;* by WILLIAM A. BONE. 8vo, pp. 491. London, 1918 (Longmans, Green and Co., Fourth Ave. and 30th St., N. Y. Price $7 net).—This is one of the extensive and valuable series of "Monographs on Industrial Chemistry," edited by Sir Edward Thorpe. It is a very able and interesting treatise on coal, and deals with statistics showing its importance, with its origin, quite elaborately with its chemical composition, with its combustion including its application to domestic heating, with the smoke nuisance, with the production of coke and gases from it, with fuel-economy in connection with iron and steel manufacture, with power production from coal, and with surface combustion. As Professor Bone is one of the inventors of the remarkable and practically important application of surface combustion, his discussion of it is particularly interesting.

The book is profusely supplied with useful tables, diagrams and figures, and it contains also a number of excellent plates, from photographs, representing manufacturing apparatus. It can be recommended to all who are interested in the scientific aspects of this vastly important practical subject. H. L. W.

4. *The Applications of Electrolysis in Chemical Industry;* by ARTHUR J. HALE. 8vo, pp. 148. London, 1918 (Longmans, Green and Co. Price $2.50 net).—This book is another of the very important series of "Monographs on Industrial Chemistry," edited by Sir Edward Thorpe. It begins with an introduction dealing with the theories connected with electrolysis, and then the methods of generating the current are described. After that the important applications are discussed, including the refining and winning of metals, the production of hydrogen, oxygen, chlorine, caustic soda, hypochlorites, chlorates, perchlorates, and many other compounds.

The book is provided with numerous illustrations, it gives many references to the literature, and it gives an excellent account of these very important industries, so that it is an unusually interesting and useful book. H. L. W.

5. *Introduction to Organic Chemistry;* by JOHN TAPPAN STODDARD. 12mo, pp. 423. Philadelphia, 1918 (P. Blakiston's Son & Co.).—This text-book which has been extensively

used since its appearance four years ago, now appears in a second edition. Many minor changes have been made and a few portions have been entirely re-written on account of the advances that have been made in the science.

While this text-book is not as large as some others on the subject, it gives a very satisfactory and clear presentation of the fundamental theories and facts and it is very suitable for its intended use in connection with lectures and laboratory practice. Many practical applications of organic chemistry are mentioned, so that the student may realize to some extent the part played by the science in ordinary life and in our industries.

H. L. W.

6. *Sounds Produced by Drops Falling on Water.*—It is doubtless a matter of common observation that sounds of short duration having a musical character are produced when drops fall upon the quiescent surface of a relatively large body of water. The predominant pitch is low when a large round stone is dropped into a stagnant pool, while the sound arising from the impact of a bullet, fired from a distant rifle, closely resembles that generated by dropping one wooden plank on another. In general, the pitch of the note is high at first, then falls, and afterward again rises. An account of some experiments performed along this line has been recently published by A. MALLOCK.

The author says: "It seemed probable that the pitch would be dependent on the resonance of the cavity formed by the impact of the falling drop, and the experiments here described were made with the object of determining the magnitude and shape of the cavity in question. It was found by trial that the same class of sounds were produced whether the falling body was a liquid drop or a solid sphere. The experiments, therefore, were made with solid spheres, as there is less complexity in the displacements caused by them than when the deformation of the fluid drop itself enters into the problem."

The experimental method may be broadly outlined as follows. Two solid spheres, initially at rest at the same level and having equal radii and densities, were released simultaneously by means of an electromagnet. One spherical shot fell into water contained in a rectangular vessel two opposite sides of which were made of sheets of plane colorless glass. The other shot tripped a key in the circuit of a Leyden jar, spark gap, etc. The photographic plate was placed against one of the plane windows of the water trough on the side most remote from the spark gap. The spark gap was so adjusted as to be at about the same level as the free surface of the liquid and on the continuation of the normal dropped upon the plane of the gelatin film from the point of incidence of the shot at the water surface. In this way shadowgraphs of the shot and of its path through the liquid were readily obtained.

In general, the reproductions of the photographs show the following characteristics of the air column within the liquid and above the descending shot. Immediately after the sphere has entered the liquid the boundary of the air column resembles a paraboloid of revolution with the axis vertical. A small fraction of a second later the elongated column begins to contract in horizontal cross-section at a short distance above the top of the shot. As the depth of the shot increases this contraction continues, thus causing the vertical plane section of the trailing air column to roughly resemble an elongated viscous droplet suspended from the apex of a fluted inverted cone, the base of which coincides with the free surface of the liquid. Next the air column is severed, leaving opposing points on the inverted cone and on the fish-shaped air recess which has the shot at its lower or head end. Finally the tail of this recess contracts and, at the same time, rings or flutings appear just above the shot. Simultaneously the cone shrinks toward the free surface of the liquid and becomes lumpy near the vertex. The configurations assumed by the liquid at, and above, its free surface are similar to the ones photographed by A. M. Worthington and beautifully illustrated both in the "Phil. Trans." (1897) and in his fascinating little book entitled "The Splash of a Drop."

With regard to the acoustical aspect of the problem the following quotation from the original paper will be sufficient. "The note which a cavity of continually varying volume would give when acting as a resonator would have its gravest pitch just before the sides coalesce. The predominant pitch would be of the same order as, but lower than, that of an open pipe of the length of the cavity, that is, the predominant wave-length would be more than four times the depth of the cavity. The larger of the two sizes of shot used in the experiments, when striking with a velocity of 16 feet per second, sometimes left an open cavity more than 4 inches deep; this would make the predominant wave-length about 1·5 feet, but only a few (3 or 4) vibrations of this length would have time to be formed, so that, incidentally, the present experiments show what a small number of vibrations can give rise to the sensation of pitch." It should be remarked, in conclusion, that the paper contains the elementary quantitative theory of the formation of the air column and an approximate equation of the plane generating curve of the aqueous envelope of the cavity. *Proc. Roy. Soc.*, **95** A, 138, 1918.

H. S. U.

7. *Polarization and Intensity of Light Scattered by Gases.*—The present paper by R. J. Strutt gives a detailed account of his second series of experiments on the scattering of light by the molecules of gases and vapors. The most important results obtained may be briefly summarized in the following sentences.

The light scattered at right angles to the axis of the primary beam by gases and vapors is not completely polarized. The ratio of the intensity of the vibrations which are parallel to the axis of the original beam to that of the vibrations normal to this direction has the values (expressed in per cent), given in the parentheses following the name of the substance: pentane (1·2), hydrogen (1·7), ether vapor (1·7), chloroform (3·0), ethylene (3·0), nitrogen (3·0), argon (3·2), carbon monoxide (3·2), carbon tetrachloride (3·5), air (4·2), benzene (6·0), oxygen (6·0), carbon dioxide (8·0), carbon disulphide (12·0), cyanogen (12·0), nitrous oxide (14·0), and helium (42·0).

The case of helium is remarkable since it polarizes far less completely than any other gas studied. The purity of the helium may have been decreased to such an extent by the special difficulties attendant upon the investigation of its optical properties as to lower the ratio of the intensities from 50 to 42 per cent. Theory indicates that, on the very plausible assumption of random orientation in the primary light, the 50 per cent ratio is to be expected if the vibration in the atom is limited to a direction fixed within the atom. Such an atom is the antithesis of the "spherical" atom or molecule which would give complete polarization of the perpendicular vibrations, that is, zero for the ratio. It is thus seen that the behavior of the helium atom at least approximates to that of a thin rod or needle. In this connection Strutt says: "There is reason to regard helium from the part it plays in radioactive phenomena, as being in a special sense a fundamental form of matter. It may be that the property here encountered is a direct result of specially simple atomic structure."

Within the limits of experimental error, the intensity of scattering by the different gases tried varies as the square of the refractivity.

Saturated vapors, even when very dense, show no increase of scattering power above that which the density would lead one to expect. If molecular aggregates are formed, they are not numerous enough to admit of detection by the experimental method employed.

Liquid ether apparently scatters about seven times less light than an equivalent mass of ether vapor. *Proc. Roy. Soc.*, 95 A, 155, 1918. H. S. U.

8. *A Handbook of Physics Measurements;* by Ervin S. Ferry. Vol. I, pp. ix, 251; vol. II, pp. x, 233. New York, 1918 (John Wiley and Sons).—This book was written by the chief author in collaboration with O. W. Silvey, G. W. Sherman, and D. C. Duncan. "The aim of the present work is to furnish the student of pure or applied science with a self-contained manual of the theory and manipulation of those measurements in physics which bear most directly upon his subsequent work in other departments of study and upon his future professional career." Since the book is designed to be commenced during the second college year the experiments require, in general, no mathematics

beyond college algebra and trigonometry. The methods of the calculus have been introduced only in the cases where their use effects appreciable economy of time and mental effort. In both volumes each chapter consists of two parts. The first part includes definitions, a description of the apparatus, the general theory of the methods, and the derivation of the equations used in the determinations of the quantities considered in the chapter. In the second part of the chapter each determination is described in detail with respect to the theory and performance of the experiment, and the computation of the result.

The first volume contains three chapters which deal respectively with general notions regarding physics measurements, with fundamental measurements and the properties of matter (25 experiments), and with optics (25 experiments). The four chapters of the second volume pertain to vibratory motion (4 experiments), to sound (10 experiments), to heat (20 experiments), and to electricity and magnetism (24 experiments). At the end of each volume are given numerous tables of physical and mathematical constants and an index. Great care has been taken both in the selection of the wide range of material and in the purely mechanical preparation of the pages, so that the two volumes reflect much credit upon the authors and the publishers. H. S. U.

9. *Comptes Rendus of Observation and Reasoning;* by J. Y. Buchanan. Pp. xl, 452, with 14 plates. Cambridge, 1917 (University Press).—This volume is essentially a collection of twenty-three papers written by the author at different times and dealing with a variety of subjects. Since lack of space makes it practically impossible to do justice to the immense amount of material presented in the book, the titles of a few of the articles will now be quoted in order to suggest the scope of the work. These are: 1 Recent Antarctic Exploration, 4 On Steam and Brines, 7 In and around the Morteratsch Glacier: A Study in the Natural History of Ice, 10 On the Solar Calorimeter used in Egypt at the Total Solar Eclipse in 1882, 13 Eclipse Predictions, 16 The Royal Society, 19 The Metrical System, and 22 Lord Milner and Imperial Scholarships.

The table of contents, which covers thirty-two pages, is virtually a complete summary of the text. A brief "summary of contents" takes the place of the customary index. The author's style is clear and pleasing, and no pains have been spared to make the volume as attractive as possible. The papers on antarctic exploration, glaciers, and the natural history of ice are extremely interesting as well as instructive. The artistic quality of all of the plates leaves nothing to be desired. In particular, the figures portraying the curious ice formations in the grotto of the Morteratsch Glacier, the solar etching of this ice, and the etching of the same by hoar-frost are very beautiful from both the esthetic and scientific points of view. The volume is undoubtedly a valuable contribution to all of the fields to which it relates. H. S. U.

10. *Elements of the Electromagnetic Theory of Light;* by LUDWIK SILBERSTEIN. Pp. vii, 48. London, 1918 (Longmans, Green and Co.).—"This little volume, whose object is to present the essentials of the electromagnetic theory of light, was rewritten . . . from my Polish treatise on Electricity and Magnetism . . . ." This text affords a striking example of the elegance and compactness of presentation which may be attained by the use of vectorial notation for, in less than fifty pages, the author has condensed all the salient points which fall under the following headings: 1, The Origin of the Electromagnetic Theory; 2, Advantages of the Electromagnetic over the Elastic Theory of Light; 3, Maxwell's Equations. Plane Waves; 4, Reflection and Refraction at the Boundary of Isotropic Media, E in Plane of Incidence; 5, Reflection and Refraction; $\mathsf{E} \perp$ Plane of Incidence. Note on the Transition Layer; 6, Total Reflection; 7, Optics of Crystalline Media: General Formulæ and Theorems; 8, The Properties of the Electrical Axes of a Crystal; 9, Optical Axes; and 10, Uniaxial Crystals. Not only does this volume merit the attention of the general scientific reader but it may be safely and especially recommended to graduate students for purposes either of review or of introduction. H. S. U.

II. GEOLOGY AND MINERALOGY.

1. *Thirty-Ninth Annual Report of the Director of the United States Geological Survey,* GEORGE OTIS SMITH, *for the year ending June 30, 1918.* Pp. 163, pls. 4.—The efficiency of the Survey organization, the reliability of its work, its knowledge of the resources of the country, and the ability of its staff have been put to the test during the past year with results that are highly satisfactory. From a peace organization engaged in scientific research it was converted, as it were, overnight into a group of officers engaged in military surveys and in searching for and developing methods of utilizing war minerals. By June 30, 322 members of the Survey were enrolled in the Army, and the entire topographic branch was at work on military maps at home and in France. Another large group was engaged in searching for oil and developing water supplies; and problems associated with the discovery, estimation, and development of manganese, potash, graphite, chromium, pyrite, and other "war minerals" were in the hands of special committees. The amount of work was enormous; for example, iron and steel alloy ores were examined in 1580 localities in 23 States and the West Indies. The country is indeed fortunate in having at hand this large force of highly trained men.

Although pressing war needs restricted the normal activities of the Survey a large amount of new geological work was done. Geological studies were carried into every State and Alaska. During the year the division of chemistry and physics made 1014 analyses of rocks, minerals, and water; investigated isotropic lead; made studies of capillarity and deep temperatures; and conducted experiments in the extraction of potash. The Water Resources Branch was unusually busy with problems relating to water supplies and water power and with the location of stock raising homesteads. The land-classification board reported on 9,972,256 acres including coal lands, oil reserves, phosphate reserves, power sites, non-irrigable lands, public water reserves, etc. The publications for the year number 229 and include 6 professional papers, 14 bulletins, 17 water-supply papers. H. E. G.

2. *Publications of the U. S. Geological Survey;* George Otis Smith, Director.—Recent publications of the Survey are noted below. See earlier vol. **45**, pp. 475, 476, June, 1918.—

Thirty-ninth annual report of the Director, noticed above.

Topographic Atlas.—Seventy-nine sheets.

Professional Papers.—No. 101. Geology and paleontology of the Raton Mesa and other regions in Colorado and New Mexico; papers by W. T. Lee and F. H. Knowlton. Pp. 450; 103 pls., 16 figs. Noticed later.

No. 106. Quaternary geology of southeastern Wisconsin; by W. C. Alden. Pp. 356; 25 pls., 2 figs. Noticed later.

Nos. 108, 120. Shorter contributions to general geology. No. 108, 1917. Part L. No. 120, 1918. Parts A, B, C, D, E, G, H.

Mineral Resources of the United States, 1916 and 1917. Numerous advance chapters.

Bulletins.—No. 655. The Lake Clark-Central Kuskokwim region, Alaska; by P. S. Smith. Pp. 176; 12 pls., 6 figs.

No. 662. Mineral resources of Alaska, 1916; by A. H. Brooks and others. Pp. 484; 18 pls., 8 figs.

No. 663. The structural and ornamental stones of Minnesota; by Oliver Bowles. Pp. 240; 21 pls., 27 figs.

No. 667. The Cosna-Nowitna region, Alaska; by H. M. Eakin. Pp. 64; 8 pls., 3 figs.

No. 670. The Salk Creek oil field, Wyoming; by C. H. Wegemann. Pp. 52; 7 pls., 2 figs.

Nos. 671, 672, 673, 674. Spirit leveling; R. B. Marshall, Chief Geographer. No. 671, New York, 1896-1905, 1912-1916. No. 672, Illinois, 1914-1917. No. 673, Kentucky, 1914-1916. No. 674, State of Washington, 1896-1917. The respective States have coöperated in each case.

No. 675. The Upper Chitina Valley, Alaska; by F. H. Moffit; with a description of the igneous rocks; by R. M. Overbeck. Pp. 82; 13 pls., 2 figs.

No. 684. Bibliography of North American geology for 1917, with subject index; by John M. Nickles. Pp. 154.

Nos. 690, 691. Contributions to economic geology. No. 690, 1918, I. Parts B, C, D, E, F. No. 691, 1918, II. Parts B, D, H.

WATER-SUPPLY PAPERS.—Nos. 409, 412, 413. Surface Water Supply of the United States, 1915. NATHAN C. GROVER, Chief Hydraulic Engineer. No. 409, IX, Colorado River basin. No. 412, XII, A. Pacific Slope basins in Washington and Upper Columbia river basin. No. 413, XII, B, Snake river basin. No. 414, XII, Lower Columbia river and Pacific drainage basins in Oregon.

Nos. 431, 432, 433, 435, 437. Surface Water Supply of the United States, 1916. No. 431, I, North Atlantic Slope basins. No. 432, II, South Atlantic and Eastern Gulf of Mexico basins. No. 433, III, Ohio River basin. No. 435, V, Hudson Bay and Upper Mississippi basins. No. 437, VII, Lower Mississippi River basin. No. 441, XI, Pacific Slope basins in California.

No. 425. Ground water for irrigation in Lodgepole valley, Wyoming and Nebraska; by O. E. MEINZER. Pp. 37-69; 3 pls., 1 fig.

No. 426. Southern California floods of January, 1916; by H. D. MCGLASHAN and F. C. EBERT. Pp. 88; 17 pls.

No. 428. Artesian waters in the vicinity of the Black Hills, South Dakota; by N. H. DARTON. Pp. 64; 13 pls., 11 figs.

No. 465. Surface water supply of Hawaii, July 1, 1916, to June 30, 1917.

3. *Geology and Paleontology of the Raton Mesa and Other Regions in Colorado and New Mexico;* by WILLIS T. LEE and F. H. KNOWLTON. U. S. Geological Survey, Professional Paper **101**. Pp. 450, pls. 103, figs. 16. Washington, 1917.—The work of Willis T. Lee in southeastern Colorado and northeastern New Mexico has resulted in a new interpretation of the age and relations of the Cretaceous and Tertiary formations. The confusing and contradictory conclusions of previous workers have been re-examined on the basis of extensive field work and the facts of age and structure built into a logical, connected history. The coal-bearing rocks formerly assigned to the Laramie were found to consist of two distinct formations, neither of which is Laramie; the lower, Vermejo, is the equivalent of the Fox Hill, and the upper, Raton, is Eocene. The unconformity separating Cretaceous from the lowest Tertiary was found to exist in all the coal fields west of the Rocky Mountains and is to be correlated with the post-Cretaceous unconformity along the eastern mountain front. The field methods devised to test this conclusion yielded a large amount of satisfactory evidence—structural, paleontologic, diastrophic, and paleophysiographic—and demonstrated that the most significant unconformities are by no means the most conspicuous. The methods used by Lee should find general application.

An examination of the evidence afforded by plants has led to an exhaustive study by Dr. Knowlton of the fossil flora of the Vermejo and Raton formations based on unusually large collections. From the Vermejo 108 forms are described including 72 new species. Only 4 species pass over the unconformity between the Vermejo and Raton. The Raton flora comprise 148 species. Dr. Knowlton's discussion of the paleobotany of the Raton Mesa is illustrated by 83 plates including 311 figures.

H. E. G.

4. *The Quaternary Geology of Southeastern Wisconsin;* by WILLIAM C. ALDEN. U. S. Geological Survey, Professional Paper **106**. Pp. 356, pls. 39, figs. 21. Washington, 1918.—Southeastern Wisconsin is classic ground for students of glacial geology, and the bibliography relating to the geology of this area of about 11,000 square miles includes upwards of 220 titles beginning with the reports of the Featherstonhaugh expedition in 1835. The large amount of field work done by earlier students resulted in describing and explaining the general features of Pleistocene and pre-Pleistocene geology, but many points remained in dispute awaiting accurate field mapping. The work of Dr. Alden has extended over a period of about 15 years, and the result is one of the most complete delineations and discussions of glacial features in print. The chapters include geologic formations underlying the glacial drift (pp. 49-112); the physiographic development and preglacial topography (pp. 113-128); outline of Pleistocene history (pp. 129-136); pre-Wisconsin glacial drift (137-171); the interval between the Illinoian and Wisconsin glaciation (pp. 180-257); deglaciation (pp. 257-309); red till and lacustrine deposits (pp. 310-324); glacial lake deposits and history (pp. 326-345). The four maps accompanying the report are particularly well designed.

H. E. G.

5. *United States Bureau of Mines;* VAN. H. MANNING. Director.—The following publications have recently appeared. See earlier vol. **45**; p. 476.—

Eighth Annual Report by the Director to the Secretary of the Interior, for the fiscal year ended June 30, 1918. Pp. 124, December, 1918.—The activities of the Bureau through the year named were largely devoted to special war work. This included, first of all, the investigation and development of toxic gases and war masks; also of gases for balloons. Further, various mineral substances specially needed for war purposes have been investigated. These included among others: nitrogen compounds, concentrated sulphuric acid, manganese, potash and tin. A study of the black sands of southern Oregon and northern California by R. R. Horner proved that they rarely contain enough gold and platinum to be worked at a profit, and no important supply of platinum can be expected from them. The results as to tin were also disappointing. On the contrary the study of a new process for the recovery of potash from the alkali lakes of

California has led to arrangements for large scale treatment at Searles Lake.

During the year, 22 bulletins, 33 technical papers and 15 other publications were issued, while 528,432 copies of the Bureau's publications were distributed. The list of bulletins recently received and not before listed (see earlier vol. **46**, p. 80 and p. 476) are as follows:

BULLETINS.—No. 103. Mining and concentration of carnotite ores; by K. L. KITHIL and J. A. DAVIS. Pp. 89; 14 pls., 5 figs.

No. 123. Analyses of mine and car samples of coal collected in the fiscal years 1913 to 1916; by A. C. FIELDNER and others. Pp. 478; 2 figs.

No. 127. Gold dredging in the United States; CHARLES JANIN. Pp. 226; 63 pls., 23 figs.

No. 129. The fusibility of coal ash and the determination of the softening temperature; by A. C. FIELDNER, ALBERT E. HALL, and ALEXANDER L. FEILD. Pp. 146; 4 pls., 38 figs.

No. 132. Siliceous dust in relation to pulmonary disease among miners in the Joplin District, Mo.; by EDWIN HIGGINS, A. J. LANZA, F. B. LANEY, and G. S. RICE. Pp. 115; 6 pls., 6 figs.

No. 140. Occupational hazards at blast-furnace plants and accident prevention, based on records of accidents at blast furnaces in Pennsylvania in 1915; by F. H. WILLCOX. Pp. 153; 16 pls.

No. 145. Measuring the temperature of gases in boiler settings; by HENRY KREISINGER and J. F. BARKLEY. Pp. 72; 31 figs.

No. 146. Technology of salt making in the United States; by W. C. PHALEN. Pp. 149; 24 pls., 10 figs.

No. 149. Bibliography of petroleum and allied substances, 1915; by E. H. BURROUGHS. Pp. 147.

No. 151. Recovery of gasoline from natural gas by compression and refrigeration; by W. P. DYKEMA. Pp. 123; 15 pls., 15 figs.

No. 156. The Diesel engine, its fuels and its uses; by HERBERT HAAS. Pp. 133; 16 pls., 57 figs.

No. 157. Innovations in the metallurgy of lead; by D. A. LYON and O. C. RALSTON. Pp. 176; 13 figs.

No. 160. Rock quarrying for cement manufacture; by OLIVER BOWLES. Pp. 160; 6 pls., 31 figs.

No. 163. Methods of shutting off water in oil and gas wells; by F. B. TOUGH. Pp. 122; 20 pls., 7 figs.

No. 164. Abstracts of current decisions on mines and mining, reported from September to December, 1917; by J. W. THOMPSON. Pp. 147.

No. 171. Melting brass in a rocking electric furance; by H. W. GILLETT and A. E. RHOADS. Pp. 131; 4 pls., 1 fig.

Among the other publications may be noted a HANDBOOK, entitled Efficiency in the use of oil fuel, a handbook for boiler, plant and locomotive engineers; by J. M. Wadsworth. Pp. 86; 4 pls., 17 figs.

6. *Gems and Precious Stones.*—Two chapters on this subject by W. T. Schaller from the volumes on U. S. Mineral Resources have been issued during the past year. From the report for 1916 may be noted the fact of a small production of diamonds in Arkansas; it is added that a report on this diamond-bearing area is in preparation by H. D. Miser of the U. S. Geological Survey. Isolated diamonds have been found in Cherokee Flat, Butte Co., Cal., and Brown Co., Indiana. The last named specimen had a weight of 1·48 carats. New occurrences of dumortierite in New Mexico and Nevada are also noted.

The chapter from the report for 1917 is especially valuable as giving a minute list of gem names covering many pages.

7. *The Adirondack Graphite Deposits;* by Harold L. Alling. Bull. 199, New York State Museum. Pp. 150; 25 figs.—This is an interesting and valuable contribution to the literature concerning our useful minerals. It describes in detail the geological structure of the graphite deposits in the Adirondack region and gives many maps and sections of particular areas. There are chapters also on the uses and origin of the mineral.

The Adirondack deposits can be roughly divided into two areas, the northern and southern which show distinct differences in character. The deposits of the northern area are mostly of the contact type, lying in the zone between an igneous and a metamorphosed sedimentary rock. The rocks most commonly so grouped are pegmatite and limestone, although graphite is also found with various other combinations. The contact deposits in general are too uncertain, too irregular and limited in extent to pay for mining. The graphite in this type of deposit is believed to be of an inorganic origin, probably derived from carbon monoxide or carbon dioxide gases.

The southern area is the region of productive mines. The deposits here are in the form of beds with strong evidence that the graphite is a definite constituent of the rock strata in which it lies. The origin in this type of deposit is considered to be organic in its nature. There are four different rock types in which the graphite is found, namely: 1, a quartz schist with 5 to 7 per cent graphite; 2, a feldspar-quartz schist with 6 per cent graphite and 10 per cent micaceous minerals; 3, a metamorphosed variety of the quartz schist in which pyroxenes and tourmaline have developed and in which the graphite has been concentrated in certain layers; 4, a meta-arkose composed almost entirely of potash feldspar. W. E. F.

8. *Genesis of the Zinc Ores of the Edwards District, St. Lawrence County, N. Y.;* by C. H. Smyth, Jr., Bull. 201, New York State Museum, 1918. Pp. 39, 12 pls.—The ore deposits of the Edwards district occur in a belt of Precambrian rocks made up chiefly of a thoroughly metamorphosed limestone. These rocks

were buried to great depths, folded and metamorphosed. This metamorphism was to a large degree contemporaneous with an intrusion of a great mass of granite and the injection of granite and pegmatite into the sediments. Later erosion exposed these rocks and then another subsidence occurred and Paleozoic sediments were deposited upon them. These latter have since been largely removed by erosion and the Precambrian rocks again exposed. The metamorphism of the limestone produced a crystalline rock contained diopside and tremolite, which subsequently have been largely altered into serpentine and talc. The sulphides, chiefly pyrite and sphalerite with only a little galena, were deposited during the period of metamorphism. They were formed after the diopside and tremolite but mostly preceding the change of the latter minerals to talc and serpentine. The ore minerals were apparently deposited by replacement action effected through the influence of hot gases and solutions evolved by the intruded granitic magma. W. E. F.

III. Miscellaneous Scientific Intelligence.

1. *Report of the Secretary of the Smithsonian Institution,* Charles D. Walcott, for the year ending June 30, 1918. Pp. 101. Washington, 1918.—The work of the Institution during the past year has been largely modified by the special war conditions existing in Washington. These have affected the labors of the staff, and particularly of the Secretary in connection with the National Research Council. It is also to be noted that the War Department allotted the sum of ten thousand dollars for experimental work in aviation in connection with the Signal Corps. Several bequests are mentioned in the report and also the gift by Dr. Frank Springer of his collection of fossil crinoids and related groups of Echinoderms. A fund of thirty thousand dollars has been arranged for to be devoted to the care of the collection. Various researches and explorations are noted, but these also have been much limited by the war. The Institution has met with a very serious loss in the death of Dr. Rathbun, already mentioned in these pages (see vol. **46**, p. 620, pp. 720-763). Among the various appendices to the report of the Secretary, that on the U. S. National Museum has been prepared by W. deC. Ravenel; the other chapters in this part of the report detail the special activities of the Institution; among these the National Zoological Park, and also the Astrophysical Observatory deserve special attention. The work of the Observatory is summarized by Dr. C. G. Abbot in the following paragraph: "During the year covered by this report, great advance has been made in the study of very long wave-length rays and their transmissibility in our atmosphere. Solar constant work at Mount Wilson has been continued and improved. An expedition under the auspices of the Hodgkins Fund of the

Smithsonian Institution, but equipped and directed from the Astrophysical Observatory, has observed the solar constant at Hump Mountain, N. C., and now is located for a term of years in exceptionally favorable circumstances at Calama, Chile. The total solar eclipse of June 8, 1918, was successfully observed. The variability of the sun is shown to have vestiges of periodicity, though predominently irregular. A great deal of attention has been given to war problems."

2. *Report of the Librarian of Congress,* HERBERT PUTNAM; *and of the Superintendent of the Library Building and Grounds,* FRANK L. AVERILL, for the year ending June 30, 1918. Pp. 191; with illustrations. Washington, 1918.—The librarian of Congress reports the progress of the department in his charge during the past year. It is not surprising that the accessions both of books and pamphlets, are somewhat less than they were in 1917; for example, 83,440 volumes as compared with 116,000. Among the numerous additions may be mentioned in the field of Orientalia, interesting records of the Ming and Ching historical records. Numerous important manuscripts are mentioned as having been added to the collection: these include the Jefferson papers; those of Jeremiah S. Black; of Reverdy Johnson; of William Wirt, and others. Of particular interest is the account of the literature and other material relating to the European War.

3. *The American Association for the Advancement of Science.*—The seventy-first meeting of the American Association was held at Baltimore from December 23 to 28. Twenty-one affiliated organizations met at the same time. The president-elect was Dr. John M. Coulter and the retiring president Professor Theodore W. Richards; the address of the latter, omitted because of illness, has been printed in the issue of SCIENCE for January 3, pp. 1-11. The next meeting of the association is announced to begin December 29, at St. Louis with Dr. Simon Flexner as the president-elect.

4. *The American Mineralogist.*—In consequence of the retirement of Mr. Wallace Goold Levison, Dr. Edgar T. Wherry, Bureau of Chemistry, Washington, D. C., will assume the duties of editor-in-chief of the American Mineralogist. The associate editors are as follows: George F. Kunz, Herbert P. Whitlock, Alexander H. Phillips, Waldemar T. Schaller, Edward H. Kraus, Austin F. Rogers, Thomas L. Walker, Samuel G. Gordon..

5. *War Neuroses;* by JOHN T. MACCURDY. Pp. ix, 132. Cambridge, England, 1918 (Cambridge University Press; price \$2.50).—This book describes the experience of one with a long record of skillful investigations of the psycho-neuroses of civil life when brought into contact in British hospitals with the special forms of neurosis which are produced by the shocks and strains of warfare. The cases on which the book is based are not startling rarities especially selected to show features of scientific

interest, but are characteristic, straightforward cases such as may be met with by the score in any hospital especially devoted to functional nervous disorders. The merit of the book lies, not in the nature of its material, but in the skill with which this material has been treated, and the clearness with which the essential facts have been set down and utilized to illustrate the special problems presented by the neuroses of war.

F. P. U.

6. *Practical Physiological Chemistry;* by PHILLIP B. HAWK. Sixth Edition, revised and enlarged. Pp. xiv, 661. Philadelphia, Pa., 1918 ((P. Blackiston's Son & Company).—In the sixth edition of this popular Practical Physiological Chemistry attempt has been made to bring it strictly up to date. This is especially true of such chemical phases of the phenomena of acidosis as have a bearing on clinical problems. Chapters on metabolism, blood analysis, gastric digestion, and quantitative analysis of urine, have been considerably extended, and the question of growth has been treated experimentally. Considerable change has been made in the procedure for the determination of various urinary constituents. Many new figures have also been introduced illustrating especially various crystalline compounds and various types of new apparatus. F. P. U.

7. *The Normal and Pathological Histology of the Mouth;* Vol. II; Pathological Histology; by ARTHUR HOPEWELL-SMITH. Second edition. Pp. x, 477. Philadelphia, 1918 (P. Blakiston's Son & Company).—This volume[1] considers the numerous morbid conditions of the hard and soft tissues of the oral cavity from the histological view rather than the clinical or pathological. The book is divided into three parts: I, The dental tissues; II, the oral tissues; III, the extra-oral dental tissues. There are chapters upon the pathological conditions of each of the main dental and oral structures. The author recognizes the importance of microbiology to a proper understanding of oral hygiene, and gives a painstaking discussion of this phase. The book is well printed, and contains numerous illustrations that add to its value. B. COHEN.

OBITUARY.

DR. ROSSITER WORTHINGTON RAYMOND, the mining engineer and for many years editor of the American Journal of Mining, later the Engineering and Mining Journal, died on December 31, at the age of seventy-eight years. He was an active worker and the author of a number of important works.

DR. REGINALD PHILIP GREGORY, the English botanist and, previous to the war in which he did active service, of the staff of Cambridge University, died on November 24, at the age of thirty-nine years.

[1] The first volume of this work was noticed in vol. 46, p. 480, August, 1918.

CONTENTS.

*Numbers of articles in parentheses are as given erroneously in the text.

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[FOURTH SERIES.]

Art. XII.—*On Ripples and Related Sedimentary Surface Forms and their Paleogeographic Interpretation;* by Walter H. Bucher.

Introduction.

Very few of the data, which the geologist can use in his attempts to reconstruct the geography of past times, allow of but one interpretation. He has to rely on combining a number of independent data and thus by elimination find an approach to the truth. The reliability of his conclusions depends, therefore, on the number of data at his command and on his ability to correctly interpret them.

The paleogeographical importance of fossil ripples was early recognized, but until recently little confidence could be placed in inferences drawn from them, since such information as existed concerning the conditions attending their formation was scattered and unsystematic.

If this paper contributes to the understanding and the confidence in the interpretation of rippled surfaces and, thereby, increases the small number of data by which the geologist can check his reconstructions, it has served its purpose.

Part I. The Origin of Ripples and related Sedimentary Surface Forms.

Table of Contents.

I. Subaqueous Current-ripples.

1. *The first critical point of current velocity.*

Below a certain velocity a current is unable to move the débris forming its bed. The point at which, with increasing velocity, motion is started, in the following discussion is called the "first critical point."[1]

In Table 1 are given the results of three series of determinations of the first critical point, which, though not giving absolute measurements of the critical velocity proper, at least indicate its order of magnitude.[2]

Umpfenbach measured the surface velocities of natural water courses at times of flood and noted the size of

[1] It corresponds to the lower critical velocity of Lechalas and to the velocity competent for traction of Gilbert's nomenclature. Gilbert, 1914, p. 194. In this and similar cases in the text, see the *Bibliography* at the end of this paper.

[2] Date obtained from artificial channels with rigid bed cannot be used directly; cf. Gilbert, 1914, p. 218.

débris that were found undisturbed at their bottom. Login and Gilbert worked with artificial channels. The abbreviated form in which Gilbert's figures are quoted does not do justice to the comprehensiveness of his data.

Umpfenbach, in contrast to Login and Gilbert, determined the surface velocities at which the débris remained unmoved in natural water courses. He probably dealt with depths measured in decimeters rather than in centimeters, which will account for the greater velocities found. None of them give bed velocity; that is, the mean of such velocities as occur sufficiently near the bed to be directly engaged in the process of traction.

TABLE I, SHOWING APPROXIMATE CURRENT VELOCITIES NECESSARY TO MOVE DEBRIS OF DIFFERENT SIZE.

Description	*Mean diameter* *mm.*	*Depth* *m.*	*Velocity* *m./sec.*	
Brick clay, allowed to settle from suspension (L)		(shallow)	0·08	(*s*)
Fine loam and mud (U)		(shallow)	0·32	(*s*)
(Fine sand) (G)	0·4	0·13	0·26	(*m*)
(Sand) (G)	0·5	0·12	0·28	(*m*)
Freshwater sand (L)		(shallow)	0·20	(*s*)
(Sand) (G)	0·7	0·2	0·34	(*m*)
Sea sand (L)		(shallow)	0·34	(*s*)
Coarse sand (U)		(shallow)	0·49	(*s*)
(Coarse sand) (G)	1·7	0·006	0·34	(*m*)
(Fine gravel) (G)	3·2	0·028	0·46	(*m*)
Rounded pebbles, size of peas (L)		(shallow)	0·61	(*s*)
Very small pebbles (U)		(shallow)	0·65	(*s*)
(Fine gravel) (G)	4·9	0·033	0·65	(*m*)
(Fine gravel) (G)	7·0	0·066	0·86	(*m*)
Gravel (U)	27·0	(shallow)	0·97	(*s*)
Gravel (U)	54·0	(shallow)	1·62	(*s*)
Bowlders (U)	171·0	(shallow)	2·27	(*s*)
Bowlders (U)	323·0	(shallow)	3·25	(*s*)
Bowlders (U)	409·0	(shallow)	4·87	(*s*)
Bowlders (U)	700–800·0	(shallow)	11·69	(*s*)

NOTE.

(U) = Umpfenbach, quoted from Penck, Morphologie der Erdoberflaeche, vol. 1, p. 283, 1894.

(L) = Login, Proc. Roy. Soc., Edinburgh, vol. 3, p. 475, 1857.

(G) = Gilbert (1914); the first three figures taken from table 9, p. 69; the others from the averages given on p. 71.

Also: (*s*) = surface velocity, (*m*) = mean velocity. Login's and Gilbert's figures have been transformed from inches to nearest mm., and from feet to nearest cm.

2. *The first appearance of current-ripples.*

Soon after a large number of grains have begun to move, often immediately after the first movement set in, a rippling appears on the surface of the sand.

Berthololy (1900, p. 84), who studied the formation of current-ripples on the bottom of shallow creeks, describes their first appearance as being similar to that of wind-formed ripples, as one can observe it on any surface of dry sand exposed to the wind.[3] After having smoothed the sand by means of a board, he observed that the first minute accumulations of sand seemed to form about some of the larger grains lying scattered over the surface without any definite arrangement. They soon began to travel downstream and to lengthen in the direction at right-angles to the current, and finally united laterally to form normal current-ripples. If the surface of the sand was perfectly smooth, the first minute accumulations of sand did not appear until after some time; as soon, however, as they had reached a certain size, they grew rapidly until they had reached their full development.

For the interpretation of the mechanical processes involved, the statement is of great importance, that the obstacle which forms the nucleus for the growing current-ripple must be very small. Otherwise, a vortex forming in front of the obstacle will prevent deposition there and even undermine it. This occurred in front of a ruler, one centimeter thick, placed on the sand at right angles of the current, while an ordinary current-ripple was built over it, when only its uppermost edge was permitted to extend beyond the surface of the sand.

Berthololy's observations and the experiments performed more recently by Blasius, Hahmann, Gilbert and others, prove beyond doubt that current-ripples may be *formed by a uniform current,* a fact that had been doubted by Darwin (1893, p. 34), and that they *originate simultaneously over the whole bed,* not successively as Forel (1895, p. 253) had thought.

Gilbert (1914, pp. 242, 243) states that in his experimental work on stream traction he found "positive evidence that the dune interval was determined by a pre-existent water rhythm." "In certain experiments a slow current moving over a bed of débris artificially smoothed and leveled, was gradually quickened until transportation began. The movement of particles did not begin at the same time all along the bed but was initiated in a series of spots separated by uniform intervals, and the first result of the transportation was the creation of a

[3] Cf., *e.g.*, Ch. Lyell, Principles of Geology, 1892, 11th edit., p. 342.

system of dunes." "In certain experiments on flume traction a slow current moving over a smooth channel bed of wood, swept along a small quantity of sand. With increase of the load of sand, local deposits were induced, which took the form of thin straggling patches, similar to one another in outline and separated by approximately equal bare spaces." Baschin (1899, p. 420) has called attention to a similar arrangement of wind-blown sand in parallel elongated patches, as it may at times be observed on asphalted streets.

3. *Rhomboid ripples.*

Still more suggestive is a peculiar form of current-ripples that was described by H. Engels (1905), the head of the laboratory of River Engineering at Dresden. In his experiments the *first effect of transportation by a uniform current* was the formation of *small rhomboidal, scale-like tongues of sand,* arranged in a reticular pattern, strikingly resembling that of the scales of a Ganoid. Each tongue has one acute angle pointing down stream, formed by two steep leesides, while the other, pointing up stream, is formed by the gentle slope extending into the reentrant angle of the leesides of two tongues of the following, alternating row.[4] I suggest the name *rhomboid (current-)ripple* for this peculiar form which must not be confused with polygonal interference ripples (cf. p. 190 ff.). In Engel's experiments, with increasing velocity of the current, common current ripples took their place.

4. *Data concerning current-ripples.*

1. *Ground plan.*[5]—Where developed over large surfaces by a current of uniform direction, as on tidal flats, current-ripples consist of numerous essentially parallel, long, narrow, more or less equidistant ridges, trending in straight or gently curved lines at right angles to the current, anastomosing frequently, in general offering a

[4] Kindle (1917) figures on pl. 19B a good example of the same type observed on a beach in Lake Erie. The only case of this very striking pattern that came to my observation, I was unable at the time (1913) to study in detail. It was in one of the distributaries of a waste delta built into Cobalt Lake, Ontario, from the flumes of the plant of the Nipissing Mining Co.

[5] Good illustrations: Brown, 1911, p. 540, fig. 3; Epry, 1913, pl. 1, fig. 2; Scott, W. B., An Introduction to Geology, 2d ed., 1909, fig. 127, p. 248; Kindle, 1917, pl. 7, 9-11.

pattern which Forel[6] aptly compared to that formed by the grooves of the palm of the human hand. Where confined to a narrow channel, the current-ripples are more or less crescent-shaped, the convex side directed down stream, often not extending across the whole channel. Where the current lacks uniformity, the shape and arrangement of the ripples tends to be irregular. Irregularities of the stream bed, of vortices within the current may give rise to a rather complicated arrangement (Bertholoty, 1900, p. 94). Vortices forming along the bank of a stream may even produce ripples trending parallel to the main current. Several such cases were observed by the author along the shores of creeks in the vicinity of Cincinnati after floods,[7] and Bertholoty (l. c.) reports similar occurrences.

2. *Profile.*—The profile of a typical current-ripple is that of a miniature dune with a gentle stoss-side and a steep lee-side. The degree of asymmetry may be expressed by the ratio of the horizontal length of the lee-side to that of the stoss-side. This will be called the "*horizontal form index,*" in contrast to $\frac{\text{wave-length}}{\text{amplitude}}$ the "*vertical form index.*" In the few cases recorded on table 3, the horizontal form index ranges approximately from 2 to 4.

3. *Lines of flow.*—The lines of flow, as represented in fig. 9A, were first recognized and figured by Darwin (1884, p. 23), who demonstrated the existence of a *vortex on the lee-side* by placing a drop of ink in the trough between two ripples. The action of this vortex causes small particles to creep up-stream on the lee-side of a ripple. This was repeatedly seen by the author as well as by other observers.[8]

4. *Traveling.*—Current-ripples travel down stream as the grains are rolled up the gentle slope and dropped into the vortex of the lee-side, to be deposited there.[9] It should be noted especially that the ripple as such is absolutely rigid, while just the grains of the top layer roll along the surface, no grains being carried in suspension. The structure of a current-ripple should, therefore, in the

[6] 1895, p. 250 (speaking of wave-formed ripples).
[7] Cf. No. 1 of table 2.
[8] Darwin, 1884, p. 22; Bertholoty, 1900, p. 86.
[9] Forel calls the stoss-side "face d'erosion," the lee-side, "face d'alluvion."

most typical case, consist of laminæ of deposition parallel to the lee-slope, cut at an oblique angle by the up-stream slope. Where the transported material consists of a very inhomogeneous mixture, this structure is easily discerned. Bertholoby, for example (1900, p. 99), observed the following layers in a single current-ripple on the dry bed of a creek: sand, humus, mud, mud and sand, sand. This structure can be preserved only if the direction of the current remains constant for sufficient length of time. Otherwise the slopes of the new ripple surface will intersect with the lines of sedimentation of the older ones, producing a complex pattern. This I have very frequently observed, *e. g.*, in the shaly sandstones of the Pottsville group in eastern Kentucky and also in some rippled limestones of the Richmond group in central Kentucky.

Bertholoby observed also that in active current-ripples the coarser grains accumulated on the lee-side.[10] In fact, the largest grains on the lee-side exceeded those on the stoss-side three to four times (1900, p. 96), probably because the smaller grains are caught oftener in their march across the upstream side, therefore traveling slower than the coarser grains, which are given a longer rest on the lee-side (1900, p. 98). Similar discrepancies in size of the grains on the two sides of current-ripples were frequently observed by the author.

Two measurements of the speed of traveling are given in tables 2 and 3. This speed is greatly increased, if during the marching of the current-ripples material is added from above. In this case, sediment is deposited on both stoss- and lee-side, although much more on the latter than on the former, resulting in a peculiarly small scale pattern of cross-bedding, which Sorby has called *ripple-drift*.[11]

Since the current in contact with the sediment must be so weak as not to carry any sediment in suspension in order to give rise to current-ripples, no sediment can be added through it directly to the rippled sedimentary surface. The preservation of current-ripples in general,

[10] Similar conditions were observed on eolian current-ripples. Forchhammer (1841, p. 7) saw on dunes of Northern Jutland the crests of eolian current-ripples covered with white quartz sand, while the hollows consisted of black magnetite sand.

[11] 1859, p. 143. I suspect that much of what Gilbert described and figured as ''Compound cross-bedding'' (Bull. Geol. Soc. Am., vol. 10, p. 139, pp. 3-5, 1899) is ripple-drift.

therefore, must be due to special conditions, which, under circumstances, may be of value to the paleogeographer. In general there are two possibilities:

1st. The sediment is carried in suspension by a strong surface current, from which it settles into the quiet bottom water, for instance, the strong surface current of a river emptying into an ocean[12] or into another river, or flowing over deeper retarded portions of its own course; or a surficial wind-drift current carrying sediment in suspension in the upper layers of the water from shallower or more disturbed regions into quieter or deeper water.

2d. The sediment settles into the water from the air, as *e. g.*, volcanic ashes or windblown sand. The green slates of Langdale, as described by Sorby (1908, p. 197, pl. 15), are a good example of the former, since they consist practically of fine-grained volcanic ash and show this structure beautifully. In case of ripple-drift, the bottom water is in gentle motion.

5. *Wave-length and amplitude.*—In addition to the quantitative data compiled in tables 2 and 3, the following observations are of importance:

(*a.*) When first appearing, current-ripples show a wave-length which is half that of their full development (Blasius, 1910, p. 468).

(*b.*) The wave-length increases with the velocity of the current. Hahmann's experiments (1912, p. 646; cf. table 2) seem to prove that the increment of wave-length is proportional to the increment of velocity. This law, of course, holds good only between the two critical points of velocity, between which current-ripples can exist. It cannot be reversed; *i. e.*, the wave-length does not decrease in proportion to the velocity.

(*c.*) Hahmann made an attempt to determine whether depth of water aside from its controlling influence on the distribution of velocities within the current influences the wave-length of current-ripples. His determinations were made with a disk, covered with sand, rotating in water. Within the narrow limits of depth at his disposal no influence of the depth of water on the wave-length was found (1912, p. 655).

[12] In this case the weak bottom current may flow in opposite direction to the surface current.—For a very interesting case of the checking of a strong surficial tidal current in the Golden Gate at periods of great freshets in the Sacramento and San Joaquin rivers, see Kindle, 1917, p. 46.

TABLE II.—Experimental Data on Subaqueous Current-Ripples.

Reference.	Wave-length. l(cm.)	Amplitude. a(cm.)	$\frac{l}{a}$	Mean Diameter of Particles. D(mm.)	Depth of Water. d(m.)	Velocity of Current. v(m/sec.)	Speed of Traveling. t(mm./sec.)
Blasius	--------	------	4–5	0·4	0·03	0·303(m)[a]	
(1910,	--------	------	later	0·2	--------		about 0·5
p. 468)	--------	------	10	--------	--------		
Hahmann	12·5	------	-----	constant	constant	0·313(s)	--------
(1912)	12·91	------	-----	"	"	0·338	--------
Table 1.	13.07	------	-----	"	"	0·35	--------
	13·18	------	-----	"	"	0·375	--------
	13·30	------	-----	"	"	0·394	--------
	13·42	------	-----	"	"	0·431	--------
	13·57	------	----2	"	"	0·45	--------
	13·72	------	-----	"	"	0·475	--------
	13·89	------	-----	"	"	0·50	--------
	13·94	------	-----	"	"	0·525	--------
Table 3.	13·92	------	-----	2·8–2·3	constant	0·375(s)	--------
	13·74	------	-----	2·3–1·8	"	"	--------
	13·5	------	-----	1·8–1·5	"	"	--------
	13·2	------	-----	1·5–1·0	"	"	--------
	12·87	------	-----	1·0–0·0	"	"	--------
	12·4	------	-----	"feiner Quartz-sand"	"	"	--------
Table 8.	13·53	------	-----	constant	0·035	constant	--------
	13·55	------	-----	--------	0·055	--------	--------
	13·55	------	-----	--------	0·075	--------	--------
Gilbert[b]	17·8	1·3	14	--------	--------	?±0·45*(m)	2·8
(1914,	–22·8	------	–18	--------	--------	--------	--------
p. 32)	33·0	------	17	--------	--------	?±0·60*(m)	7·6
	–38·1	1·9	–20	--------	--------	--------	--------
Table 4.	"dunes"	------	-----	0·3 (A)	0·02–0·06	0·31–0·51(m)	--------
	reported	------	-----	0·4 (B)	0·02–0·14	0·33–0·83	--------
	--------	------	-----	0·5 (C)	0·02–0·18	0·34–0·83	--------
	--------	------	-----	0·7 (D)	0·02–0·15	0·27–0·89	--------
	--------	------	-----	1·7 (E)	0·04–0·19	0·36–0·92	--------
	--------	------	-----	3·2 (F)	0·06–0·11	0·81–1·06	--------

[a] In column 7, m = mean velocity, and s = surface velocity as in Table I.
[b] Gilbert's figures have been transformed from feet to nearest cm. or mm. The velocities marked with asterisks are not given in Gilbert's paper, but are supposed by the author to represent probable values, judging from the data given in the tables. They are mentioned only, in order to make possible a comparison between the rate of increase in wave-length and current-velocity in this and in the other experiments.

TABLE III.—Observational Data on Subaqueous Current-Ripples.*

Author	Locality.	l cm.	a cm.	$\frac{l}{a}$	horizontal form index.	D mm.	d m.	v m./sec.	t mm./sec.
Bucher ----	bank of creek, after flood	1·1–2·0	0·1	10	1·8	av. 0·5 max. 2·5	few cm. ---	---	---
*Kindle, 1917 ------	St. Lawrence River	3·8	---	---	---	---	0·076	barely percep-tible	0·03[a]
(p. 13) ----		5·0	---	---	---	---	0·15		0·04
(p. 12) ---	" "	---	---	4–6	---	---	---		---
Bucher ----	in gutter after heavy rain	5·7	0·3	19[d]	---	fine sand with mud	---	---	---
Hahmann, 1912 ------	sea shore (undertow of wave) ------	6·0	0·3	20	---	---	---	---	---
Bertholoy, 1900 (p. 31)	---	---	---	4–6	---	---	---	---	---
(p. 91)	creek -------	---	0·5–1·5	---	---	sand	---	---	---
	" -------	---	2–5	---	---	coarser material	---	---	---
*Wyman, 1866 -----	lake shore[c] (wave of translation)	7·6	---	---	---	---	---	---	0·04
*Sorby, 1908 ------	sea shore ----	8·9	1·8	5	(1·8)[b]	---	---	---	---
	creek -------	10·2	0·9	11	(4·7)[b]	---	---	0·305 (s)	1·3
*Kindle, 1917 fig. 3, opp. p. 8 ------	Avon river, N. S. -------	9·1	0·7	13	3·8	---	---	---	---
	tidal flats, N. S. ---------	8·2, 8·9	6·7–0·7	12	2·3, 1·8	---	---	---	---
	" "	13·4, 14·9	1·6–1·4	8, 10	1·8, 2·6	---	---	---	---
*Brown, 1902 ------	sea shore, Labrador ---	7·6–10·2	1·9	4–5	---	---	---	---	---
Hahmann, 1912 ------	Rhine river --	15	1·0	15	---	---	---	---	---
*Sorby, 1908 ------	sea shore, England ---	30	---	---	---	---	---	---	---

* The figures taken from authors marked with an asterisk have been transformed from inches to the nearest mm. The symbols at the heads of the columns the same as those used on Table II.

[a] These were oscillation ripples formed by "onshore waves working in the presence of a barely perceptible current."

[b] Computed from the angles of slope given (9°, 19°; 18°, 30°).

[c] Augur lake near Keeseville, Clinton Co., New York, which is about one and one-fifth mile long and one to two-fifths of a mile wide. The steep side of the ripples faced the land; they were produced by the waves of translation resulting from waves 90 cm. long.

[d] This abnormal ratio was due to lack of sediment, for on the lee-side of each ripple the concrete bottom of the gutter was exposed for the distance of about 1·5 cm.

(*d.*) The wave-length decreases with increasing salinity, *i. e.* density of the water, not, however, as a linear function. The higher the concentration, the greater is the decrease.

(*e.*) The wave-length increases with rising temperature. This increase is not due to the effect of temperature on the density of the water: for it continues uniformly from below to beyond 4°C.

(*d.*) and (*e.*) are due to the changes in the viscosity of the liquid. The viscosity of solutions decreases with rising temperature and increases with increasing salinity. The higher the concentration, the more rapid the increase of viscosity. The curves constructed by Hahmann after his experiments, showing the relations between wave-length, density and temperature, correspond directly to those showing viscosity as a function of temperature and density, except that they are the reverse of the latter (for details compare Hahmann, pp. 667 to 668). The wave-length, therefore, is inversely proportional to the viscosity of the liquid.

(*f.*) The wave-length increases with increasing size of the grain, whether in linear proportion or not, could not be determined. In case of mixtures, the largest grains, if present in sufficient numbers, determine the wave-length (Hahmann, pp. 648-9). Fine grains mixed with coarser material help greatly to increase the sharpness of the crest without, however, affecting the wave-length.

(*g.*) The wave-length is independent of the density of the débris. Hahmann mixed iron-filings and fine sand in equal proportions and obtained the same wave-length as with fine sand along (pp. 653-5). (Spec. gr. 2·6 vs. 7·5!).

(*h.*) The wave-length appeared to be independent of the thickness of the bed of sand (p. 655).

(*i.*) No data exist concerning the influence of the shape of the grains.

5. *The formation of current-ripples.*[13]

From the foregoing we can describe the formation of current-ripples as the establishment of a layer of vortices with a horizontal axis, separating the essentially rigid bed from the liquid. The resulting arrangement of flow

[13] See also p. 199 ff.

lines must represent an *optimum of conditions of flow,* probably a minimum of friction, as any form of contact between the bed and the liquid other than that of current-ripples proves to be unstable, and always tends toward the establishment of the latter.

That we are, in all probability, dealing with a *minimum problem,* is also indicated by the fact that, under conditions not yet specified, instead of the normal parallel, straight ripples, rhomboid ripples make their appearance, offering a pattern which recurs frequently in the solution of minimum problems (cf. Engels, p. 675).

That the ripple form really offers a mechanical advantage over the even surface is directly shown by Gilbert's observation, that transportation reaches a maximum with the definite establishment of ripples.

The formation of current-ripples must be due to the fact that any accidental shifting of sandgrains into a position favorable to the establishment of vortices of suitable size and spacing, is liable to be permanent, while any unfavorable changes put the sandgrains into unstable positions from which they will be moved again.

The process is initiated by the small vortices setting up in the small depressions left by such grains as, owing to their size, shape, position, or other cause, are the first to be moved (King. p. 204). As the small vortices coalesce and rapidly grow up to their final size, an equilibrium is established between the currents of different velocities within and without the vortical layer which separates the sediment below and the lowest level of uniform flow above.

The comparison of these vortices with "a kind of ball-bearing to allow the upper and more rapidly moving layer . . . to pass along more easily" is quite appropriate (King. p. 205).

The distribution of velocities necessary for this equilibrium alone determines the size and spacing of the vortices, and this, in turn, the size and shape of the current-ripples.

The distribution of velocities is determined by: (*a*) the velocities existing at the upper and lower boundary of the vortical layer, and (*b*) the viscosity of the liquid.

The *velocity at the upper boundary* of the vortical layer is a function of the mean velocity of the stream. It probably affects chiefly the height of the vortices. An increase of the height of the vortices, other things being equal, increases the wave-length of the ripples.

The *velocity at the lower boundary* is affected by the bed resistance, which is a function of the size of the grains. An increase in the size of the grain means reduction of the velocity of the bottom current. This must disturb the equilibrium, since owing to this retardation, the same volume of water can not pass the crest of the vortices.

I suggest that the inclination of the gentle slope of the current-ripple regulates the discharge of water across the crest and thus counteracts the retardation of the bottom current. Its effect is probably analogous to that of the approach to a weir on its discharge. In a series of experiments made by Rafter[14] in 1898 for the U. S. Deep Waterways Commission at the Canal of the Cornell Hydraulic Laboratory, the following values of the variable factor M of the formula for the discharge of a weir were found:

Up-stream slope	*Head on crest in feet*				
	1·0	2·0	3·0	4·0	5·0
26°......	3·44	3·66	*3·68*	*3·70*	*3·71*
18°......	*3·82*	*3·69*	3·55	3·55	3·55
14°......	3·44	3·48	3·48	3·48	3·48
11°......	3·33	3·35	3·38	3·39	3·39

The crest of this weir was 0·66 feet wide and had a vertical down-stream slope. Although a submerged weir would offer a closer analogy to the case of current-ripples, these experiments suffice to illustrate the effect of the up-stream slope on the discharge. In this case, the most favorable angle for low velocities (1-2 feet head) is smaller than that for higher velocities (3-5 feet head).

The coarser the grain, and therefore, the smaller the velocity of the bottom current, the smaller the inclination of the gentle slope of the ripple has to be, in order to give the same discharge as with finer grains. Such a reduction of the inclination of the gentle slope, other things being equal, necessarily increases the wave-length of the ripples. It is thought that the gentle slope of the current-ripple adjusts itself automatically to the needs of the whole system and thereby increases the wave-length, when the size of the grains of the sediment increases.

[14] Quoted from M. Merriman, Treatise on Hydraulics, 1912, p. 163-164.

Increasing *viscosity* reduces the energy of the whole system which, in the first line, decreases the height of the vortices and with it, of course, the wave-length of the ripples.

A comparison of the range of wave-lengths obtained by Hahmann in his experiments[15] with that of current-

Fig. 1.

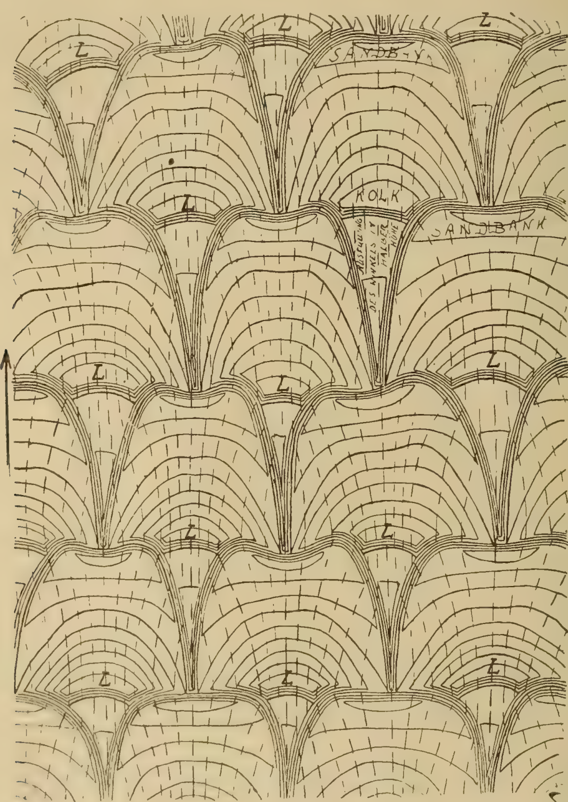

Fig. 1. Contour map representing the ideal form of linguoid current-ripples. L = lowest point; dotted lines = lines of flow of water. (Copied from H. Blasius, 1910, fig. 3.)

ripples observed in nature brings out a remarkable discrepancy. Between the extremes of velocity (0·313-0·525 m/sec.) and of grain (average diameter from below 0·1 mm. to 2·8 mm.) the wave-length varies between 12·4

[15] Cf. tables 2 and 3; for complete data see original paper.

and 13·94 cm. in Hahmann's experiments. The range observed in nature, on the other hand, extends from 1·5 to 30 cm! This discrepancy seems to indicate that another factor enters into the equilibrium of forces which determines the spacing, that is, the wave-length, of current-ripples.

I suggest that *the vertical distribution of velocities above the vortical layer exerts a strong influence on that within it.* In Hahmann's experiments, made with a sand-

FIG. 2.

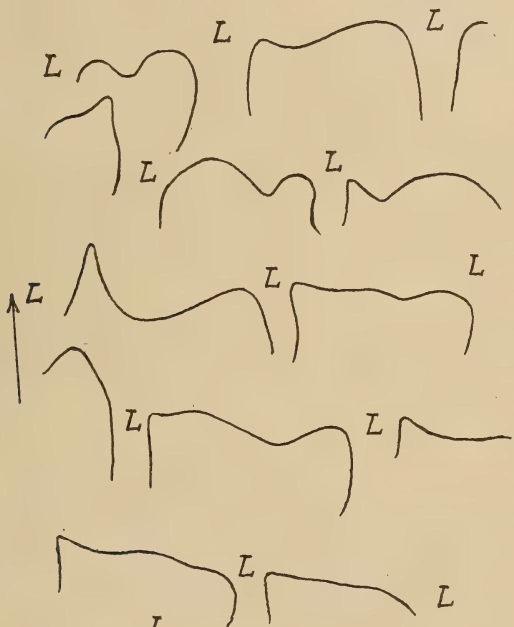

FIG. 2. Outline of actual shape of linguoid ripples formed in experiment trough (ground-plan). (Redrawn after H. Blasius, 1910, pl. 50, fig. 11.)

covered semicircular disc rotated under water, the distribution of velocities was determined solely by the internal friction of the liquid. The depth of the water was small and the velocities changed rapidly from a minimum in contact with the bed to the maximum at the surface. In nature, the vertical distribution of velocities varies greatly according to slope of bed, depth of water and other conditions, as a glance at the latest curves published by Gilbert (1914, pp. 244-246) will show. This difference may account for the different results.

6. *Linguoid current-ripples.*[16]

A peculiar form of current-ripples, resulting from a transformation of the common type, was described by Blasius (1910). In his experiments, each current-ripple, regular at first, was broken up into a series of alternating small "sandbanks" and hollows.

Each "sandbank" has the shape of a tongue or shingle with a notch somewhere near the center. The "tongues" of one row lie opposite the lines of contact of those of the preceding and following rows. The points of deepest excavation are not located right behind the highest crest of each tongue, but opposite the line of contact of two adjoining ones. Upstream of each such deep hollow, in the angle between the sides of two adjoining tongues, is found a flat triangular area, which in height stands half way between the top of the crest and the bottom of the hollow. The actual form of the ripples as seen in nature is much more irregular and often deviates widely from this ideal form (cf. fig. 2). For this form of current-ripples I suggest the name *linguoid* (*current-*) *ripples.*

The essential feature of these linguoid ripples is the fact that they present a complication of the flow lines in the horizontal in addition to that of the vertical plane. Fig. 1 represents Blasius' ideal map reconstruction of such ripples in contour lines with the corresponding flow-lines, which are characteristically sinuous. Blasius interprets the transformation of the straight flow-lines into this pattern of sinuous lines as a direct analogy to the well-known law,[17] according to which water laden with sediment and flowing in a straight channel, will soon change its straight direction of flow and the uniform transportation into a sinous line of flow with erosion on the outer and deposition on the inner sides of the curves on alternating sides of the channel.

With the scanty data at hand it is impossible to define the conditions that lead to this transformation of current-ripples. Linguoid ripples seem, however, confined to sandbanks and shores of rivers and tidal flats, where the water-level underwent a rapid change leading to complete exposure. In such situations they are very common.

[16] Good illustrations : Kindle, 1917, pl. 16, 17, 33 (fossil).
[17] Handbuch d. Ingen. Wiss., pt. 3, vol. 1, p. 350.

II. Sand-waves and Related Surface Forms.

1. *Second critical point of current velocity.*

At a certain velocity, which differs for each grade of débris, the mode of transportation is changed and the current-ripples disappear. "As the velocity of the current increases some of the grains leap as well as roll, and some, instead of dropping over the crest of a dune and resting, leap to the next dune. The dune grows less distinct in form and finally at a critical velocity it disappears, dune motion ceases, and the sand surface becomes comparatively even."[18] Correspondingly, Bertholoy observed that in creeks, with increasing volume, that is velocity, of the water all current-ripples disappeared in certain places (1900, p. 92).

This is due to the fact that the mechanical effect of the current is extended below the surface, destroying the immobility of the sand bed, which is the prerequisite of the existence of current-ripples. Instead of the topmost grains rolling and skipping over a bed of sand, we find a whole layer of mixed sand and water in motion, grading insensibly into the motionless substratum. Above this layer of moving sand and water we find water with little sand in suspension, the transition not being gradual but abrupt (cf. Gilbert, 1914, fig. 5, p. 27).

A. *Regressive Sand-waves.*

1. *The third critical point.*

After the second critical point there followed in Gilbert's experiments a "smooth phase," in which the sand surface was comparatively even, the motion of the sand extending quite a distance below the surface. With increasing velocity a third critical point was reached at which the sand surface again assumed a waved appearance. These new sand-waves, in contrast to current-ripples, traveled up-stream. To emphasize this contrast Gilbert called them "anti-dunes." For reasons to be given later, this concise term is not used in this paper, but for it is substituted that of "regressive sand-waves." Similar sand-waves are common in shallow, silt-laden streams and have repeatedly been described in literature. They will be discussed with those observed in the experiment.

[18] Murphy in Gilbert, 1914, p. 32.

2. *The first appearance of regressive sand-waves.*

Concerning their first appearance, when observed in shallow streams of sandy tidal fore-shores, Cornish writes (1901, tidal, p. 198):[19] "Almost as soon as the velocity . . . . is attained at which the water becomes notably turbid, a train of sand-waves arises with startling suddenness, the wave-fronts quickly extend across the stream at right angles to the current, and the amplitude of the sand-wave sometimes becomes so great that the surface of the sand at its crest is nearly on a level with the surface of the water above its trough.

Pierce (1916, p. 43) describes the appearance of water-waves connected with regressive sand-waves in the lower San Juan as follows: "At one moment the stream is running smoothly for a distance of perhaps several hundred yards. Then suddenly a number of waves, usually from 6 to 10, appear. They reach their full size in a few seconds, flow for perhaps two or three minutes, then suddenly disappear."

3. *Data concerning regressive sand-waves.*

1. *Ground-plan.*—The axes of regressive sand-waves lie transverse to the direction of the current. In the experimental trough they occupied its full width; in natural streams Gilbert observed them reaching either from side to side of the channed or else forming well-defined rows in the direction of the current (cf. also Pierce, l. c.).

2. *Profile.*—In profile these sand-waves differ from current-ripples in being symmetrical with flat, gently rounded crests.

3. *Lines of flow.*—There are no vortices; the flow lines of the water in general are everywhere essentially parallel to the bed surface. The surface of the water follows the gentle swell of the sand surface underneath, so that the depth of water is approximately the same over crest and hollow. "The velocity in a wave-trough is greater than near the crest. The sand grains flow nearly parallel to the bed as they pass through the trough, but at the crest they have an up and down motion, as well as a forward motion. On the crest of the larger waves their forward motion is small compared with their vertical motion" (Gilbert, 1914, p. 32).

[19] For a good photograph of the water-waves connected with regressive sand-waves, see Cornish, 1899, pl. 1, fig. A.

4. *Traveling.*—Regressive sand-waves, as stated already, owe their name to the fact that they travel in the direction opposite to that of ripples, that is upstream, some of the sand being scoured from the down-stream face and deposited on the up-stream face (Gilbert, ibid., p. 32).

This progress is, however, not continuous, since all regressive sand-waves in nature as well as in the experiment are subject to a peculiar rhythm, which Gilbert describes as follows: "Not only is a row of anti-dunes a rhythm in itself, but it goes through a rhythmic fluctuation in activity, either oscillating above a mean condition or else developing paroxysmally on a plane stream bed and then slowly declining. Paroxysmal increase starts at the down-stream end of a row and travels up-stream, gaining in force for a time, and the climax is accompanied by a combing of wave-crests. Where the débris is very coarse, as on the outwash plains of glaciers, a din of crashing bowlders is added to the roar of the water."

In the experimental trough some of these waves remained "for two minutes or longer, but most of them not longer than one minute." "Sometimes two or more will disappear at once and leave the surface without waves for a distance of ten feet or more."[20]

5. *Wave-length and amplitude.*—In streams plowing their way through sandy beaches to the sea, Cornish observed regressive sand-waves, measuring but 23 cm. from crest to crest (1899, p. 626). In Gilbert's experiments (1914, p. 32), their wave-length ranged from 60 to 90 cm, some showing amplitude of 1·5 cm, which would give a value of 40 to 60 for amplitude over wave-length. With different grades of sand (ib., table 4) they were observed at the following velocities and depths:

Diameter of grains (mm.)	Mean velocity (m./sec.)	Depth (m.)
0·3	0·72–0·99	0·01–0·05
0·4	0·76–1·20	0·01–0·07
0·5	0·83–1·36	0·02–0·07

The author observed the water-waves associated with these sand-waves during a cloudburst at the mouth of a small stream entering the Kentucky River a few miles above Worthville. Their wave-length was estimated to

[20] See also Pierce's observations.

be about 100 cm., in water hardly more than 30-40 cm. deep.

In San Juan River, Pierce observed regressive sand-waves measuring 450-600 cm. from crest to crest with an amplitude of about 100 cm. In the deeper sections they appeared at their best development on rapidly rising stages of the river up to 10 feet gage height. With further rise of the river the movement was "drowned out" (1916, p. 42).

Fig. 3.

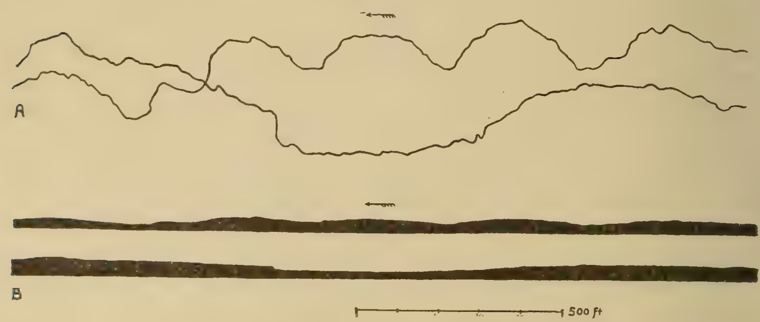

Fig. 3. Two profiles of sand-waves observed and measured in Mississippi River near Lake Providence, La. (After Hider, A., 1883, pl. 5.) Vertical scale = 10 times horizontal. B. The same, not exaggerated.

B. *Progressive Sand-waves in Rivers.*

1. *Definition.*

In the deeper parts of large streams and rivers the sediment moves in ripples of truly gigantic proportions. Their shape justifies the name "sand-waves," while their size, a serious menace often to navigation, suggested the name 'reefs," both of which are used by English engineers.

2. *The first appearance of "sand-waves."*

These sand-waves exist only in water of high velocity, above the third critical point, carrying great quantities of sediment in suspension. Direct observation of their mode of appearance, therefore, is impossible. It is of importance, however, that Hider, who has made a most careful study of these sand-waves in the lower Mississippi River, found that regularity of shape and constancy of wave-length are not attained until the river has remained stationary for some time (1883, p. 2196).

3. *Data concerning sand-waves in rivers.*

1. *Ground-plan.*—Hider describes these sand-waves as "a series of ridges irregular in shape, transverse to the direction of the current, which in deeper water and the most rapid current under favorable conditions become more regular in shape and size approaching the form of waves" (ib., p. 2199).

Waves of dimensions large enough to be accurately measured by sounding extend beyond the line of the main current and deep water (ib., p. 2196). At Helena (Ark.), Johnson found them extending from one-half to three-fourths the distance across the river (1885, p. 65).

2. *Profile.*—The numerous profiles given in Hider's report show that the profile of such sand-waves is extremely irregular.[21] In the upper part of fig. 3, I reproduce two series of waves, as given by Hider. In the lower part, the same two series are shown without exaggeration of height. That we are not dealing with the typical profile of wind-dunes as seen in current ripples, with a sharp crest, gentle windward and steep lee-sides, is obvious. Gently rounded, broad crests, often nearly symmetrical, characterize these sand-waves.

3. *Lines of flow.*—No direct observations on the lines of flow of the water within the neighborhood of these sand-waves are on record. There is some indirect evidence, however, which seems to have considerable weight.

A necessary prerequisite for the formation of vortices is that the obstacle behind which they form be rigid. The sediment forming the bodies of these sand-waves is, however, by no means rigid. At a point where the Mississippi was 65 feet deep, McMath, having descended in a diving bell, in stepping to the sand bed, "sank into it about 3 feet, and then thrusting his arm into the yielding mass, could feel its flowing motion to a depth of two feet, the velocity diminishing downward" (Gilbert, 1914, p. 156).

Similar observations were made on the gravelly beds of the upper part of the Rhine and of its small tributary Birsig. The bed of these mountain streams was found

[21] A part of these irregularities, if not most, may be only apparent, due to the great difficulties encountered in sounding from a boat, at high stages of the river especially.

at high water to be a regular gravel stream saturated with water, being in motion down to a depth of over 3 m.[22]

There seems to be, therefore, the same gradation of motion downward from the surface of the sediment which Gilbert observed in his "anti-dunes." It appears highly probable that it is connected with the same manner of flow, *i. e.*, absence of vortices and parallelism between flow-lines and surface of the sediment.

4. *Traveling.*—The large sand-waves of rivers travel down-stream. "The heavier material[23] finds its way down-stream by being pushed or rolled up the flat anterior slope of the wave by the action of the current and dropped over the crest of the wave where it remains until the wave has progressed far enough down-stream to leave it again exposed to the action of the current." But the amount of material transported near the bottom "as measured by the progression of the waves, as shown on a profile, it is believed represents but a small amount of the material actually in motion along the bottom" (ib., p. 2199).

At low stages of the river, with small velocity of the water, such sand-waves can be seen to progress slowly after the manner of wind-dunes or current-ripples, as was for instance described by Partiot. He refers to the lee-side of such sand-waves as the "talus" unto which the sand is dropped from the crest, with an inclination of about 45 degrees, in strong contrast to the gentle up-stream side (1871, p. 270).

This form, however, is no sand-wave at all in the sense in which the term is used here, but a subaqueous dune and is obviously the result of a transformation of a sand-wave. That this dune-form is not stable at higher velocities was observed by Partiot himself. With increasing velocity he saw the sediment carried beyond the talus on the lee-side; the crest rapidly was reduced, the advance was greatly retarded or the "dune" remained stationary. If the velocity of the water was not diminished in due time, the "dune" often disappeared entirely.

This shows conclusively that the dune-form and, probably, the dune mode of progression do not exist at veloci-

[22] Pestalozzi, Die Geschiebsbewegung und das natuerliche Gefaelle der Gebirgsfluesse, Prog. eidgenoess. polytechn. Schule, 1878-1879, Zürich, p. vi. Quoted from Penck, Morphologie der Erdoberflaeche, 1894, vol. 1, p. 284.

[23] Coarse sand, gravel and small bowlders, Hider, 1883, p. 2198.

TABLE IV.—Observational Data on Subaqueous Sand-Waves.[a]

Author.	Locality.	l cm. (average)	a cm. (average)	$\frac{l}{a}$ (average)	d m.	v m./sec.	t mm./sec.
	1. *Tidal meta-ripples, exposed*						
Kindle, 1917	St. Mary Bay, N. S.	61–121	7–15	(8–17)	exposed at low tide	--------	--------
Cornish, 1901	Findhorn, Scotland	107	--------	--------		--------	--------
	Mundsley, Norfolk *open shore*	147	--------	17	"	)[b]	--------
Kindle, 1917	Kingsport, N. S.	152–244	7–13	(12–35)	"	--------	--------
Cornish, 1901	Barmouth, Wales *open shore*	275	--------	--------	"	--------	--------
" "	Montrose, Scotland	402	35	12	"	)[c]	
" "	Dovey estuary, Wales	400	16	25	"	--------	--------
" "	Goodwin Sands, Kent *open sea*, 6 miles from shore	456	--------	--------	"	1–1·5[d](*s*)	--------
Kindle, 1917	Windsor, N. S.	456–610	13–51	--------	"	--------	--------
Cornish, 1901	Severn estuary, Wales	1150	59	20	"	)[e]	--------
	2. *Meta-ripples in rivers exposed at low water.*						
Bucher	Little Miami, Ohio	275	15	18[f]	"	--------	--------
Kindle, 1917	Ottawa R., Ont.	912–1370	30–61	(15–45)	"	--------	--------
	3. *Sand-waves in rivers in motion.*						
Hider, 1883	Mississippi river Lake Providence, La.						
	1. *Shallow water section, at high water.*						
	sandbank 2000′ from shore	1370	30–101	13–45	11·16	(smallest)	--------
	1200′ from shore	7620	244	31	17·68	--------	0·05
	800′ " "	12192	366	33	24·38	--------	0·07
	400′ " "	22860	558	41	27·43	(greatest)	0·12
	2. *Same at low water.*						
	1200′ from shore	7620	152	50	8·53	--------	--------
	800′ " "	8077	204	40	15·24	--------	0·04
	400′ " "	7315	244	30	18·29	--------	0·03
	3. *Deep water section at high water.*						
	600′ from shore	9449	152	62	24–29	--------	--------
	1000′ " "	8717	201	43	26–30	--------	0·16
	1400′ " "	12192	274	45	24–26	--------	0·13
	4. *Same at low water.*						
	600′ from shore	8321	192	43	(17–23)	--------	--------
	1000′ " "	9357	198	47	(18–24)	--------	0·04
	1400′ " "	12040	308	40	(17–23)	--------	0.03
Johnson, 1879	Mississippi river, at Helena, Ark.	10000	152	65	4–9·15	(1·09 (*m*) average for month)	0·06

[a] All figures transformed from feet and inches to nearest centimeter. The symbols the same as those used on Table II.

[b] For the Newarp banks, twenty miles SE of Mundsley, 7 miles off the coast, tidal currents running from 1 to 2 m./sec. are recorded in the British Island Pilot, vol. 7, 1915 (No. 150, Publ. U. S. Hydrographic Office).

[c] In Montrose harbour the tidal current at times reaches the velocity of 2·6 m./sec. (quoted by Cornish from North Sea Pilot, Pt. 2, 5th edit., 1895).

[d] Greatest velocity of tidal currents at neap and spring tides; quoted by Cornish from King's Pilot for the English Channel, 12th edit., p. 143.

[e] 2·6–5·3 m./sec. given for the tidal portion of Severn by Grabau (Princ. of Stratigr., 1913, p. 663). Cornish emphasizes the fact that ridges do not form in center of most violent current (p. 185).

[f] Horizontal form index = 10.

ties above the third critical point. Such observations made in clear water offer no evidence at all as to the conditions existing with high velocities.

5. *Wave-length and amplitude.*—Table 4 gives a number of measurements of wave-length and amplitude of progressive sand-waves.

Hider states that wave-length, amplitude, and rate of motion of the sand-waves are dependent upon "their location with reference to their distance from the thread of the main current, being greatest at high water and decreasing in height and size as a lower stage is reached."[24] In other words: Wave-length and amplitude change with the velocity of the current, and in the same sense. The reversibility of the process is due to the fact that every pronounced change of the stage of the river destroys the existing set of sand-waves and gives rise to new ones. At a rapid change from a lower to a higher stage, much of the sediment making up the waves is thrown into suspension obliterating the original wave form, while "if the fall in stage is rapid and long-continued, the waves, which appeared at the higher stage, become covered up and a new series of waves of similar dimensions corresponding to the lower stage and the decreased velocity of the current are formed" (Hider, p. 2195).

The wave-length increases very much faster than the velocity. This fact and its probable causes are discussed on pp. 177 ff.

C. *Large Ripples exposed after high water along Rivers and on Tidal flats.*

1. *Along rivers.*

After high water the sandbars in all rivers and creeks exhibit large ripples in great variety.

1. *Ground plan.*—In ground plan their crests are "smooth curves which are frequently parallel for several waves in succession" (Ockerson p. 2571), trending at right angles to the current.

All I have seen showed a tendency to break up along the strike into a number of more or less curved crescent-shaped parts, separated by a short distance of smooth sand. In general, the larger the sand-wave is, the more uniform is it in its entire length.

[24] *Ibid.*, p. 2196; Johnson, 1879, p. 1966.

2. *Profile and structure.*—The contrast in the slopes of the up and down-stream sides is striking. Ockerson states, "the bluff part of the wave . . . . is frequently nearly vertical, the slope of the up-stream side is generally very gentle." Partiot gives 45° as the angle of the lee-side in one case (p. 270). In the cases observed by me, the horizontal form index ranged from 7 to 10.

It is this typical dune shape which distinguishes the large ripples exposed after high water from the sand-waves in the deeper parts of the same river.

The observations made by Hider, however, leave no doubt that these ripples have the same origin as the sand waves and owe their dune-like profile to a transformation resulting from the decrease of the velocity and the depth of the water. Hider, in speaking of the large sand-waves in the Mississippi River, says their size decreases "as the water becomes of less depth, until, in shallow water and removed from the main current, they

FIG. 4.

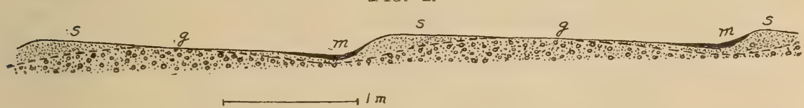

FIG. 4. Cross-section of meta-ripples observed on a sand-bank in Little Miami River after a flood; m = mud; s = sand; g = coarse sand full of small pebbles.

resolve themselves into waves or ridges transverse to the direction of the current, varying from 20 to 100 feet apart, and from a few inches to one or two feet in height" (p. 2196).

The structure of large ripples observed on sand-banks of the Little Miami River near its mouth offer good evidence of this process of transformation (cf. fig. 4). Paving the bottom of the hollows and the adjoining slopes for a short distance was a layer of sticky mud, about three to five mm. thick; the adjoining part of the gentle slope was covered with fine sand, underneath which appeared a very coarse sand full of small pebbles which formed the bulk of the sand-wave, while the crest proper consisted of sand without any pebbles. The core, consisting of the coarser materials, was nearly symmetrical when it became stationary, but the sand and mud dropped by the slackening current was deposited over this solidfied "wave" giving it its "dune" shape. In deeper water with more sediment to settle on it, the core would be completely hidden and a perfect "dune" formed.

3. For data on *wave-length* and *amplitude*, see table 4.

2. *On tidal flats.*

The large ripples so common on tidal flats were described in a very elaborate paper, amply supplied with excellent photographs by Cornish,[25] from which the following data were taken.

1. *Ground plan.*—Where well developed, the pattern exhibited by these sand-waves in ground plan is that of typical current-ripples, long, more or less sinuous and parallel lines of ridges, presenting the appearance of a regular train of waves, despite the fact that the succeeding individual waves show an average difference of 33·2 per cent of the mean wave-length (p. 174). Cornish points out that "this appearance probably depends more on the parallelism of the ridges than upon the equality of their wave-lengths, especially when the eye elevation is small."

At Montrose, N. B., Cornish observed that "with a strong westerly gale blowing, the ridges were much more sinuous, and many pools of water remained at low tide owing to dams across troughs where sand had been washed in from the ridges" (p. 182).

In general also "the wave fronts of the ebb-facing ridges are . . . more sinuous than those of the flood; they suggest formation when the waters are running together as the banks dry out" (p. 191).

The trend of these sand-waves with reference to the shore line is characteristic: on open shores, such as at Mundsley (p. 183), or above the mouth of Barmouth estuary (p. 174), or on the Goodwin Sands (p. 189), six miles off the N-S shore of Kent, these tidal sand-waves were invariably found to trend at right angles to the shore. In the case of the Goodwin Sands especially, they trend in the direction of the wind and at right angles to the waves "which are not insignificant on the Goodwins even when the wind is light." In the indentations of the shore line, bays and estuaries, of course, the sand-waves trending at right angles to the shore of the estuaries may run parallel with the general shore line.

[25] 1901; good illustrations also in Kindle, 1917, pl. 8.

This arrangement of the sand-waves is in itself the best proof of their current origin.[26] That wind-drift may be a strong factor in the formation of sand-waves of this size seems to be proved by the following observation:

Cornish visited Pegwell Bay on an afternoon previous to which the wind had been blowing into the Bay for at least twenty-four hours with a force 4 of the scale 0-12, increasing during the night to force 6. "There had been a strong current setting into the Bay in the morning, and the flats of sticky sand exposed at low water were covered with tidal sand ridges of about 8′ wave length and 3″ amplitude . . . In calm weather, I am informed these sands are smooth, except for the ordinary small ripple mark. This observation shows that "tidal" sand-ridges can be formed by a drift of water caused by the wind setting into a bay" (p. 190).

2. *Profile and structure.*—"In well-developed ridges the summit is not coincident with the top of the cliff, but some distance on the weather side, which is slightly concave in its lower and convex in its upper portion" (p. 171). This gives the top of the ridges a rounded appearance.

"Symmetrical ridges with both faces sloping at about 12° are very rare above low water mark; generally the slower reverse current appears to have no effect upon the form of the ridges."

These large ripples, of course, face with the current that produces them, with the flood current where the ebb-current is too weak to change their form, otherwise with the latter. Occasionally the same estuary at low-water will show on different parts of its exposed flats ripples facing in opposite directions (p. 171). Cornish also observed large ripples facing up-stream covered with ordinary current-ripples facing with the ebb (p. 174), which was not able to reverse them. In general, current-ripples may cross these sand-waves at any angle.

Cornish gives little information concerning the mechanical composition of the material of these sand-waves. The terms "sand," "sticky sand" and mud-flats" occur repeatedly; nothing, however, enables us to decide whether these terms apply to the sediment as a whole or

[26] These sand-waves of the Goodwin Sands with an amplitude of 90 cm. have repeatedly been quoted as an example of the supposed maximum dimensions of wave-formed ripples.

only to a superficial layer formed just before exposure. One case forms an exception. "On one of the shoals the sand is mixed with stones and cockle-shells. . . . The leeward portions . . . consists of sand which has been picked out from among the coarser materials, held floating for a time in "eddying suspension," and finally deposited on the lee of the ridge. The weather side of the ridges, now faced with shingle and cockle-shells, assumes a slope almost as steep as the talus of the lee-side, because the coarser material does not slide so readily as the finer sand would do under like conditions.[27]

3. *Traveling.*—By means of stakes driven to a depth of about three feet into the sand, in Montrose Harbor, N. B., Cornish studied the changes of a series of sand-waves for several weeks in detail.

Toward neap tides the ridges facing with the ebb were smoothed out and the sands remained almost featureless. "As the tides increase, well-defined steep ridges appear, which grow in height and also apparently by elimination of certain ridges, in average wave-length. As the tides fall off again the height or amplitude of the ridges rapidly decreases, the wave-length decreasing very slowly" (p. 194). In three days the amplitude diminished 42 per cent, the wave-length only 2 per cent, that is, remained practically constant.

These sand-waves show a daily advance toward the lee, which in the case mentioned above amounted to an average of 83 cm. a day. This advance is, of course, limited to the relatively short duration of high water twice a day.

In some cases, Cornish observed that certain sand-waves became stationary, while others near by moved freely with the tides, the former differing not only in size, but also in tone of color from the ordinary ridges. "On the whole it seems that among the tidal sand-ridges, which are exposed at low water, a setting of the sand sometimes occurs" (p. 194).

4. For data concerning *wave-length* and *amplitude,* see table 4.

3. *Formation of Sand-waves.*

It is suggested that the term "sand-waves" be defined to include progressive and regressive sand-waves, as

[27] P. 193; cf. photograph pl. II, fig. 24.

described above, but to exclude any other forms. Sand-waves, in this sense, can not exist with velocities smaller than those creating them. With a decrease of velocity they either disappear or are transformed. They form above the third critical point of velocity, are slightly asymmetrical or symmetrical, have flat, gently rounded crests and no eddy on the lee-side.[28] In all these features they differ fundamentally from current-ripples, which form below the second critical point of velocity, are strongly asymmetrical, with rather sharp projecting crests sheltering an eddy.

FIG. 5.

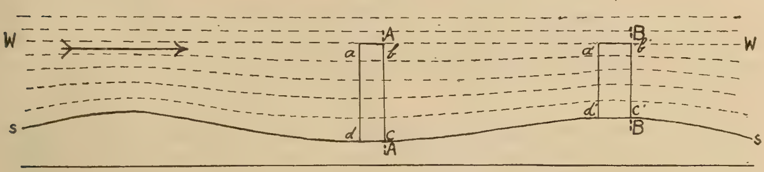

FIG. 5. Longitudinal section of a progressive sand-wave, to illustrate the increase in velocity of the bottom current at the crests and its decrease in the troughs. *abcd* represents the quantity of water which passes the cross-sections A-A and B-B in the unit of time. The velocity is proportional to the horizontal distances *ab* and *a'b'*.

Regressive and progressive sand-waves differ in the direction of traveling and in their mode of appearance. Both characteristics seem, however, to be of a secondary nature, not essential for the production of the wave-form.

The up-stream motion of the regressive sand-waves is due to the fact that the small amount of water, often hardly sufficient to cover their crests when at rest, literally has to climb up the weather-slope of the sand-wave and fall down its lee-slope. Consequently, it is retarded by gravity on the weather-side, causing sediment to be dropped, and accelerated on the lee-side, causing erosion. Thus, while all grains are moving down-stream, the wave-form moves up-stream.[29]

This process, however, is only a function of the depth of the water.[30] There is no reason why at a greater depth sand-waves should not form also. Cornish remarks: "The commencement of the smaller sand-

[28] This is at least highly probable for the large sand-waves of rivers.

[29] Gilbert, 1914, p. 34; Cornish, 1901 (Tidal), p. 198.

[30] According to Gilbert (1914, p. 34) the second and third critical points are reached "when the depth of water bears a certain numerical relation to a power of the mean velocity near the cube."

waves, as I have frequently observed, does not require that the water surface should be previously in waves. Therefore, I infer that in deep streams sand-waves will be similarly produced when the velocity reaches the point at which the lower strata of water become heavily charged with sand in eddying suspension" (1901, p. 198).

The mode of progression which is to be expected in deeper water may be explained with the help of fig. 5. The quantity of water which, in the unit of time, passes the cross-section A-B between the level of uniform flow (*w-w*) and the sand surface, (*s-s*) is represented by the area *abcd*. The same quantity, when passing the cross-section A′-B′, is greatly reduced in height and therefore must increase its horizontal dimensions (*a′b′c′d′*). Since it has to pass in the unit of time, this means an increase of velocity.

The velocity, therefore, is increased from the trough to the crest and decreased from crest to trough. As with decreasing velocity sediment is thrown down, the sand-wave must move down-stream. It seems highly probable that this is the mode of progression of the sand-waves of large streams.

The paroxysmal appearance and disappearance and the rhythmic fluctuation in activity of the regressional sand-waves, bear all characteristics of phenomena of interference of two systems of waves, the sand-waves below and some system of water-waves above (Gilbert, 1914, p. 244) and need not to be discussed any further here.

We may, therefore, describe the formation of sand-waves as *the establishment of a new surface of contact, offering an optimum of conditions of flow, probably a minimum of friction.* As above a certain velocity (first critical point) the smooth surface of the sediment at rest proves unstable, so here above a certain higher velocity (third critical point) the smooth surface of the sediment in motion again proves unstable. This time the sediment yields as a whole, not grain by grain, as in the case of current-ripples. The sediment mixed with water, over which the water mixed with sediment flows, is itself in constant motion to a considerable depth; it flows too. It behaves like a viscous liquid. If we consider it as such, sand-waves may be explained as *friction-waves between two liquids of different velocity.*

In 1889, Helmholtz gave the mathematical evidence[31] that in case of two liquids passing each other with different velocities, the flat surface represents an unstable equilibrium, as the amount of energy used up along the contact is greater with a flat than with certain wave-like surfaces. He at once applied this theory to water-waves and to waves within the atmosphere, the existence of which he had inferred from observations which were the immediate cause of these investigations.[32]

Of the laws derived from his formulas, the following are of importance for the application of this theory to sand-waves:

(1.) The linear dimensions of such waves increase as the square of the velocities of the two media; that is, with doubled velocity of wind, water waves will increase four times their original size.

(2.) The smaller the difference between the densities of the two liquids, the greater is the wave-length. For instance, a wind velocity of 10 miles per second would at 0° C. produce water waves of 0·8 m. length, while between two layers of air at 0° and 10°, it would form waves of 900 m. length.[33] Water waves of 5-10 m. length would correspond to air waves of 15-30 km. length.

In view of the incompleteness of the data on hand and of the great complexity of the process in rivers, we can not hope at present to use these deductions to test this interpretation of the origin of sand-waves.

At best we might see if the order of magnitude of the waves observed in nature is consistent with it.

At high water stage, Hider found near Lake Providence (La.), on the up-stream side of a sandbar, sand-waves of 13 m. length formed at a depth of 11 m.; 1600 ft. across the channel, near the line of the swiftest current, the sand-waves measured 228 m. from crest to crest at a depth of 27 m. Unfortunately no measurements of discharge or velocity accompany his report. In order to obtain some idea concerning the range of velocities found in the same river at different depths and stages,

[31] Wissenschaftliche Abhandlungen, vol. 3, pp. 315-322, 1889; cf. Reynold's experiments, Phil. Trans. Roy. Soc., London, vol. 174, pp. 943-944, 1883.

[32] 1886, *ibid.*, vol. 3, p. 287.

[33] d. for air at 0° C. —0·001293.
" " " 10° C. —0·001247.
" water " 0° C. —1·000.

we turn to Humphreys and Abbot's Report of the Mississippi River. Here we find, for instance, the following sub-surface velocity observations[34] made at Vicksburg, 1858.

At the highest stage of the river (depth about 23 m.) the velocity was:

	May 13	Aug. 7
Surface	2·35 m./sec.	2·65 m./sec.
Depth of 21 m.	2·25 m./sec.	1·80 m./sec.

At a medium stage (depth about 16 m.):

	Sept. 28	Sept. 28
Surface	1·59 m./sec.	1·59 m./sec.
Depth of 15 m.	1·45 m./sec.	1·00 m./sec.

Using these figures as examples, we are justified in assuming that the currents at the bottom of the 27 m. section as to all probability at the very most were four times as strong as those in the 11 m. section, probably much less.

In case of a ratio of velocities of 1 : 4 at the two points, which at least lies within the range of possibility, the lengths of the sand-waves should be in the ratio 1 : 16, which would give for the 27 m. section a wave-length of 208 m. The wave-length actually found was 228 m.

The ratio of velocities, however, in all probability, was very much smaller. Another factor of at least equal importance must therefore influence the wave-length.

In Gilbert's experiments, "anti-dunes" of 0·6-0·9 m. length were produced with currents of ±1·00 m./sec. velocity, at a depth measured in centimeters. The velocity of the current that produced the 13 m. sand-waves was as to all probability hardly much greater. This, as Gilbert has pointed out already, seems to indicate that *depth is an important factor* in the formation of sand-waves. This is to be expected in the case of friction waves, while in the case of current-ripples a direct influence of an increase of depth on the size of the vortices, etc., would hardly seem intelligable and was never observed. Depth does not appear in Helmholtz's formula, because, owing to the great difficulties of treating such a complex problem mathematically, it was

[34] Humphreys and Abbot, Report upon the Physics and Hydraulics of the Mississippi River, 1861, p. 258. In the figures quoted, feet were transformed into meters, to the nearest centimeter.

derived for the simplest case only, namely, waves formed on the contact of two liquids of infinite extent.

If this interpretation of the nature of sand-waves is correct, it is evident, as was indicated already, that they can not exist at velocities other than those creating them. When the velocity decreases with the fall of the river or the tide, the sediment from the water above the waves fills up the troughs, forming smaller waves, corresponding to the smaller depth and velocity, on the newly created surface. As the velocity drops below the third critical point, the bodies of the waves settle and become rigid, a vortex forms on the lee side and now the weak current, like wind on a dune, moves but the grains of the surface layer, rolling them up the weather slope and dropping them on the lee side. Since the angle of rest of ordinary materials differs greatly from the gentle slope of the sand-wave, this must undergo a fundamental change in form, from more or less symmetrical waves to strongly asymmetrical "dunes."

It appears to be advisable to use different terms to distinguish between the friction-waves and the secondary forms derived from them. I, therefore, suggest to limit the term "sand-waves" to the former and to use the term "meta-ripples" for the latter.

Where the meta-ripple consists of uniform material, this secondary origin of its outline can not be demonstrated. But where the material is heterogeneous, it becomes at once evident by the fact that the coarse material forms a core with a "hood" of fine material placed asymmetrically on one side.

The secondary nature of the meta-ripples explains a well-known feature of cross-bedded river deposits. They show the steeply inclined layers which formed on the lee-side of meta-ripples and associated complex forms during the subsiding stages of the water, facing in different directions and therefore cut at different angles by the plane of the accidental exposure.. They show the pattern, but *never the surface forms to which it is dwe,* as should be expected, if these forms existed on the bottom of the river during high water, after which they could be preserved under the sediment dropped from suspension. The inclined layers are invariably cut off by a "true bedding plane," wherever followed by sediment of similar grain. This plane indicates the depth to which the sediment was set in motion at the next rising of the river, and thus offers a good evidence for the instability of the meta-ripple form at higher velocities.

The ripples of the tidal flats probably are such "meta-ripples," but they present more complicated conditions than those observed along streams. Once formed, they are not easily destroyed, since only the greatest velocity attained during high tide can erase them. This however, is limited to such a short period of time, that it usually is unable to remove them.

Correspondingly, Cornish could not only identify the same sand-waves after successive tides, but even found them better developed with increasing tides, while they rapidly decayed when the neap tides approached.

Except at the time of their first formation, they behave like large current-ripples. It is, therefore, to be expected that they also show the interference pattern so common in current-ripples, which is characteristic of the action of vortices. This pattern was indeed repeatedly observed by Cornish, for instance, on the Severn Shoals.[35] Here the ebb current runs nearly at right angles to the flood-current. When it increases in velocity after the slack water period, eddies must form in the horizontal as well as in the vertical plane on every bend of the rather sinuous sand-waves, causing a convergence of currents on the weather and the lee side and prolonging it across the trough, thus producing cross-bars in the troughs, which form strings of pools, in which salmon are often found impounded between tides. That interference patterns are rarely seen in tidal meta-ripples is probably due only to the rare occurrence of ebb and flow currents running at an angle to each other, not to any inherent difficulty of formation.

III. Oscillation Ripples.

1. *The first appearance of oscillation ripples.*

Darwin, in his classical investigation "on the formation of Ripple marks" describes the first appearance of oscillation ripples in his experimental trough[36] as follows:

"When a very small quantity of sand is sprinkled in

[35] 1901, p. 188 and fig. 18, plate 1.

[36] This experiment can easily be repeated with almost any vessel rocked to and fro.

and the rocking begins, the sand dances backwards and forwards on the bottom, the grains rolling as they go. Very shortly the sand begins to aggregate into irregular little flocculent masses, the appearance being something like that of curdling milk. The position of the masses is, I believe, solely determined by the friction of the sand on the bottom, and as soon as a grain sticks, it thereby increases the friction at that place. The aggregations gradually become elongated and rearrange themselves. . . . Some of the elongated patches disappear, and others fuse together and form ridges, the ridges become straighter, and finally a regular ripple mark is formed'' (1884, p. 23).

It should be noted that in this as in other experiments in which stationary waves were formed, the ridges and furrows do not correspond to the nodes and antinodes of the stationary waves, each one giving rise to a number of ripples. Their formation, therefore, is *independent* of the stationary nature of the wave in such experiments. They form equally well in oscillating currents produced in a vessel rotated alternately in opposite directions, where there is no evidence of stationary waves, or at the bottom of water bodies agitated by waves where the same reversal of current takes place.

2. *Data concerning oscillation ripples.*

1. *Groundplan*[37]—In groundplan the pattern of oscillation ripples is the same as that of current-ripples, but of striking regularity, the ridges usually being practically equidistant and parallel. Between rocks and other irregularities of the surface, however, their arrangement may be very irregular and complex, as can be seen on every shore.[37a]

2. *Profile.*—The profile of current-ripples is strictly symmetrical, with sharp crests and broad round hollows.[38] The contrast between the original and the cast is therefore marked and offers to the geologist a means to distinguish the upper and lower surface of strata in regions of complicated structure. A good illustration

[37] For good illustrations see Brown, 1911, pl. 41; Kindle, 1917, pls. 20, 21.

[37a] Cf. e. g. Forel, 1895, vol. 2, fig. 98. De Candolle noted that in his experiments the ripples were less regular if produced on an inclined surface; 1883, p. 252.

[38] For excellent illustrations see Daly, Geology North American Cordillera, Canada Dept. of Mines, Memoir 38, pl. 17.

of this use of ripples in structural geology is offered by the controversy of Rothpletz[39] and Stuchlik[40] on the structure of the Oligocene lignite beds of Peissenberg, in the foothills of the Bavarian Alps, which also serves as illustration for the fact that, although pointed out long ago,[41] this difference between cast and original is not as familiar to geologists as it should be.

Ripples with double and multiple crests are interesting abnormalities about which little more is known than their existence.[42]

All oscillation ripples show a more or less perfect assortment of grains, with the lightest grains forming the crests and the heaviest the bottoms of the troughs. The ripples along the shore of any pond usually show the dark particles of organic nature, pollen, fragments of leaves, soot, etc., lining the crests of the ripples, while the troughs are clean sand. Off the west side of the island of Bourbon in the Indian ocean, the French engineer Siau[43] observed ripples the crest of which was formed by white coral sand, the troughs by black basalt sand. The presence of this assortment of grains is perhaps the most reliable characteristic of oscillation ripples.

3. *Lines of flow.*—The very complicated system of stationary vortices which is set up by the oscillating current was studied in a masterly way by G. H. Darwin, whose well-known paper may be consulted for details. The vortices ascend from either side of the ripple crest, rise above it and descend to the center of the trough. Here, by combined action, they build up the small central ripple so common in oscillation-ripples. Owing to the

[39] Rothpletz, Die fossilen oberoligocaenen Wellenfurchen des Peissenbergs u. ihre Bedeutung fuer den dortigen Bergbau, Sitzungber. math. phys. Klasse, Kgl. Bayr. Akad. Wiss., 34, pp. 371-382, 1904.

[40] Stuchlik, Die Faziesentwickelung d. suedbayrischen Oligocaen-molasse-Jahrb. K. K. Geol., Reichsanstalt, Wien, 56, 1906.

[41] Jukes and Geikie, Student's Manual of Geology, 3d edit., 1871, p. 63; Fuchs, Th., Studien ü. Fucoiden u. Hieroglyphen, Denkschr. Wien, Akad. Wiss., 62, p. 372, figs. 1 and 2, 1895; Van Hise, C. R., Principles of North American pre-Cambrian Geology, 16th Ann. Rept., U. S. G. S., pt. I, 1896, pp. 719-721.

[42] See *e. g.* Forel, 1895, vol. 2, figs. 100 and 101, p. 273; Cornish 1901, p. 194 and pl. 2, fig. 25 (excellent photograph).

[43] The locality is St. Gilles, practically on the westernmost point of the island of Bourbon or Réunion, about 5 miles S.W. of St. Paul (see *e.g.* the small map of Réunion in "La Grande Encyclopédie,") not St. Gilles in the Atlantic Ocean, as Forel stated erroneously in his paper of 1883, a statement which has found its way into most textbooks. Cf. Comptes Rendus, vol. 12, p. 775.

action of these vortices, the particles near the crest swing from one side to the other, while those in the trough oscillate to and fro, with smaller amplitude, as can easily be observed in artificial and natural ripples. The phase of the later is the same as that of the former in the case of strong oscillation, but opposite if the oscillation is weak.

4. *Traveling.*—Oscillation-ripples are stationary. They can not advance in either direction, owing to the formation of vortices alternately on either side of the ripple as the current is reversed.

The preservation of typical oscillation-ripples under a thick layer of rather coarse sand, as it is frequently seen in many sandstone formations, offers the same problem as that of current-ripples, but more surprising yet. The very existence of oscillation-ripples excludes any, even the slightest current action in the vicinity of the sedimentary surface. Since we can not assume that the sharp crested ripples had hardened sufficiently to resist modification through the current, which carried the additional sediment, the latter must have existed a sufficient distance above the bottom, so as not to reach it, but drop its load unto it. The necessary conditions are the same as those outined for current-ripples on page 156. It should be noted especially that a storm may throw a great quantity of sediment into suspension at one locality, while at another, perhaps not far distant, its only effect on the sea-bottom is the production of oscillation-ripples. The wind-drift set up by the storm may carry such sediment from the former to the latter locality in the upper levels of the water. The much-quoted observations of sand left on deck by breaking waves over a depth of 75 feet on the banks of Newfoundland, may serve to illustrate to what extent sand may be thrown into suspension by storm waves.

The action of the vortices, no matter how weak, will always tend to keep the crest of the ripple sharp, never, however, to round it off. Mere decrease of wave action[44] can, therefore, not account for the small ripples with symmetrical round crests and hollows, that are sometimes found both in modern[45] and in fossil sediments.[46]

[44] As suggested by Gilbert, 1899, p. 136.

[45] See *e. g.*, Kindle, 1917, pl. 21, figs. A and B.

[46] E. g. one specimen in Ordovician limestone in the collection of the geological department of the University of Cincinnati.

They must owe their shape to a secondary transformation, perhaps connected with the setting of the sediment[47] after the wave motion has ceased.

5. *Wave-length and amplitude.*—A number of measurements of wave-length and amplitude were compiled in table 5.

The following observations pertain to wave-length and amplitude:

(*a.*) When first appearing, oscillation-ripples show a wave length which is half that of their full development. (Darwin, 1884, p. 23.)

(*b.*) The wave-length increases with the velocity of the current, that is, amplitude over period of the oscillation. De Candolle's and Darwin's experiments have shown that *the increment of wave-length is proportional to the increment of velocity.* This law, of course, holds good only between two critical points of velocity, between which oscillation-ripples like current-ripples can exist. It can not be reversed; that is, the wave-length does not decrease with the velocity.

Darwin noted that "when once a fairly regular ripple-mark is established, a wide variability of amplitude in the oscillation is consistent with its maintenance or increase." Forel demonstrated that any oscillation weaker than that which produced the ripple will not affect its orientation, even if its direction diverges from the original up to 45° (1895, p. 263). This explains Forel's observation, that at the same locality, in the Bay of Morges, near the center of the north shore of Lake Geneva, the oscillation-ripples never changed their direction during three months of observation, although waves reach the bay from all directions between east, south and west. Their orientation corresponded to waves from the south, the direction of the strongest winds. At the shore they swung into parallelism with the shore-line like breaking waves (ib., p. 270).

Since the amplitude of the oscillation at the bottom of the water body is a function of the height of the water wave above, this must bear a definite relation to the wave-length of the ripples. It is not impossible that this relation one day will be utilized for a direct determination of the decrease of the wave-amplitude with depth.

[47] The few fossil examples of this type seen by the author consisted of very fine-grained limestone, originally a "mud."

TABLE V.—Experimental and Observational Data on Oscillation Ripples.

Author.	l* cm.	a cm.	$\frac{l}{a}$	D mm.	d m	λ[a] m.	a m	$\frac{\lambda}{a}$	τ sec.	c m./sec.	v m./sec.
Experimental Data.											
DeCandolle, 1883	0·8	-----	----	"dust"	0·035	-----	-----	----	----	-----	-----
	2·2–2·8	-----	----	"	0·05	-----	-----	----	----	-----	(0·2)[b]
Forel, 1895	3·9	-----	----	sand, very fine	k[c]	k	-----	----	k	-----	-----
	5·1	-----	----	medium	k	k	-----	----	k	-----	-----
	7·6	-----	----	very coarse	k	k	-----	----	k	-----	-----
*Darwin, 1883	1·4[b]	-----	----	k	k	-----	-----	----	----	-----	0·06–0·14
	1·7	-----	----	k	k	-----	-----	----	----	-----	0·16[b]
	1·75	-----	----	k	k	-----	-----	----	----	-----	0·19
	2·1	-----	----	k	k	-----	-----	----	----	-----	0·25
	2·4	-----	----	k	k	-----	-----	----	----	-----	0·33
Observational Data.											
*Udden, 1916, in small hollow in rock	0·6	0·1	6	fine silt	0·012–0·025	-----	-----	----	----	-----	-----
*Kindle, 1917; lake bottom (Fig. 4)	3·3	0·5	6	-----	0·1–0·3	-----	-----	----	----	-----	-----
	3·5	0·4	9	-----	"	-----	-----	----	----	-----	-----
	5·8	0·7	8	-----	"	-----	-----	----	----	-----	-----
	6·2	1·2	5	-----	1·83	-----	-----	----	----	-----	-----
	7·9	1·4	6	-----	"	-----	-----	----	----	-----	-----
St. Lawrence river	5·0	0·9	5·5	-----	0·13	-----	-----	----	----	-----	-----
Bucher; small pond in Park	4·5	0·6	8	medium sand	0·075	-----	-----	----	----	-----	-----
*Cornish, 1901; sea shore, England	5·0	0·9	5·5	-----	-----	-----	-----	----	----	-----	-----
Forel, 1895; Lake Geneva	6	1	6	-----	-----	-----	-----	----	----	-----	-----
Stuchlik, 1906; lake bottom	6	-----	----	-----	0·3	1·8	0·12	15	1·5	1·2	-----
same locality	10	-----	----	-----	after	strong	storm	----	----	-----	-----
Hahmann, 1912; banks of Rhine	3·5–4·5			sandy mud							
after flood	5–6	-----	----	sand	-----	-----	-----	----	----	-----	-----
sea shore (North)	20–30	-----	flat	-----	-----	-----	-----	----	----	-----	-----
*Hunt, 1882; sea shore	33	4·5	7	-----	-----	-----	-----	----	----	-----	-----
Forel, 1895; Lake Geneva	2–40	-----	----	-----	0–8·8	-----	-----	----	----	-----	-----
Siau, 1841; sea shore St. Giles, Bourbon	30–50	10–15	3–5	gravelly sand	-----	-----	-----	----	----	-----	-----

[a] The symbols of the first five columns same as those used on Table II; λ = length of water-waves; a = amplitude of water-waves; τ = their period; c = their velocity; v = the corresponding current velocity at contact with sediment.

[b] Computed from data given in original papers. (Approximate maxima only; true velocities probably smaller.)

[c] k = constant.

The figures taken from authors marked with an asterisk transformed from inches to nearest mm.

At present practically no data comparing amplitude of water waves and wave-length of ripples are available. A collection of such data would represent a distinct contribution to the study of ripples.[48] Merely to compare water-waves and ripples observed at the same time, would, however, be insufficient according to Forel's experiences mentioned above. The sand should be smoothed out first over a considerable area and the formation of ripples by the waves should be observed.

(*c.*) Forel's experiments and observations have shown conclusively that the wave-length diminishes with increasing depth of water. The most beautiful example of this relation is offered by the ripples of coral sand and basalt grains off the island of Bourbon in the Indian Ocean observed by Siau (cf. p. 184). At the inlet of the barrier reef he observed ripples measuring 30-50 cm. from crest to crest. Down to a depth of 20 m. at least, the black troughs and white crests could be distinguished with slowly decreasing wave-length. By means of the sound the existence of these ripples was shown down to a depth of 188 m. The wave-length had decreased so much that both crest and hollow were found impressed on the grease-covered bottom of the sound.

This decrease is, of course, due to the reduction of current-velocity with increasing depth, and therefore in reality nothing but a special case of (*b.*).

It should be noted, however, that with relatively strong waves "for moderate depths the size of ripples is not very sensitive to variation of water depth," as observed by Gilbert on the bed of Lake Ontario (1899, p. 138).

In a series of observations (1917, p. 26) made along the shore of Lake Ontario, near Wellington, Ontario, Kindle found a regular increase of the wave-length with depth. He found in water:

less than	½	ft.	deep	ripples	1–2	in.	long;
in water	1¼	"	"	"	2–4	"	"
" "	2½	"	"	"	3½–4	"	"
" "	10	"	"	"	4–6	"	"
" "	11	"	"	"	4½	"	"
" "	20	"	"	"	4–5	"	"

[48] The only observation of this kind that has come to my notice is that by Stuchlik, which shows the wave-length of the ripple equalling one half of the amplitude of the wave under the conditions given in Table V. Cf. Gilbert's statement (1899, p. 138) "that at the most the ripple-marks are only half as broad as the waves rolling above them are high."

This calls attention to a factor which is of some importance in connection with the interpretation of fossil ripples. The waves which produced a velocity sufficient to form ripples of 4-5 inches wave-length at a depth of 20 ft., had, of course, a higher orbital velocity at the depth of 2 feet. This velocity ought to have produced ripples of larger wave-length, since 5 inches (12·7 cm.) probably was not the greatest wave-length possible on the sediment in question. According to Forel's observations, such large ripples, if ever formed, would persist. Their general absence is good evidence that they never formed. We are, therefore, led to the conclusion that *above a certain minimum depth a given bottom oscillation of a water wave will not produce ripples.* This is probably due to the abnormal conditions of flow resulting from the "breaking" of the wave. In shallower water, therefore, only smaller waves will produce ripples, of course of smaller wave-length. Consequently along a gently sloping shore we should theoretically expect to find at first a rather rapid increase of the wave-length of the persisting ripples to a certain depth and then a very gradual decrease down to very small size.

(*d.*) The experiments of De Candolle, Darwin and Forel show that *the wave-length increases with increasing size of the grain.* According to Forel, in mixtures, the largest grains, if present in sufficient numbers, determine the wave-length.

(*e.*) Forel makes the statement that the wave-length of oscillation-ripples is inversely proportional to the density of the grains. This is, however, not based on experimental evidence and seems quite improbable in face of Hahmann's experiments with current-ripples. (See p. 159.)

(*f.*) Darwin found that ripples formed on a very thin layer of sand were smaller than such formed under equal conditions on a thick layer of sand. His explanation of this phenomenon is that "the maximum velocity of the water relatively to the bottom must depend upon the intensity of the vortices, and this depends upon the height of the ripple-mark." If this can not develop, the former must remain lower, thus reducing the wave-length of the ripple.

(*g.*) No data exist concerning the influence of the shape of the grains.

3. *The formation of oscillation ripples.*

A comparison of pages 157 ff. and 188 f. of this paper shows the perfect identity of all factors entering into the formation of oscillation- and current-ripples, so far as observed in nature and experiment. We are, therefore, justified in considering the oscillation-ripple as nothing but a modification of the current-ripple resulting from the reversal of the current. For every half oscillation the relation between sediment and current is that existing in current-ripples. The reversal of the current complicates the process, but it does not change its nature.

IV. Complex Ripple Patterns.

Once formed, all ripples may be subject to tranformation, in the course of which one type may be changed into another or entirely new compound patterns produced.

1. *Transformation of one type into another.*

Meta-ripples may be reshaped by waves acting in the same direction as the preceding current; their surface material is assorted and a sharp crest[49] placed in the center of the originally broad, round ridges. If small current and oscillation-ripples are in this way transformed one into the other, there is nothing to indicate the change. Oscillation-ripples are extremely sensitive even to very gentle current action, as shown by Kindle's observations (1917, p. 31).

2. *Oscillation cross-ripples.*

A special form of compound rippling, to which the term "*interference-ripples*" or "*cross-ripples*" should be limited, consists of polygonal, usually more or less irregular pits, arranged side by side like stones in a mosaic.[50] Two fundamental types can be distinguished, the "rectangular" and the "hexagonal" type, which usually occur together and rarely show their pure form. Both consist of parallel ridges connected by crossbars. In the hexagonal type the crests of the parallel ridges zigzag, forming obtuse angles which in adjoining crests face in opposite directions with crossbars connecting the

[49] Analogous to that shown on a sand ridge of different origin on the beach of Lake Ontario in fig. 10, pl. 5, American Geologist (Fairchild, 1901).
[50] Kindle, 1914; 1917, pp. 34-36.

apices on alternate sides of each ridge. The rectangular type consists of two sets of ridges intersecting at right angles.[51]

Figure 6 shows a plaster cast of a small unlabeled specimen in the collection of the Department of Geology of the University of Cincinnati. It is a red, thin, hard, sandy shale which I suspect to belong to the Newark Series, judging from other labeled slabs found in the

FIG. 6.

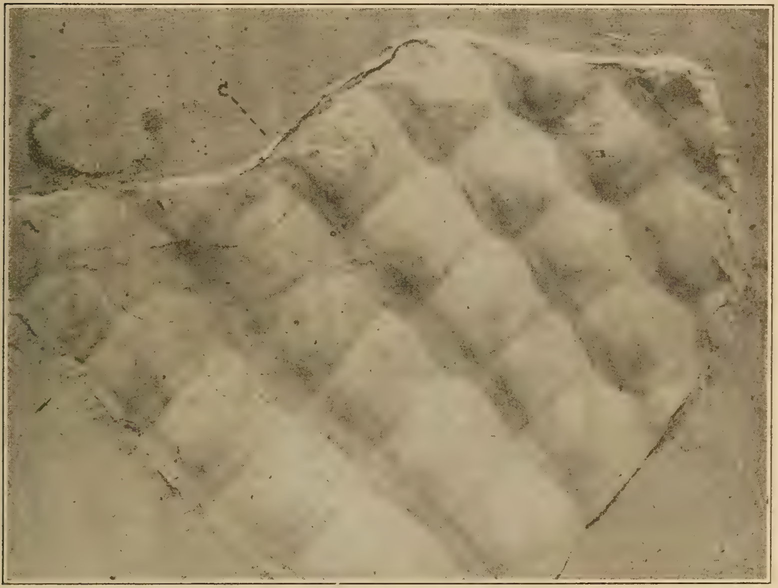

FIG. 6. Hexagonal interference-ripples superimposed on current-ripples. Plaster cast of a specimen of red sandy shale; $c =$ the narrow dark shadow of the steep face of the current-ripples. (For dimensions see text.)

same case. It is covered with a delicate pattern of hexagonal interference ripples which, however, in this case, are clearly superimposed on typical current-ripples.[52] In this case, the orientation of the pattern was

[51] For illustration of the rectangular type, see Kindle, 1917, pl. 23, fig. C; of the hexagonal type, see fig. 8 of this paper.

[52] The dimensions of this specimen are as follows:

	wave-length	amplitude	$\frac{l}{a}$
current-ripples:	3·1—4·5 cm;	0·3 cm;	10—25;
oscillation ripples: (*i.e.* the cross-bars).	2·1—3·0 cm;	$<$0·1 cm;	21—30;

obviously determined by that of the preexisting set of ripples.

A simple experiment confirmed the suspicion, aroused by this specimen, that *cross-ripples result from the intersection of an oscillation with a preexisting set of ripples.* A vessel, containing a fine grade of carborundum powder as sediment, was rocked by hand. After one to two hundred oscillations a set of good ripples had formed. Then the direction of oscillation was changed. Up to a difference of 45°, as Forel had already observed, no important change in the shape and orientation of the ripples first formed was observed. At 90°, rectangular interference ripples were produced, that is, a new set of ripples was set up in the troughs between the old ones. At intervening angles of intersection, however, the crests of the first ripples quickly changed to a zigzag line, while the growing new ripples shifted to alternating positions in adjoining troughs, producing the hexagonal interference pattern.

In fig. 7 the processes involved are shown in diagrammatic form. The lines A-A represent the first set of ripples. The long arrows at the upper end of each diagram indicate the direction of the oscillation which tends to produce the ripples B-B. These can exist only, if they intersect A-A at right angles. (Fig. 7*a*.) If formed at a smaller angle, as in figure 7*b*, they are rapidly transformed into the hexagonal pattern, figure 7*c*. The small, curved arrows indicate the horizontal components of the vortices in the lee of the growing second set of ripples (B-B) and their deflection by A-A. The arrows drawn with dotted lines correspond to the second half of an oscillation, when the current is reversed.

In figures 7*a* and 7*c*, these arrows are grouped symmetrically on both sides of B-B, not, however, in 7*b*. This explains, why a diagonal pattern of cross-ripples does not form. The unequal power of the vortices on opposite sides of the growing ripples must cause a shifting of the lines of attack, until the difference no longer exists. We recognize therefore in this transformation again the *tendency to establish a state of equilibrium.*

Since ripples in nature are neither strictly parallel nor straight, the cross-ripples are usually very irregular and the typical forms confined to small portions of the rippled surfaces only (cf. fig. 8).

Cross-ripples, therefore, *may form anywhere,* in shal-

FIG. 7.

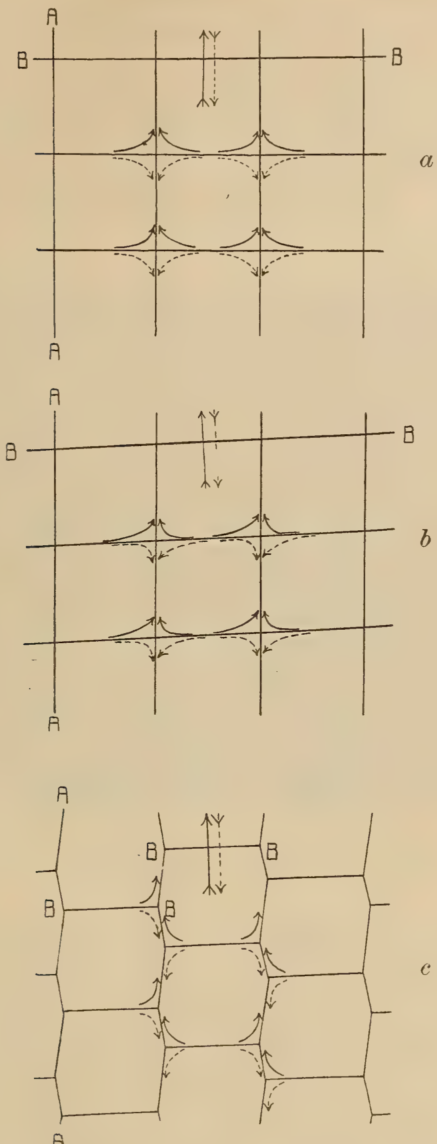

FIG. 7. *a-c,* diagrams to illustrate the influence of the horizontal components of the vortices on the formation of interference-ripples. *a,* rectangular cross-ripples; *b,* hypothetic form of rhombic cross-ripples; *c,* hexagonal cross-ripples.

A-A = the first set of ripples formed; B-B = the second set of ripples (oscillation-ripples), produced later. The straight arrows at the top give the direction of oscillation; the curved arrows indicate the horizontal components of the vortices in the lee of the growing second set of ripples. The first half of the oscillation is represented in full lines, the second in dashed lines.

low pools as well as in lakes and in the open sea and are certainly independent of "coves or indentations of the shore-line, or the ends of bars, piers or stranded logs," where, according to Kindle,[53] "the action of the wind on the surface is split up into two or more sets of oscillations moving in different directions." This statement is of considerable interest to the paleogeographer, since cross-ripples occur over large areas in marine sediments,

FIG. 8.

FIG. 8. Hexagonal interference-ripples exposed on the right bank of Miami River at Dayton, Ohio, after the flood of 1913.

e. g., in the limestones of the Eden Group (Ordovician) of the Cincinnati anticline. At certain levels within the lower part of the Maysville Group (Mount Hope formation), they are found regularly in the vicinity of Cincinnati and recur in abundance in its partial equivalent, the Garrard formation of Kentucky one hundred miles south of it, over large areas.

3. *Current cross-ripples.*

Cross-ripples may also result from the *intersection of a current with a preexisting set of ripples,* if the action

[53] 1917, p. 35. That Kindle never found them "along a straight and uninterrupted shore-line" in Nova Scotia, is not surprising in view of the extraordinary development of tides and tidal currents on that coast.

of the current is sufficiently weak and only of very short duration. As there is no oscillation of the current, there is no reason for a transformation into the hexagonal pattern, and the two sets of ripples may be found *intersecting at any angle.* (Rectangular and diagonal patterns.) Menzel[54] observed the formation of cross-ripples of this type by a single wave on the sloping beach of the summer resort Gross-Moellen on the Baltic. A wave of translation, rushing up the slope in an oblique direction, produced relatively large current-ripples, while the water, in flowing back down the slope, gave rise to a large number of smaller ripples which intersected with the first ones at angles ranging from ninety down to few degrees.

It seems doubtful if there is any other current sufficiently weak and of short duration to produce this effect, unless it is a very weak wind-drift.[55]

4. *Compound ripples.*[56]

A great variety of forms of complex rippling owe their origin to the *simultaneous interference of wave-oscillation with current action.* All seem to be characterized by a systematic breaking or offsetting of the crests of the current-ripples. A systematic discussion of these forms, to which the term "compound ripples" might well be applied, is impossible at the present time, since practically no observations are available of the factors entering into their formation, or even of the forms themselves.

V. Eolian Ripples and Dunes.

Although this paper deals primarily with subaqueous ripples, a discussion of the principles underlying their formation would be very unsatisfactory if it were not put on a broader basis. In extending the discussion to eolian ripples and dunes, I limit myself to the presentation of such facts as have a direct bearing on the question to

[54] Menzel, H., Monatsber. Zs. Deutsch. Geol. Ges., vol. **61**, p. 69-70 (1 figure), 1909; see also: Dammer, B., *ibid.*, p. 66-69; Schucht, F., p. 217-218; Menzel, H., *ibid.*, p. 427-430; Strasser, R., Bericht. 42, Vers. Oberrhein. Geol. Ver., 1909, p. 124 ff.

[55] The specimen from the Berea s.s., Berea, Ohio, figured on pl. 26 of Kindle, 1917, probably should be explained this way. (Note especially the rounding of the crests of the symmetrical ripples.)

[56] For illustrations, see Kindle, 1917, pl. 14, 15, 28, 29. See also p. 174, the effect of a gale on tidal meta-ripples.

what extent the principles established for subaqueous ripples are applicable to eolian ripples. An adequate treatment, especially of the surprising variety of forms of dunes and of the great diversity of factors entering into their formation, would lead too far.

1. *Eolian current-ripples.*

The general characteristics and the origin of sub-aerial current-ripples are the same as those of sub-aqueous ripples. They form and exist between two limits of wind velocity, corresponding to our first and second critical points. (Hahmann, 1912.)

Their formation on a smooth sand surface begins with the appearance of small pits (King, 1916, p. 197), which gradually coalesce to form ripples and increase considerably in size till they reach the maximum development for the given wind velocity. This process is exactly the same as already described for water ripples, but owing to the much smaller density of air, it meets with greater difficulties. Perfect uniformity (Cornish, 1889; Hahmann, 1912) as well as too great a disproportion (King, 1916, p. 204) in the size of the grains prevents the formation of ripples. In the former case to move one grain means to move all, while very large grains among much smaller ones will not move, when necessary, with sufficient readiness, thus effectively preventing the small eddies to coalesce.

As to shape and structure, wind-formed current-ripples in general resemble those formed under water. Of the characteristics that have been suggested by different authors as a means for the distinction of eolian and subaqueous ripples, only one seems sufficiently established, to warrant its application in the interpretation of fossil ripples. From a great number of individual measurements of both eolian and subaqueous ripples, Cornish drew the conclusion that the ratio of wave-length to amplitude, that is, the vertical form index, is considerably greater in the former. The average for subaqueous ripples is 12; for eolian 18.[57] These ratios are of value primarily as averages. They seem, however, to apply fairly well to most cases. From the data in my tables it seems that the ratio is even more likely to be larger in

[57] Cornish, V., On Snow Waves and Snow-drifts in Canada, Geogr. Journal, vol. 20, p. 151, 1902.

water-formed ripples, while it may be very much smaller in wind-formed ripples. Thus, among the values given in table 2, we find the indices 4, 5, 6, while Cornish reports that in the long train of moderately large ripples measured on dune sand north of Ismailia, Egypt, the individual ratios varied from 11·3 to 54 (exceptionally).[58] Kindle[59] found on the moulds of two examples of water-made ripple mark taken respectively in the St. Lawrence river and Lake Ontario, the indices 4 and 6·3, while the ratios of two examples of moulds of wind-made ripples taken at Wellington were 24 and 25. "The sharp contrast in the height of the crest in dune ripples and in subaqueous ripples is illustrated by the profiles of examples of both types which have about the same amplitude" given in figs. 2 and 3 of his paper.

While it is desirable to have this rule confirmed by a much greater number of observations, we are certainly justified in applying it at least tentatively to fossil ripples.

The wave-length of eolian ripples ranges from about 2 cm. to 100 cm.; they were even reported as large as 200 cm. (Baschin, l. c.). It is, however, highly probable that these largest ones, at least, were not formed independently, but owe their origin to conditions presently to be described.

The wave-length of eolian ripples increases with the velocity of the wind (Hahmann, 1912, p. 658-659). From Sokolow's observations it seemed to follow that the wave length also increases with the size of the grains; Hahmann's experiments, however, seemed to prove the opposite. He assumed that in his experiments the air blast was not allowed to act long enough on the sand. This explanation is plausible, but it remains to be verified. If my interpretation of the influence of the size of the grain on the inclination of the weather side is correct, there does not seem to be an inherent reason why the effect should not be in air the reverse of that in water.

A very important series of observations was recently published by W. J. H. King (1916). He observed on the lee of some stones rippling of larger amplitude super-

[58] *Idem,* On Desert Dunes bordering the Nile Delta, *ibid.*, 15, pp. 27-28, 1900.

[59] Kindle, E. M., Recent and fossil ripple-mark, Geol. Surv. Canada, Mus. Bull., 25, p. 12, 1917.

imposed on the ordinary rippling, obviously caused by the obstruction offered by the stones. In a similar way he saw a small new dune produced on the lee side of a large dune within one year.[60] In an experimental trough he produced the same effect by inserting a 3-inch (7·6 cm.) partition and exposing the sand to the wind.[61] First the ordinary ripples with 4 in. (10 cm.) wave-length formed; but gradually *a series of larger ripples developed* quite independently of the smaller ones, with an amplitude of about 3 inches and length ranging from 18 to 21 inches (average about 50 cm.). *These remained stationary* while the smaller ripples continued their march towards the lee side,—a clear indication of their dependence on the immovable obstacle.

Many of the cases on record of wind-formed ripples of exceptional wave-length probably were formed in an analogous way; for instance, the heavy rippling observed by King in the col between two adjoining crescent dunes, the tapering ends of the barchanes forming the obstacles.

2. *Eolian dunes.*

The chief obstacle in the way of a satisfactory discussion of the fundamental principles underlying the formation of dunes, lies in the fact that it is very difficult to form a quantitative estimate of the role played by secondary factors in the production of the final shape of each dune observed. Such factors are for instance:

(*a.*) The presence of obstacles, especially of vegetation, which may give rise to a dune and influence its final height and shape.

(*b.*) The presence of moisture within sandy surfaces, especially within dunes.

(*c.*) The changing, at shorter or longer intervals, of the direction of the wind.

(*d.*) The changing of the average or the maximum velocity of the wind.

(*e.*) Changes in the supply of sand, as to quantity or material.

(*f.*) The traveling of dunes, in consequence of which a dune may be observed under conditions quite different from those under which it came into existence.

[60] p. 195; excellent photograph opp. p. 200.

[61] To prevent the fine dune sand used from being blown away, it was sprinkled with coarser grains. On all ripples formed under the lee of an obstacle, the large grains concentrated on the crest, which was sometimes entirely covered by them (p. 199).

All of these factors seem to approach a minimum in desert regions with winds of constant direction and unlimited sand supply. Turning to such regions, we find there two radically different types of dunes: transverse and longitudinal dunes. The former were perhaps observed on the largest scale by Sven Hedin who traveled for months through dune regions of the Takla-makan desert of inner Asia, in which one dune crest followed the other at uniform intervals of several kilometers, each about 150 m. high.[62]

Longitudinal dunes are developed on a large scale in the extensive dune area separating the oases Dakhleh and Kufra in the Libyan desert, where the north-north-

Fig. 9.

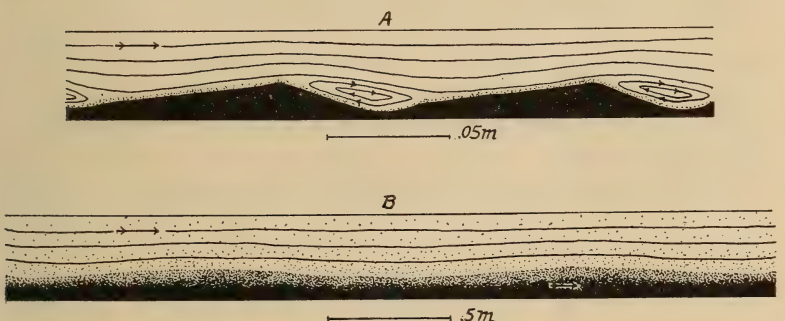

Fig. 9. Diagrams to contrast current-ripples (A) and sand-waves (B). Sand grains in motion represented by dots; the sediment at rest shown in black.

west trend of these dunes, parallel to the direction of the prevailing winds, effectively prevents direct communication between the two oases.[63]

According to Cornish (1897, pp. 294-5), both types occur in the Indian desert. Near the Rann of Cutch, the dunes are longitudinal; further inland they are transverse, and between the two districts intermediate forms are shown on the maps. Cornish considers the strength of the wind as the most important factor conditioning the difference between longitudinal and transverse dunes.

VI. General Conclusions.

In the preceding chapters the various surface forms of sediments discussed were interpreted as offering a mini-

[62] Quoted from Solger, Duenenbuch, p. 154.
[63] Beadnell, H. J. L., Geogr. Journal, vol. 35, p. 379 ff., 1910.

mum of resistance along the contact of fluid and sediment.[64] It is held that any other form of contact represents an unstable condition which is disturbed by the slightest cause. The fortuitous changes following such a first accidental disturbance are thought to lead finally to the establishment of the optimum surface form, owing to the fact that any change favorable to its completion is liable to be permanent while any others are followed by further rearrangements until all parts of the surface have reached the equilibrium. This interpretation calls for an analytical study of great complexity which I am unfortunately unable even to attempt. It also calls, however, for the accumulation of a store of reliable quantitative data to allow of the application of a general analytical solution of the problem to specific cases.

This problem in its most general form may be formulated as follows: What is, under certain favorable conditions, the shape of the surface of contact offering a minimum of friction between a fluid and an unconsolidated sediment?

Under certain conditions outlined in a previous chapter this optimum surface is that of current-ripples (and oscillation-ripples). It is characterized by the vortical layer intercalated between fluid (water or air) and sediment. It should be emphasized, however, that *the vortices are not the essential element in the formation of current ripples.* They are suction eddies, such as develop in the lee of any obstacle in the way of a moving fluid. The shifting and piling up of grains into larger obstacles with larger eddies in their lee and placed at regular intervals is directed from above by the fluid outside the zone of eddies. The vortices, for our purpose, may be considered as part of the sediment, not of the fluid above. The surface of equilibrium for the free fluid above the ripples plus vortices is *sinuous* in profile. A similar surface we find again in the sand-waves, established directly on the contact of fluid and sediment, without the intercalation of vortices. The two conditions of contact, while

[64] Snow under the action of wind shows surface forms similar to those of sand. The ''Sastrugi'' of arctic and antarctic regions are as serious obstacles to explorers (*e.g.* Nansen, Nordenskjoeld) as the sand dunes of the deserts. That the phenomena of rippling and dune formation of snow and sand are strictly analogous, was emphasized by Tschirwinsky, P. M. (Zs. Gletscherkunde, vol. 2, p. 103-112, 1907). For numerous quantitative data concerning snow-ripples and dunes see Cornish, Geogr. Journal, vols. 17, 18, 20.

differing considerably in the distribution of energy and consequently in their laws of existence, nevertheless appear to be expressions of the same general principle which we may now give in this form: *A sinuous surface of contact between a fluid and a sediment offers a minimum of friction.* The details of the form of this contact surface in each case are defined by the controlling conditions. It even is not impossible that more than one curve will satisfy certain conditions.

We may now, for a moment, turn back to the problem of the origin of dunes. Since the definition of the term "dune" does not include a rhythmic repetition of the pattern, there are, in reality, two quite different processes involved, viz. the origin of isolated dune hills, and the origin of the rhythmic repetition of the dune-pattern characteristic of the larger dune regions.

The first problem does not directly concern us here. Any obstacle in the way of sand-transporting wind, either a foreign object,[65] or a primary irregular accumulation of the sand itself,[66] is bound to collect sand around itself and hold it under the influence of the suction eddy on the lee-side, which under ordinary wind conditions, does not allow the sand-grains to escape from their hold.[67] This process obviously is independent of the size of the obstacle. Whether, however, an initial dune will persist or be "blown" away, depends on its rate of growth and the velocity and direction of the strongest winds.

That the rate of growth of wind-formed current-ripples is not sufficient to allow them to gradually grow up into "dunes"[68] is shown conclusively by experimental evidence (cf. p. 196). The regular systems of transverse dunes can, therefore, not be explained as full-grown ripples. Their formation becomes, however, intelligible in the light of King's observations and experiments, which prove that corresponding to every initial obstacle, for instance a dune, of given size and wind of sufficient velocity there exists a sinuous surface which,

[65] Vegetation, stones, minor irregularities of underlying topography, etc.

[66] Due to irregular deposition of sand carried in suspension in sandstorms; to unequal distribution of moisture in a sandsurface being temporarily eroded, etc., etc.

[67] A land surface may be entirely stripped of loose sand by frequent strong winds, only such sand being retained which happens to be caught on a dune. This "curious power" of dunes "for collecting all the sand in the neighborhood" was recently discussed by King (l. c., p. 207).

[68] As suggested by Cornish, for example (Geogr. Journ., 1907).

when established, offers a minimum of friction. Whether the surrounding surface be flat or consists itself of independent dunes, all fortuitous changes in the distribution of sand must gradually lead towards the formation of this optimum surface. In regions with uniform winds this process will finally produce a series of transverse dunes. That it will create new dunes on level sand surfaces is shown by King's observations in the vicinity of Cairo.[69] Since the minute shiftings of grain after grain on the sand surface are of the same order of magnitude on the dunes as on the ripples, the building up of a series of transverse dunes requires correspondingly more time, measured by years instead of minutes.

Turning back to our general discussion, we may express the principle underlying the formation of ripples in a broader way still. The sinuous surface differs from a level one in *substituting a rhythmic variation of velocity for uniform flow.* Since my attention was first called to this phase of the question, I have tried on many occasions to find an indication of a preexisting rhythm in the motion of wind or water passing over an immovable surface. I watched pieces of cork blown over the pavement by wind, or small stones or sandgrains rolled by water under a variety of circumstances without being ever able to discover any indication whatsoever of a rhythmic motion of these bodies. I, therefore, consider the rhythmic flow of water as the *result, not as the cause* of the formation of ripples.[70]

Analogous undulating contact surfaces of least resistance originating under very different conditions are not uncommon in nature, some even of every day occurrence.

At the contract of *air and water,* the prototype of all waves has given the clue to this interpretation.[71] Layers of *air* of different velocity and density give rise to air-waves[72] of large dimensions, often rendered visible through condensation of moisture (mackerel sky). The

[69] It should be noted, that in his experiments, described in the same paper, there was no "growing up" of small current-ripples, but the larger "dunes," caused by the obstacle, were superimposed on the rippled surface and their size and wave-length was determined entirely by the pre-existing obstacle.

[70] Baschin, *e. g.*, assumes such pre-existing periodic changes of the pressure of wind on rigid surfaces, such as asphalt pavements (1899, pp. 419-420).

[71] A brief abstract of the modern theory of water waves based on Helmholtz's work already referred to, is found in Kruemmel, O., Handbuch der Ozeanographie, vol. 2, pp. 61 ff.

[72] For a brief general discussion see, *e. g.*, Baschin, 1899.

existence of similar waves at the contact of *two immiscible liquids* of different specific gravity and opposite direction of flow was demonstrated by O. Reynolds in a very elegant experiment.[73]

A remarkable observation was published by Geinitz.[74] In many brick factories the wet clay is formed by a press into long bars and then cut to the proper size by means of a wire, moving much like the blade in a breadcutting machine. Geinitz observed that this wire does not cut a smooth surface, but passes through the clay in a sinuous curve, producing on the surface of the cut a pattern exactly analogous to that of current-ripples, showing the same anastomosing, gently curved ridges with a steep and a gentle side, and a wave-length from crest to crest of 0·14 to 0·2 cm. The steep side, however, faced the wire, that is, "up-stream."

Geinitz called attention to the delicate ruffling of the surface of schistosity of many slates, which may represent an analogous phenomenon of friction.[75]

Another no less remarkable observation is reported by V. Cornish.[76] On steep roads from the Saddlestone Slate Quarry and Cove Quarry, Coniston, Lancs., sledges are used to convey the slate down to the railway, the load for a sledge being half a ton. The sledges are only dragged downhill, each, when empty, being placed in the cart to which on the down journey it acts as a drag. These sledges produce on the road undulations of a symmetrical and rounded form, resembling a curve of sines. Their average wave-length is 14′ 9″ for both roads, while their height averages 7·5″. The length of the sledge-runners is 4′ 7″. Similar undulations of nearly the same dimensions were observed by Cornish on snow-covered roads in Canada, where they are called "cahots." For

[73] Phil. Trans. Roy. Soc., London, vol. **174**, pp. 943-944, 1884.

[74] Geinitz, E., Ripplemarks auf Ziegelsteinen, Centralbl. f. Min., etc., 1911, p. 640-643 (with illustrations).

[75] This rippling of the cleavage surface may attain larger dimensions in slates and schists (cf. Henke, Zeitscher. Deutsch. Geol. Ges. Monatsberichte, 1911, p. 104). True ripple-marks must, however, not be mistaken for it in rocks showing slaty cleavage in argillaceous layers. For an interesting discussion see Krause, Zeitschr. Deutsch. Geol. Ges. Monatsberichte, 1911, p. 196-202.

Whether the peculiar pattern, found commonly on the surface of the layers of the so-called "Wellenkalk" of the European Trias may be ascribed to the same cause, as Geinitz suggests, appears quite doubtful.

[76] Cornish, Vaughan, On Regular Undulations produced in a Road by the use of sledges, Brit. Assoc. Adv. Sci., Report, 1902, p. 730-731; 1903, p. 314 and plate 10 (excellent photograph).

the production of such undulations, the clay must be of the right degree of dampness and the snow in the state to bind under pressure.

While original irregularities in the road certainly tend to produce this effect, the author "has found, by experiments with a miniature sledge, that, when the detritus of the road consolidates readily under pressure, these undulations arise spontaneously by the action of a steadily moving sledge when furrowing a homogeneous and level road." In the author's experiments the definite wave-length of these undulations was about three and a half times the length of the sledge.

The peculiar cross-ridges so numerous on our asphalted automobile roads apparently owe their origin to the same process. Their intimate connection with original irregularities is evident in most cases.

An analogous process was observed by A. M. Miller[77] on the Canadian Pacific R. R., west of Sudbury, Ontario. A freight train, moving over a track built across "muskeg" on a fill with ordinary ties, threw the track into very pronounced undulations, which caused the mud and water to be squashed out at regular intervals (roughly estimated at 20 feet).

The transverse ridges sculpturing icicles and stalactites perhaps represent another expression of the same tendency to form the sinuous surface of least friction.

The peculiar ruffling of rock surfaces polished by the sand-blast action of desert storms, described by Hobbs as "strikingly similar to the ruffled surface of a billow or water,"[78] may owe its origin to the same cause. The enlargement of slight original irregularities of the surface may well have proceeded in such directions which tended to establish a surface of least resistance rather than any other.

A hand specimen of nearly white St. Louis limestone, collected by N. M. Fenneman from the bottom of one of the subterranean streams in White's cave near Burksville, Mo.,[79] suggests an analogous process at the contact of limestone and water (see fig. 10). The surface is covered with more or less irregular rhomboidal pits

[77] Oral communication.

[78] Hobbs, W. H., Range and Rhythmic action of sand-blast erosion, Bull. Geol. Soc. Am., vol. 26, p. 63, 1915.

[79] Now in the collection of the geological department of the University of Cincinnati.

resembling in shape and arrangement the rhomboidal ripples described on an early page. The bottom of each rhomb rises from its lowest point in one acute angle to its crest in the opposite angle, from which along the adjoining two sides there is a sudden drop to the bottom of the next pit. The gentle slope faces upstream, the steep one downstream. It seems, as though the combined action of corrosion and corrasion had led to the establishment of that surface form, which we infer from the observations on similar sand-ripples to offer a minimum of friction.

FIG. 10.

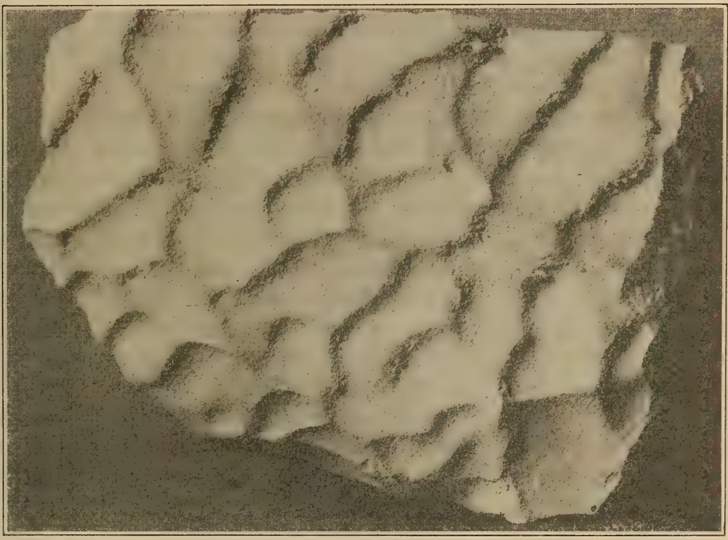

FIG. 10. Specimen of white, fine-grained limestone from the bottom of a stream in White's Cave, near Burkville, Mo. The steep sides face with the current.

This rhomboidal pattern of ripples represents a notable deviation from the ordinary undulating contact surfaces described, in that the crestlines are arranged diagonally to the direction of flow of the water. Diagonal lines are also introduced along the sides of linguoid ripple marks, although in quite a different way.

Blasius called attention to the fact that the distribution of sediment with reference to any thread of water passing over the sides of linguoid-ripples is the same as that of shoals in river channels. Most textbooks of geology refer to the shoals on the inner side of meanders and the "crossings" between two bends. It seems to be less well known, however, that a depositing stream will distribute its load in a *straight* channel in a similar way,[80] with shoals on alternating sides, connected by "crossings," so that the main current flowing from the deep on one side in order to pass over to following deep on the other side has to traverse the shallow "crossing."

Compare with this the lines of flow on fig. 2. The similarity of the arrangement is striking. The conclusion drawn by Blasius seems inevitable that the formation of both is governed by the same principle.

One might consider rhomboid and linguoid-ripples as transitional forms leading to the other extreme, that of longitudinal ridges and furrows of which the longitudinal dunes are the most remarkable examples.

According to Johnston's investigations,[81] beach cusps represent a peculiar special case of longitudinal ridges. They are of a certain interest in this connection since Johnston's interpretation of the method of formation of these cusps as due to the establishment of a state of equilibrium through gradual, more or less fortuitous changes, is exactly analogous to that given for ripples. He writes: "The tendency of wave action will be to develop from initial irregularities a *smaller* number of broad and shallow depressions on that portion of the beach traversed by the swash." "Equilibrium will be established when adjacent channels are of approximately the same size, and at the same time of a size appropriate to the volumes of water traversing them."[82]

A closer analogy with longitudinal ridges is offered by the drumlins, the origin of which must probably be explained along some such lines. Their origin as friction phenomena is emphasized by Fairchild's statement, that "one important and essential factor" is "the movement of the ground contact ice due to thrust or push of the rearward ice."[83]

[80] Cf. the beautifully illustrated paper by H. Engels, Untersuchungen uber die Bettausbildung gerader oder schwach gekrümmter Flusstrecken mit beweglicher Sohle, Zs. Bauwesen, vol. 55, p. 663 ff. (plates 63-67), 1905.

[81] D. W. Johnston, Beach Cusps, Bull. Geol. Soc. Am., vol. 21, pp. 599-624, 1910.

[82] *Ibid.*, p. 621.

[83] H. L. Fairchild, in discussion of W. C. Alden's paper on Radiation of glacial flow as a factor in drumlin formation, Bull. Geol. Soc. Am., vol. 22, p. 734, 1911.

Detailed investigations will have to decide whether in the foregoing discussion imagination has been led to falsely group together heterogeneous phenomena or not. We should, of course, never lose sight of the fact that the working of the principle is very different in the different cases. The conception, however, of the tendency of two substances in moving past each other to form a surface of contact which offers a minimum of resistance by substituting a rhythm for uniform motion is of fundamental value. This, however, is itself but a special case of a still broader conception, that of the principle of least work, which according to H. von Helmholtz[84] is probably as general a law of nature as that of the preservation of energy.

VII. Nomenclature.

The term ''Sedimentary Ripples'' which appears in the title of this paper, may now be defined to include all *undulating surface forms which originate as surfaces of least friction or parts of such along the contact of a moving fluid and an unconsolidated sediment, with their crests trending at right angles or obliquely to the direction of flow of the fluid.* This definition excludes all such undulations as form at the contact of two layers of rock, for instance, the corrugations found on the cleavage faces of slate or the peculiar variety of mudflow structure imitating ripples, which was described by Fuchs[85] from the lower surfaces of ''Flysch'' sandstones and proven experimentally to form when a viscous mass (like plaster of Paris) flows over a yielding substratum (like sand). Such forms might be referred to as *''Pseudo-ripples.''*

It also includes beach-cusps and other longitudinal surface structures, for instance, longitudinal dunes. The word ''dunes'' would be preferable to ''ripples'' as a general term, as suggested by Gilbert, but its firmly established usage which includes all kinds of wind-shaped hills prevents such a redefinition. The terms used in this paper for the different types of ''sedimentary ripples'' and their classification, are given in the following table.

[84] H. von Helmholtz, Wissenschaftliche Abhandlungen, vol. 3, p. 209-210 (Ueber die physikalische Bedeutung des Prinzips der kleinsten Wirkung).

[85] Theodor Fuchs, Studien ueber Fucoiden and Hieroglyphen, K. Akad. Wiss., Wien, vol. 62, pp. 371-374, 1895.

Classification of Sedimentary Ripples.

	Current of uniform direction		*Current oscillating*
	Subaqueous	Eolian	
I. Ripples forming at low velocities, (below the second critical point), with no sediment in suspension. A part of the fluid moving in horizontal vortices set up as grains shift on the surface of the sediment otherwise at rest.	Current-ripples *a.* normal *b.* rhomboid *c.* linguoid	Current-ripples	Oscillation-ripples
II. Ripples forming at high velocities, (above the second critical point), with more or less sediment in suspension. 1. A part of the fluid moving in horizontal vortices set up by a preëxisting obstacle of relatively large size, with the bulk of the sediment at rest.	?	Transverse dunes	?
2. No horizontal vortices; the fluid moving everywhere in the same direction at contact with the sediment, which itself is in motion; the ripples destroyed or transformed when motion ceases.	Sand-waves *a.* progressive *b.* regressive	?	(impossible)
III. Resulting from a transformation of sand-waves, when the velocity of the current fails:	*a.* Meta-ripples *b.* Para-ripples[86]		

IV. Resulting from the interference of two sets of ripples.
1. One set forming after the completion of the other.
   a. The second set consisting of oscillation-ripples: Oscillation cross-ripples.
   b. The second set consisting of current-ripples: Current cross-ripples.
2. The two sets forming simultaneously: Compound ripples.

[86] See Part II, in a later number.

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[Part II will follow in the April number.]

Art. XIII.—*The Age of the Brandon Lignite and Flora;* by Edward W. Berry.

The small deposit of lignite near Brandon, Vermont, has excited an interest out of all proportion to its size ever since its discovery in 1848. This was due, in the first instance, to its uniqueness among New England deposits and to the diversity of strange fossil fruits which it contained. Its location makes it of very great importance in any broad consideration of the evolution and migration of the fossil floras of eastern North America, since except for a few scattered and small florules in New Jersey, Maryland and Virginia and these for the most part quite different in age, it is the sole relic of Tertiary vegetation north of Georgia, and it has also an important bearing on geological climates provided its age can be determined with reasonable accuracy.

I received recently from W. A. Nelson, the State Geologist of Tennessee, two fossil fruits from the clays of the western part of that state which prove to be unmistakably related to forms described from Brandon and not known from any other localities. This has led to a reawakening of my interest in the Brandon flora and to the present attempt to fix its age more definitely.

The late Edward Hitchcock was the first one to describe the Brandon locality and some of its fossil fruits, which he did in 1853,[1] subsequently reprinting what is substantially the same account in his Geology of Vermont eight years later.[2] The deposit lies at the western base of the Green Mountains about two miles northeast of the town of Brandon in a region of Cambrian quartzites, schists and dolomites, and is now entirely hidden by Pleistocene deposits. Associated with the lignite are clays and limonite, both formerly worked at different times for iron, paint and paper clay. Its interest may be indicated by the fact that there are no comparable Tertiary lignites within upwards of one thousand miles, that the contained flora is largely unique and is, except for Pleistocene, the only fossil flora thus far discovered in

[1] Hitchcock, E., Description of a Brown Coal Deposit in Brandon, Vermont, this Journal, (2) vol. 15, pp. 95-104, 1853.

[2] Hitchcock, E., Geology of Vermont, vol. 1, pp. 226-234, 1861.

Vermont, and also except for the Pleistocene, the only trace of post-Paleozoic deposits in that state.

Hitchcock submitted samples of the wood to Professor Bailey, who pronounced them to be exclusively dicotyledonous; and fruits to Lesquereux, who published an account of them in 1861[3] and freely discussed their probable age. Fifty years later Knowlton published additional notes and announced the presence of coniferous wood.[4] During the coal strike of 1902-1903 the old workings were reopened and G. H. Perkins, the State Geologist of Vermont, was thereby enabled to secure an unparalleled collection of the fruits, which he described and figured in several admirable papers published in 1905 and 1906,[5] together with geological notes by Dale and Woodworth, and an account of the microscopic character of some of the lignites by Jeffrey & Chrysler.[6]

With this brief synopsis of the history of the investigations I turn briefly to a consideration of the views regarding the age of the deposits. Opinion has been almost unanimous from the first that the deposit was of Tertiary age, and this conclusion appears to me to be indisputable. Hitchcock stated with some slight reservation that the deposit was Pliocene or newer Tertiary, and made the rather bold assertion that it represented a marine Tertiary formation that extended from Canada to Alabama, the latter opinion being based upon the wide distribution of limonite or brown hematite, really of diverse origin and without bearing on the question.

Hitchcock was undoubtedly influenced in reaching an opinion regarding the age of the lignite by Lesquereux, who had identified five out of a total of twenty-three then known forms with European Miocene species, chiefly from Oeningen in Baden (Tortonian stage). At the same time, Lesquereux noted resemblances to plants from the "upper lignitic formation which extends on both sides of the Mississippi, and which I had opportunity to explore

[3] Lesquereux, L., Fossil Fruits from Lignites at Brandon, Vermont, this Journal, (2) vol. **32**, pp. 355-363, 1861: Geology of Vermont, vol. **2**, pp. 712-713, 1861.

[4] Knowlton, F. H., Notes on the Fossil Fruits and Lignites at Brandon, Vermont, Bull. Torrey Bot. Club, vol. **29**, pp. 635-641, pl. 25, 1902.

[5] Perkins, G. H., Rept. State Geol. 1903-1904, pp. 153-162, 174-212, t. f. 8, pls. 75-81: Idem for 1905-1906, pp. 188-194, 201-230, pls. 46-48, 52-58: Bull. Geol. Soc. Am., vol. **16**, pp. 449-516, pls. 86, 87, 1905.

[6] Jeffrey & Chrysler in Perkins, Rept. State Geol. for 1905-1906, pp. 195-201, pls. 49-51.

in Arkansas.'' The latter refers to formations now known to be exclusively of Eocene age (Wilcox, Claiborne and Jackson groups), which Lesquereux also regarded as of Miocene age, both views being also those of Newberry.

Notwithstanding the opinion of Lesquereux, Dana, in the first and subsequent additions of his Manual, shrewdly placed the Brandon lignite in the Eocene, because of the stratigraphic relations of the Gulf deposits, Knowlton (op. cit.) appears to have been of the opinion that the Brandon deposit was of Miocene age, and Woodworth concurred in this view, stating that the earlier Tertiary was a time of erosion in New England. The current opinion founded on this tradition appears to definitely place the deposits in the Miocene, Chamberlin & Salisbury's Text going so far as to label them the Brandon formation and stating, quite without basis, their occurrence in Vermont, Pennsylvania and Georgia.[7] In the study of the Eocene floras of the Gulf states I became so far convinced that the Brandon flora was not Miocene that I stated in the introduction to my work on the lower Eocene flora that the Brandon flora was pre-Miocene.[8]

The cumulative evidence for this opinion will now be given. The flora of Brandon as made known through the researches of Perkins, and to a less extent by the work of the other authors previously mentioned, comprises about 150 species of fruits and seeds and two or three additional forms based upon wood structure. None of these have in late years been regarded as identical with previously described forms from deposits of known age, and this conclusion appears to be fairly well-founded for the great majority of the Brandon species. Although I would be inclined to depreciate the multiplicity of species described by Perkins this in no wise affects the question of age.

The botanical character of the Brandon flora is difficult to evaluate owing to our lack of knowledge of the precise botanical relationship of the majority of the fruits. Nevertheless the greater proportion of the forms are such as would be incapable of existence in New England under existing climatic conditions, and of genera present in the lignite that are found in the existing flora of New England, namely Juglans, Hicoria, Nyssa, Pinus, etc., Jug-

[7] Manual, vol. III, p. 261.
[8] U. S. Geol. Surv. Prof. Paper 91, p. 6, 1916.

lans and Hicoria come from a warm climate ancestry and the center of distribution of existing Nyssas is in the South Atlantic states. In addition to these more definitely determined forms the Brandon flora contains a variety of so-called species, some of which to be sure are illy understood, that suggest relationship with existing tropical and sub-tropical Menispermaceæ, Sapotaceæ, Rubiaceæ, Tiliaceæ, Malvaceæ, Cucurbitaceæ, Sapindaceæ, and Lauraceæ. According to Jeffrey the bulk of the lignite studied microscopically belongs to the Lauraceæ, and both Lesquereux and Perkins have identified the genus Cinnamomum in this flora. The latter reaches its present northern limits in Florida (cultivated) and in the rain-forests of Formosa and southern Japan.

The Brandon flora could not have existed except in a humid warm climate. The question then is: Could this flora fit into the Miocene environment of Vermont? An affirmative answer was most natural when, following Heer's wonderful discoveries in the Arctic region, it was believed that the circumpolar floras extending to within a few degrees of the pole itself, were of Miocene age. This supposition has now been definitely disproved and the maximum northward spread of the Tertiary forests is known to have been much earlier, certainly in the Eogene as opposed to the Neogene portion of the Tertiary, and probably at a time corresponding to the time of the greatest northward extent of tropical floras in our Gulf states, which was in the late Eocene (Jackson) and earliest Oligocene (Vicksburg).

Although Miocene floras for comparison with the Brandon flora are practically nonexistent along the Atlantic coast of North America, traces of such floras as are recorded from Maryland and Virginia[9] are of a decidedly more temperate facies than that of Brandon despite their much more southern and lower location. The largely undescribed flora from southern New Jersey (Bridgeton) which is of newer Tertiary age (late Miocene or early Pliocene) is also quite different from that of Brandon and indicative of less warm climatic conditions. More weighty perhaps in any consideration of Miocene climate is the evidence of the much more abundant marine faunas of the Atlantic Coastal Plain Miocene. These clearly

[9] Berry, E. W., U. S. Geol. Surv. Prof. Paper 98 F, 1916.

indicate temperate oceanic waters and a marked, if not quantitatively great, lowering of temperatures in the Miocene, during which the marine life of the middle Atlantic coast penetrated southward to Florida and replaced the sub-tropical faunas of the upper Oligocene. The paleobotanical evidence of this change of climate is seen in the south in the presence of temperate forest trees such as the elm in the Aquitanian or Burdigalian Alum Bluff formation of Florida. I conclude from the foregoing considerations, which might be amplified with much greater detail, that the Brandon flora can not be of Miocene age.

More direct evidence of the age of the Brandon flora, largely unpublished, may now be summarized. I have already alluded to Lesquereux's discovery of a resemblance between the Brandon flora and that of the Eocene of the Mississippi embayment. This rests to some extent upon general facies and is not as conclusive as could be wished since in the one case we are dealing with coastal floras largely represented by leaf impressions, while in the other case we are dealing with an inland flora represented by fruits and seeds gathered by streams and deposited in a single limited basin, the two separated by over 1000 miles, mostly latitudinal in direction. In spite of these difficulties the peculiar Brandon genus Monocarpellites, whether an identical species or not I hesitate to say, is found in the Wilcox, as are several Nyssa stones. The genera Juglans, Hicoria, Cinnamomum, Aristolochia and Sapindus are present in both. An undescribed Laurinoxylon from the Wilcox is very close to the one so abundant at Brandon. Nyssa stones of large size and closely allied to, if not identical with, a Brandon type, occur in both the Claiborne and Jackson of the Gulf states.

The genus Tricarpellites to which Perkins refers twenty species of fruits from Brandon, is a genus founded by Bowerbank and known elsewhere from only the Ypresian stage of the Eocene of Sheppey. Moreover other of the Brandon fossils suggest comparisons with, and some are very close to, other Sheppey forms, the latter representing an early Eocene accumulation of fruits by a river system located in what is now the Thames basin. For example the genus Monocarpellites, so abundant at Brandon and present in the Wilcox, appears to be congeneric with Bowerbank's genus Hightea, which is a common fossil at Sheppey. The most striking difference in the English flora is the abundance of the palms, and its more decidedly tropical character. Another fact bearing on the age of Brandon is that the coniferous wood described by Knowlton is so nearly related to a species described by Schmalhausen from the Eocene of southwestern Russia that the Brandon form is made a variety of the latter. Furthermore two fruits found in the Eocene of Maryland (Nanjemoy formation) and described as Carpolithus by Hollick[10] are not only strictly comparable with fruits from Brandon which are referred variously to Apeibopsis and Cucumites, but both are likewise comparable with the genus Wetherellia founded by Bowerbank upon Ypresian forms from the London Clay of Sheppey.

Summarizing the foregoing statements they are seen to comprise, 1. general considerations of unsuitable climatic environment during the Miocene and an unlikeness between the Brandon flora and such Miocene floras as are known from the Atlantic coast of North America; 2. the presence of closely related, if not identical, species in the Eocene of Maryland, of the Mississippi embayment region, of southern England and of southwestern Russia.

These all point in the one direction and are sufficiently weighty to justify considering the Brandon lignite and its contained flora as of Eogene instead of Neogene age. Much as I dislike these terms I hesitate to attempt a closer correlation, since Eocene floras in North America are much more extensive and better known than Oligocene floras, and the possibilities of the Oligocene age of the Brandon deposit cannot be lost sight of, although the evidence derived from the extensive European Oligocene floras and the resemblance to American and other Eocene floras leads me to regard the Eocene age of the Brandon flora as the most probable of the two possible assumptions.

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Baltimore, Md.

[10] Hollick, A., Md. Geol. Surv., Eocene, p. 258, pl. 64, figs. 11, 12, 1901.

Art. XIV.—*An Amphibian from the Eocene;* by F. B. Loomis.

Among the specimens collected from the Lysite beds of the Lower Eocene on Bridger Creek, Wyoming, by the Amherst College expedition of 1905, is a well-preserved skull of an amphibian. It is about 1¼ inches long and represents an individual about the size of a mudpuppy (*Necturus*). Though Amphibians must have lived in the ponds and moist places then, as both before and since Eocene times, I believe none has heretofore been found. The Lysite represents flood-plain deposits, under a rather arid climate, as do most of our western Eocene epicontinental deposits, but there must have been streams and moist places, and this form presumably lived in or near some such place.

Unlike such amphibian remains as have been found in the Tertiary, this skull can not be referred to any of the living genera, though it seems to be clearly one of the Caudata, and belongs to the family Salamandridæ, and be as near to the genus *Triton* as to any of the living types; but it differs in so many material points that I am not by any means confident that it can be considered in any way ancestral. It is peculiar among all amphibians in having a small splint-like supraoccipital bone, and among caudate types in having a trace of the parietal foramen, though the actual opening is closed and plugged with bone. The anterior part of the skull is fused into a solid roof, and I can not see where the nasal passages opened anteriorly, though the interior openings are large. The cartilage bones of the posterior part of the skull are unusually completely ossified, and the otic region is developed so as to form a strong projecting process on the ventral side. Most of the skull is preserved except the quadrate region, and parts of the squamosum and pterygoid bones.

I have called the form *Ototriton solidus* gen. and sp. nov. The type is in the Amherst College Cabinet, and comes from Bridger Creek, Wyoming, from the Lysite beds, associated with *Eohippus kraspidotus, Phenacodus vortmani, Notharctus venticolus, Paramys bicuspis,* etc.

The frontals and nasals of both sides are fused together and to the maxillæ; so that the whole anterior part of the skull is solidly roofed over. The premaxillæ, however, were free and must have been small. They are lacking, but along the front of the skull are grooves into which they set (see fig. 1 B, P. mx). In this respect, but in no other, the skull suggest *Necturus*. The parietals extend back from the frontals to the rear of the cranium. (The line cutting off the rear part of the parietals is not a suture but a crack.) These bones are paired, and along the middle line in the rear, separated from each other by the narrow splint-like supraoccipital bone; most unusual in amphibians, but very clear here. Near the front of

Fig. 1.

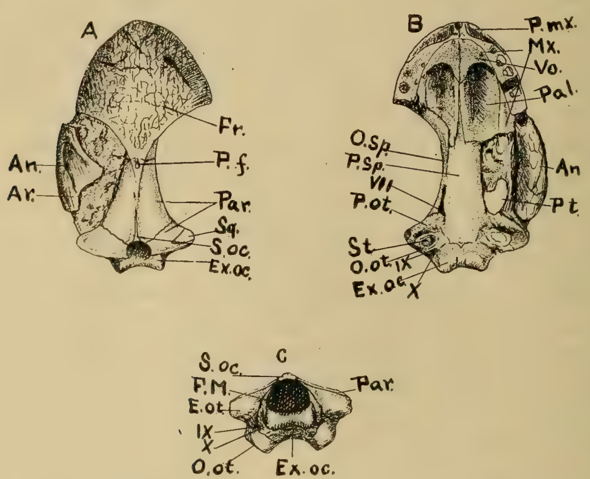

Fig. 1.—Skull of *Ototriton solidus*, natural size; A from above, B from below, C from the rear.

An. angulare; *Ar.* articulare; *E. ot.* epiotic; *Ex. oc.* Exoccipital; *Fr.* Frontal; *F. M.* Foramen Magnum; *Mx.* Maxilla; *O. ot* Opisthotic; *O. sp.* Orbitospenoid; *Pal.* Palatinum; *Par.* Parietal; *P. mx.* Premaxilla facets; *P. ot.* Prootic; *P. sp.* Parasphenoid; *Pt.* Pterygoid; *S. oc.* Supraoccipital; *St.* Stapes; *Vo.* Vomer; VII, IX, X Foramena of cranial nerves.

the parietals is a depressed area, in which there is an oval groove which can represent nothing but a parietal foramen, though it is closed and plugged with bone; but very clearly outlined, especially when magnified. Along their posterior border the parietals flare up a little making a low crest across the rear of the skull. The proximal end of the squamosum bone is present but that is all.

The maxillæ carry a row of simple conical teeth set along the outer margin (acrodont); and probably extended onto the premaxillæ, which are lacking though indicated. Inside these are several tiny teeth indicating a second inner row, of much smaller size. The palate is strongly arched for an amphibian, its anterior portion being roofed by the vomers, each of which has a tiny tooth on the front margin. On the posterior border of the vomers, open the posterior choanen; and from this point back the palate is even more arched. The palatal bones are strongly arched and unusually wide, extending back in this specimen to beyond the middle of the skull; and possibly the pointed rear ends are missing. The arrangement of the vomers, palatines, and the choanen is most like that of the newts, especially in the extended palatals, in the development of the choanen, and in the arching of the palate. Still it is not close enough to Triton so that I would want to put it in the same genus. The parasphenoid is of moderate size, and it tends to be confluent with the exoccipitals and otic bones, but faint suture lines indicate the boundaries I have shown in fig. 1 B. The back part of one of the pterygoids is present and this is separate from the palatal bones entirely.

The two occipital condyles are confluent and completely ossified, making a saddle-like articulation for the skull. The whole otic region is completely ossified and strongly developed. The inner ear chamber has inflated the otic bones so that they have developed a stout process around it, on the out end of which is the stapes, wholly ossified, and in place on the left side, though lost on the right. The epiotic also is largely inflated and develops into strong lateral knobs from which the squamosum starts.

The back end of the lower jaw is present and of typical caudate pattern, but there is not enough of it to offer any basis for comparisons.

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SAMUEL WENDELL WILLISTON

While occupying a position high among the leaders of science in America, and before his powers had begun to wane, or the clarity of his scientific vision to grow obscure, Professor Williston was called to his account. He died on August 30, 1918, in the sixty-eighth year of his age.

Although of New England stock and Boston nativity, Williston's boyhood through the completion of his school and collegiate education was spent in Kansas, as were many of the most productive years of his after life. New Haven, Lawrence and Manhattan, Kansas, and Chicago were his places of residence, although the pursuit of his researches took him farther afield.

At Yale he studied medicine, taking his M.D. in 1880, and filling the chair of anatomy in the Medical School from 1886 to 1890. Previous to this, however, he had become interested in fossil vertebrates, and studied under Professor Marsh, aiding to a large degree in field work in the Kansas Chalk and in the dinosaurian deposits of the Morrison. As an appreciation of his attainments in research, Yale conferred the Ph.D. degree upon Williston in 1885; this judgment was reaffirmed in 1913, when he received from Yale an honorary Sc.D. We have, however, no record of the actual research in paleontology which he may have accomplished during his association with Professor Marsh. It was mainly to find an outlet for his ideas that he took up the study of insects, especially the Diptera, as a side issue. This group became, however, of such absorbing interest that by 1896 he had published no fewer than eighty-three authoritative papers upon it—more than half of his entire output of scientific publication up to that time.

In the year 1890 Williston was elected professor of geology and anatomy and dean of the Medical School of the University of Kansas, and there he wrought some of his best work until called to Chicago. Lawrence being not far from the fossil areas, Williston spent season after season in the field, securing a large and representative series of fossils from Kansas and the contiguous states. It was but natural that he should turn his attention to the mosasaurs and plesiosaurs of the Kansas

Cretaceous, producing valuable monographic studies on both groups. From 1897 on Williston's paleontological papers began to appear in increasing proportion, finally almost to the exclusion of those on the Diptera, there being, all told, one hundred and twenty-two of the former to ninety-two of the latter.

In 1902 came the call to the chair of paleontology in the University of Chicago. Here Williston found the nucleus of a collection of Permian vertebrates, and he determined to undertake research in that group. Skilled assistance, together with his own indefatigable endeavors, has brought together at Chicago a collection of Paleozoic land vertebrates that is incomparable both for its extent and the perfection of the material, for Williston describes entire skeletons, whereas his predecessors had to be content with individual bones and fragments. Paper after paper on these obscurely known forms came from his prolific pen. The material was prepared under his guidance, and drawn and photographed entirely by his own hand, a feature that gives a unique value to the product.

Two books appeared during Professor Williston's term at Chicago, his American Permian Vertebrates and his Water Reptiles of the Past and Present, concerning both of which groups he had thought and studied until none knew them better than he. A book on the Evolution of the Reptiles was in course of preparation at the time of his death.

Williston possessed a broad and accurate knowledge of human and comparative anatomy, so that his morphological results were rarely in error; when such was the case, however, no one was more willing to acknowledge it than he. His knowledge of the flies was both comprehensive and minute, and it is characteristic of him that after years of paleontological study, to the utter exclusion of entomology, he was able to revise and extend his great Manual of the North American Diptera, treating the minutiæ of description with a thoroughness of grasp which showed that little had escaped his memory in a dozen years.

Williston's contributions to science, aside from the material value of the collections which he aided in building up at Yale, Kansas, and Chicago, are, first, his entomological work, mainly with the Diptera, which covered the description of hundreds of genera and species, although he cared little for the name of a form or who gave it so long as he "knew what he was talking about." His work was mainly on the flies of North America, although some from Central and South America were touched upon. His principal general work was a privately printed Synopsis of the Families and Genera of North American Diptera, 80 pages, 1888, followed by a second edition of 220 pages in 1896, and a third of 405 pages in 1908, the latter two being known as manuals. This work, always authoritative, is looked upon in its final form as the standard on North American flies.

Williston published but six minor papers on recent zoology, mainly on the habits of certain animals and birds which came casually under his observation. Of comparative anatomy as such there were but two, although his entire paleontological work is of that nature. Three reports on sanitation, especially river pollution, appeared in 1888-1890, while he was health officer of the city of New Haven. Five times he was called upon to pay tribute to departed colleagues, while five more papers refer almost exclusively to mankind, one of them dealing with his Central Asiatic origin, the other, on the finding of an arrowhead with the remains of *Bison occidentalis,* being one of the two unshakable bits of evidence for the contemporaneity of man and extinct animals in North America.

Of geology (stratigraphy), but twelve papers treat exclusively, the authorship of one of which he shares with Professor Case. Williston speaks mainly of the Kansas Chalk, the Niobrara Cretaceous and the Pleistocene of Kansas, and the Red Beds of Kansas and the Southwest. Such geological work as he did has high value, but Williston could hardly be considered a stratigrapher of note because of the paucity of his contributions along that line.

Evolutionary problems arose from time to time in his work, though few of his papers, except his incompleted book on the reptiles, deal exclusively with that department of research.

To the reviewer, Williston's work in paleontology naturally makes the greatest appeal, and indeed it constituted nearly one-half of his entire number of titles and of his entire literary output, for out of something more than four thousand printed pages, seventeen hundred referred to fossil vertebrates; but one invertebrate paper, that on *Uintacrinus,* which is so intimately associated with the Cretaceous vertebrates, coming from his pen. Comparatively few contributions treated of the mammals or of the fishes, and the birds were given scant attention, although some of the most beautiful and interesting Mesozoic ones, *Hesperornis* and *Ichthyornis,* were found in his adopted State. It was to the reptiles that he turned for material, largely, I suppose, because of their abundance in Kansas and because of his having been first employed in their collection. He not only wrote more extensively of them than of any other class, but he thought of paleontological problems and taught the science largely in terms of reptiles, and it is within this group that his research rises to the rank of eminence. From the Chalk, he wrote of pterosaurs, and to him and to Eaton we owe our knowledge of the culminating flying reptiles, *Nyctodactylus* and *Pteranodon.* He wrote of plesiosaurs—work of monographic value although never brought together in monographic form. Turtles also engaged his attention, and on mosasaurs none other than Dollo of Belgium has made nearly so many or so valuable contributions; his restorations of the principal genera, *Clidastes, Tylosaurus,* and *Platecarpus,* are standard. These results were monographed, appearing mainly in Volume IV of the reports of the University Geological Survey of Kansas, 1898.

Williston's later work, after his transference to Chicago, added a new luster to his fame. This was on the older reptiles and amphibians of the Permo-Carboniferous. His influence was broader than the actual scope of his own writings, for two of his pupils, Doctor Roy L. Moodie and especially Professor E. C. Case, have supplemented their master's work, thus giving us a surprisingly large amount of information of a very exact and complete character concerning these early terrestrial forms.

Williston was loath to speculate in print, nor was he at all inclined to express opinions concerning the classification and relationships of the vertebrate groups, despite his splendid taxonomic work on the Diptera; he was, however, very frank in his constructive criticism of the attempts of others. His first general statement of reptilian classification was really that contained in his Water Reptiles (1914), Chapter II, where he says: "The following scheme differs only in minor details from the more conservative of the generally accepted views, and those differences are, for the most part, the writer's own opinions, to be taken for what they are worth. It may be said decisively that no classification of the reptiles into major groups, into superfamilies or subclasses, that has so far been proposed is worthy of acceptance. . . . And we have very much more to learn about the early reptiles before any general classification of the reptiles can be securely founded.'' It was hoped that Williston's projected book on the Evolution of the Reptiles would give further expression to his taxonomic views. The importance of publishing this work, even though incomplete, is very great.

I have before me many letters from Williston's pupils and colleagues, written in response to certain inquiries of mine. They are unanimous in their expression of the highest esteem for the man, the teacher and the investigator, the soundness of whose observations and conclusions will grow more and more apparent with the passing of time.

Richard Swann Lull.

SCIENTIFIC INTELLIGENCE.

Chemistry and Physics.

1. *Properties of Lead Isotopes.*—Theodore W. Richards, who has previously made important investigations in regard to the differences between ordinary lead and the lead from radioactive minerals, has recently in coöperation with Walter C. Schumb determined the refractive index and solubilities of common lead nitrate and of ''uraniolead'' nitrate from Australian material. The highly interesting fact is revealed that while the atomic weights of the two kinds of lead are 207.20 and 206.41, and while the densities of the metals vary in the same ratio, there is no appreciable difference in the refractive indices of the solid nitrates, as they were found as a mean of many concordant determinations at 20° to be 1.7815 and 1.7814. On the other hand, the solubilities of the salts at 25.02° were found to vary, being 37.342 and 37.280 parts in 100 parts of water, but these results are precisely proportional to the molecular weights of the salts, within the limits of experimental error, so that the molal solubilities in 1000 parts of water are practically identical,

1.7993 for common lead nitrate and 1.7991 for the isotope from uranium.—*Proc. Nat. Acad. Sci.*, **4**, 386. H. L. W.

2. *A New Source of Glycerine.*—In a report to Congress the U. S. COMMISSIONER OF INTERNAL REVENUE states that the facilities of the Bureau for chemical experimentation have been utilized in developing a new and successful process for producing glycerine. It was feared that the ordinary method of producing this important constituent of explosives from fats, in connection with a shortage in their supply, might fail to produce a sufficient supply for military purposes. In Germany this situation occurred, but it was overcome by the development of a synthetic process.

The new process consists in recovering the glycerine produced by the fermentation of sugar. It was found that in this way any quantity of glycerine that might be required could be produced, and this was confirmed by a large scale experiment. It appears that the process is capable of profitable commercial application.—*Jour. Indust. Engr. Chem.*, **11**, 74. H. L. W.

3. *The Occurrence, Chemistry, Metallurgy, and Uses of Tungsten.*—This monograph of 264 pages by J. J. RUNNER and M. L. HARTMANN, including an extensive bibliography of the subject by the latter author, has been issued recently by the South Dakota School of Mines, Rapid City, S. D., as Bulletin No. 12, Departments of Geology and Chemistry.

The book is an important and interesting one. The industrial demand for tungsten has greatly increased in recent times, not only on account of its use for filaments in incandescent electric lights, but particularly because of its increased application as a constituent of "high speed" and other special steels, to which about 90 per cent. of the present production is devoted. The fact that the tungsten ore production had been practically a German monopoly, led to a great stimulation in the search for new available deposits. Since about the middle of 1915 much of the ore has been produced in the United States, so that in 1916 we produced more tungsten than any other country. South Dakota, which stands fourth among our producing states, has already mined over a million dollars worth of tungsten ores from the Black Hills district.

The book discusses the geological occurrence of tungsten with special reference to the Black Hills, and it gives an excellent account of its metallurgy, properties, uses, etc., as well as the analytical methods applied to its ores and products. H. L. W.

4. *An Advanced Course in Quantitative Analysis;* by HENRY FAY. 8vo, pp. 111. New York, 1917 (John Wiley & Sons, Inc.).—Professor Fay has prepared this course particularly for the use of students in the Massachusetts Institute of Technology. It gives an excellent series of directions, with copious explanatory notes. The book begins with a clear statement in regard

to the precautions necessary in sampling for analysis. The "mineral analysis" included in Part I comprises the determination of silica, potassium and sodium in silicates, iron aluminum, manganese, calcium and magnesium in spathic iron ore, sulphur in pyrites, titanium in iron ores, copper by iodimetry and the proximate analysis of coals. The "metal analysis" of Part II includes the analysis of phosphor-bronze, and besides this only the determination in irons or steels of carbon, manganese, phosphorus, sulphur, silica, copper, nickel, chromium, tungsten and vanadium. The book is supplied with an atomic weight table as well as with tables of 4-place logarithms and antilogarithms, but as no analytical factors appear to be given, it seems that the students are expected to calculate these for themselves.

H. L. W.

5. *Reduction Methods in Volumetric Analysis;* by EDMUND KNECHT and EVA HIBBERT. 12mo, pp. 135. London, 1918 (Longmans, Green & Co., New York. Price $1.75 net).—The authors of this book introduced the employment of titanous chloride in volumetric analysis about 16 years ago, and applied this reagent to a great variety of determinations, including important applications to the estimation of many dyestuffs. Their results and those of others were described in a monograph about eight years ago, while the present book is a new issue of that work with an addendum of about 26 pages describing recent applications of the titanous chloride methods. The book is worthy of the careful attention of analytical chemists, for the methods are well described, and many of them appear to deserve more extensive application than they receive at present.

H. L. W.

6. *A Handbook of Colloid Chemistry;* by WOLFGANG OSTWALD. Translated by MARTIN H. FISCHER. 8vo, pp. 284. Philadelphia, 1918 (P. Blakiston's Son & Co. Price $3.50 net).—This is the second English edition, corresponding to the third German one. Numerous notes have been added to the translation by Emil Hatschek. This standard work, dealing with a branch of chemistry of great importance, is so well known in its first edition which appeared about three years ago, that it is merely necessary to say here that only a moderate amount of matter has been added in the present edition in order to explain the recent important advances in the subject. H. L. W.

7. *The Genesis of the Law of Error.*—In replying to certain adverse criticisms by F. Y. Edgeworth of an earlier paper by R. A. SAMPSON the last named writer has presented a point of view which will doubtless be illuminating to physicists, even if it may not entirely satisfy the exponents of mathematical ultrarefinement. The following quotation indicates the part of the discussion which seems to be of general interest: "Where then does the Law of Error come from, and why does it apply,

on the whole, so unerringly to the most diverse and unselected material? That it does not apply always and of necessity, may be taken as admitted. That it does apply very closely and very commonly is a matter of experience.''

If a distribution of errors subject to the regular law—that is, occurring proportionately to $\exp(-h^2x^2)$—be taken, if each element of this be replaced by another distribution obeying the same law, and if the results be then collected in the order of their magnitude, a third final distribution will emerge which is again subject to the original law. This is the reproductive property of the law of error which has been apparently proved by a number of writers. By itself such a property leads nowhere, for its application is limited to domains already subject to the law. It is therefore necessary to make an excursion outside it to find the genesis of the law.

Accordingly, let a distribution be taken which does not follow the law $\exp(-h^2x^2)$ strictly but which fluctuates around this law; for example, in the manner expressed by $\exp[(-h^2x^2)(1+a \cos kx)]$. If, as above, this be disturbed by a second distribution of the same kind, say $\exp[(-h^2x^2)\ (1+a' \cos k'x)]$, a third resultant distribution will be obtained in which *the fluctuating element tends to efface itself.* ''Hence if we go on piling error upon error, provided each has the fluctuating character indicated above, we shall as a limit converge to the pure law of Gauss.'' More generally, in order to obtain an approximation to a set of numbers fluctuating about the law of distribution $\exp(-h^2x^2)$, where h is an adjustable constant, nothing more is necessary than to take any holomorphic function as originating the error and then to let the frequency curve register the number of times individual values occur, disregarding at the same time the order in which these values arise naturally.

''If then we suppose that errors are not of mysterious character, *sui generis,* but are simply the mass of numberless neglected disturbances, each occurring according to regular law and order of its own, it is seen that we obtain the approximation to Gauss's law which is necessary to begin with, by the *operation of neglecting the circumstances and order of their origin, and scheduling merely in sequence of magnitude the number of times that each particular value occurs.* It is this operation that is the significant act which effaces the individuality of the contributing elements and permits us to obtain, apparently from nothing, the law of Gauss; for if we go on repeating it for more and more sources of error, we obtain the law with greater and greater purity.''—*Phil. Mag.,* **36**, 347, 1918. H. S. U.

8. *Atomic Number and Spectral Series.*—Ever since the discovery of series relationships between the lines of ordinary spectra (λ 2000-λ 8000, say), attempts have been made to find an empirical law connecting the constant frequency differences

with some general physical quantity such as atomic weight. As is well known, partial success was first attained by Kayser and Runge, and by Rydberg, who showed that the frequency differences ν between the components of a doublet series, and the differences ν_1, ν_2 between the components of a triplet series, vary in such a way that, for the same column of the Mendelejeff table, the ν's are roughly proportional to the squares of the atomic weights. Better agreement between the quantities in question was found later, by Runge and Precht, to be effected by their so-called law which is, that the logarithm of ν is a linear function of the logarithm of the atomic weight. More recently, the pioneer work on characteristic X-rays, by Moseley and others, has led to the belief that atomic numbers are more fundamental than atomic weights. This being granted, the obvious thing to do is to try to find a connection between the frequency difference ν and the atomic number N.

In this direction, a certain measure of success has been attained in a recent paper by H. BELL. As suggested by Moseley's law, $\sqrt{\nu} = m(N-N_0)$, Bell plotted the square root of the frequency as ordinate against the atomic number as abscissa, for elements of the same Mendelejeff family. In general, the points thus plotted fall fairly closely on straight lines. For example, in the case of the doublet series, Li, Na, K, Rb, Cs, or Al, Ga, In, or N, As, Sb, Bi, etc., satisfy the linear law. Similarly, for the triplet frequency intervals, this relation is found to hold between Mg, Ca, Sr, Ba, Ra, etc. In two instances, the diagrams show that one right line branches from another at a certain element. For illustration, at the K point of the Li-Na-K-Rb-Cs line there originates a line passing through Cu and Ag. The paper also contains the numerical data obtained by substituting in both the formula given above and in the logarithmic relation proposed by Runge and Precht. On the whole, the advantage seems to favor the linear equation. For lack of space, the author's discussion of the exceptional cases and of the theoretical aspect of the problem will have to be omitted.—*Phil. Mag.*, **36**, 337, 1918.

H. S. U.

9. *Mirrors, Prisms and Lenses;* by JAMES P. C. SOUTHALL. Pp. xix, 579. New York, 1918 (The Macmillan Co.).—This volume is essentially a text-book on geometrical optics. Although, of necessity, a part of the ground covered coincides with the corresponding portions of the author's earlier volume entitled "The Principles and Methods of Geometrical Optics," nevertheless the two books are not coextensive, and they were written with entirely different objects in view. Since the present book is intended primarily for students whose mathematical attainments are relatively small, the analytical developments have been made as simple as is consistent with clearness and rigor.

In the earlier chapters the subject-matter is presented in great detail and in a very elementary manner. In addition to line diagrams, four full-page, half-tone reproductions of photographs, illustrating various phases of reflection in one or more plane mirrors, are given. The subject of reflection is immediately followed by chapters on refraction at plane surfaces, such as slabs and prisms. In particular, the power of an ophthalmic prism, and the definition and use of each of the terms "centrad" and "prism-dioptry" are discussed. The topics of reflection and refraction of paraxial rays at spherical surfaces are next introduced as appropriate introductions to the discussions of thin lenses, changes of curvature of wave-fronts, astigmatic lenses, symmetrical optical instruments, compound systems, thick lenses and combinations of lenses and mirrors, etc. Chapter XIII deals with the optical system of the human eye and with the magnifying power of optical instruments. The next chapter relates to dispersion and achromatism. The last chapter (XV) pertains to rays of finite slope, to spherical aberration, to astigmatism of oblique bundles, etc.

Throughout the text the author has paid attention to the practical applications of the general principles. For example, adequate space is devoted to the heliostat, Hadley's sextant, the lens-gauge, toric lenses, ametropia, emmetropia, correction lenses, etc. One of the needs of the student is met by the large number (440) of problems which are collected at the ends of the chapters. The same high standard which was set in the earlier volume has been fully maintained in all respects, so that the book removes one of the causes which may have militated against the offering of courses on geometrical optics in American colleges and universities. H. S. U.

10. *Physics for Technical Students. Sound, Light, Electricity and Magnetism;* by William Ballantyne Anderson. Pp. xiii, 458; 373 figures. New York, 1919 (McGraw-Hill Book Co.).—This volume constitutes the second part of "Physics for Technical Students," the first part having been published in the year 1914 (see **37**, 480, 1914). It commences with chapter XIX, page 337, and it is subdivided into: Part IV, Sound (55 pages, 25 problems), Part V, Light (154 pages, 45 problems), and Part VI, Electricity and Magnetism (230 pages, 87 problems). "Material, which in the author's opinion might be omitted in a briefer course, appears in finer print." Stress is laid on the practical applications of the subjects discussed because the text is designed primarily to meet the needs of classes in Agriculture and Engineering. The two volumes may be obtained bound in one.

Taken as a whole, the present volume possesses all the desirable features that characterized the companion volume and which caused the earlier part to meet with no small measure of success. In particular, attention may be called to the excellence of the diagrams relating to the wave constructions pertaining to spherical mirrors and lenses. On the other hand, the material selected for the subject of light does not seem to be well balanced for practical purposes. For example, prisms are almost neglected, whereas diffraction gratings and spectroscopic phenomena have a disproportionate amount of space devoted to them. J. Stefan's name is consistently spelled "Steffan" both in the text and in the index. H. S. U.

11. *Hindu Achievements in Exact Science;* by Benoy Kumar Sarkar. Pp. xiii, 82. New York, 1918 (Longmans, Green, and Co.).—"The main object of this little book is to furnish some of the chronological links and logical affinities between the scientific investigations of the Hindus and those of the Greeks, Chinese and Saracens." The subject-matter is conveniently divided into sixteen chapters dealing respectively with arithmetic, . . . , differential calculus, astronomy, physics, chemistry, . . . , surgery, anatomy and physiology, etc. Not only is the book valuable as a contribution to the history of Hindu science, but also because it brings to light many interesting facts regarding national priority.

For example, in arithmetic, the Hindus invented both the symbols of numbers or numerals and the decimal system of notation. "In modern times the numerals are wrongly known as 'Arabic' because the European nations got them from their Saracen (Arab) teachers." Hindu trigonometry was in advance of the Greek in certain particulars, such as the tables of sines and of versed sines. The term "sine" is said to be an Arabic corruption from Sanskrit "shinjini." "Bhaskaracharya anticipated Newton (1642-1727) by over five hundred years (1) in the discovery of the principles of differential calculus and (2) in its application to astronomical problems and computations." With regard to physics one quotation will suffice: "Mookerji points out a compass on one of the ships in which the Hindus of the early Christian era sailed out to colonize Java and other islands in the Indian Ocean. The Hindu compass was an iron fish (called in Sanskrit *matsya-yantra* or fish machine). It floated in a vessel of oil and pointed to the north."

It is thus clear that some of our ideas concerning the general history of early scientific knowledge will be profoundly modified by reading this very interesting little book. Confidence in the reliability of the text is strengthened by the bibliographical list of seventy-nine authoritative works from which the author has derived most of his data. H. S. U.

12. *The Life and Discoveries of Michael Faraday;* by J. A. Crowther. Pp. 72, 1 portrait. London, 1918 (Society for Promoting Christian Knowledge).—This little book belongs to the series entitled "Pioneers of Progress: Men of Science"

edited by S. Chapman. The material is appropriately presented in five chapters the captions of which are: I Early Life, 1791-1813; II Scientific Training, 1813-1831; III Electrical Researches (First Period), 1831-1845; IV Electrical Researches (Second Period), 1845-1855; and V Old Age, 1855-1867. The author's style is smooth and attractive, and the subject-matter is so important and inspiring that, having once commenced the first chapter, the reader finds it very difficult to lay aside the little book before the last page has been reached. It is to be hoped that this volume will be generally brought to the attention of graduate students in physics and chemistry so that they may be lured into the fascinating, but too often neglected, field of the history of the great pioneers of science. The only drawback to the book is the very poor quality of the paper upon which the pages are printed. H. S. U.

II. Geology.

1. *Appendages of Trilobites;* by Charles D. Walcott. Smithson. Misc. Coll., **67**, No. 4, pp. 115-216, pls. 14-42, text figs. 1-3, 1918.—When a young man, the present Secretary of the Smithsonian Institution became interested in trilobites, and in 1876 published his first description of the ventral anatomy of this group. These first studies culminated in 1881, and were published by the Museum of Comparative Zoology, the specimens having in the meantime been transferred to Louis Agassiz; they had to do in the main with *Calymene* and *Ceraurus,* and remain unique to this day. In 1894, Walcott returned to the subject, developing now the ventral anatomy of *Triarthrus.* During the past eight years he has been getting from the Middle Cambrian of British Columbia specimens of *Neolenus* with the legs preserved, and in the present publication he brings together all that is known of the ventral anatomy of the trilobite group, with an abundance of photographs and drawings interpreting these difficult fossils. The work contains a wealth of information regarding *Neolenus, Triarthrus, Calymene, Ceraurus,* and *Isotelus,* and will long remain one of the standards on trilobite anatomy. Restorations of the three first named genera are given. The author states that this is his last word on the subject, since he does not again expect to write on the appendages of the trilobites.

Neolenus is a specialized trilobite, with a large pygidium, and one's attention is at once attracted to its long and powerful posterior crawling legs. In this respect the genus is very unlike the primitive *Triarthrus. Neolenus* also has two long and spinose caudal rami, organs unknown in any other trilobite. Its exopodite or breathing limb is again unlike that of any other form, being a long, unjointed, paddle-like blade replete with hollow, hair-like tubes.

In all of the above we readily accept the author's views, but in regard to his epipodites, structures unknown in any other trilobites, it is difficult to understand why these are not exopodites. The other new structures which Walcott calls exites have been seen in but a single and very badly crushed specimen, and one is at a loss to know what they represent, as there is nothing in other trilobites with which to compare them. They do not appear to be breathing organs or brood pouches, but because of the irregular, prominent spines on the coxopodites, the like of which are seen elsewhere only in *Neolenus,* one is led to speculate as to whether these exites are not after all only the basal joints of the crawling legs.

Professor Percy E. Raymond, of Harvard University, has been engaged for two years on a somewhat similar study of the ventral anatomy of the trilobites, which he intended to publish last year; upon learning of Walcott's present study, however, he laid his work aside to await its appearance. Through the kindness of Walcott, Raymond has had access to the more critical specimens of *Neolenus,* and his results will appear during this year in the memoirs of the Connecticut Academy.

The trilobite, Walcott says, "is a primitive crustacean," originating "far back on the line of descent from the original crustacean type which existed in pre-Cambrian or Lipalian time." Their main food, he thinks, was annelids, and some of the trilobites grubbed for them in the mud. He figures many tracks and burrows, not all of which, however, appear to have been made by trilobites. In conclusion, we must add that no greater discovery of fossils ever was made than that of Walcott in the Middle Cambrian rocks "on the ridge connecting Mounts Wapta and Field," near Field, British Columbia. Walcott's recent publications have opened a wonderland in which all paleontologists will revel and learn of a host of invertebrate organisms such as was expected by no one from these ancient rocks. C. S.

2. *Mississippian formations of western Kentucky.* I. *Descriptions and correlation of the Mississippian formations of western Kentucky;* by CHARLES BUTTS, pp. 7-119, pls. 1-28. II. *The formations of the Chester series in western Kentucky and their correlates elsewhere;* by E. O. ULRICH, pp. 1-272, pls. 1-11. Kentucky Geological Survey, 1917 (on the title page the date is given as 1917, on the cover as 1918, but the book was not received at New Haven until January 30, 1919).—This is a very comprehensive and detailed report on the Mississippian formations of western Kentucky, and more especially those of the Chester series of the Mississippi valley. It is a great contribution to American stratigraphy, and is the result of coöperation between the Kentucky Geological Survey and the United States Geological Survey. Barring the peculiar title page, which gives no idea of the actual content of the volume nor who

the authors are, it is one of the best state reports published in recent years. It is well printed, and abundantly illustrated with charts and maps, photographs of rock outcrops, and plates of fossils illustrating the guide species for the various formations here established. The Mississippian system includes all between the Devonian and Pennsylvanian, and it is only here and there that a hint is dropped by Ulrich that he still holds to his Waverlyan and Tennesseean systems. The latter, he says, ''will probably be ranked as a system comprising three coordinate series, the Meramec below, the Monte Sana in the middle, and the Birdsville above'' (p. 197). The Meramec includes the Warsaw, Spergen, and St. Louis formations.

We are told by Butts that after the youngest Mississippian strata of Kentucky and Illinois were deposited and this area became land, the last of the Mississippian sea continued farther south and laid down in Alabama the Parkwood formation, which is at least 2000 feet thick. Then followed everywhere a land interval of unknown length, and when the Pottsvillian sea returned to the Mississippi valley it laid down in Alabama a thickness of 10,000 feet of strata that are ''older than the oldest Pottsville of the Mississippi valley'' (118). This striking statement again brings out the extraordinary imperfection of the geologic record and warns all stratigraphers to consider well the character of contacts between formations.

There is a marked difference of opinion between Ulrich and Weller as to the base of the Chester, and in regard to some of the minor correlations as well. The former would draw the bottom of the Chester at the base of the Ste. Genevieve, and the latter at the top of the same formation. Ulrich remarks that ''the most effective and the most widely displayed of the physical breaks in the upper Mississippian rocks is the one at the top of the St. Louis limestone'' (191). In regard to this, Butts remarks that Ulrich's conclusions can apparently only be refuted ''by disproving the correctness of his determination of fossil forms'' (p. 86). Ulrich, to establish his views, finds it necessary to go into much detail regarding the fossils, and as the crinoids, and more especially the pentremites, are the stratigraphic guides mainly relied on, he describes four new species of corals, two of *Dizygocrinus,* six of *Talarocrinus,* twenty-two of *Pentremites* (remarking, however, that he has in his collection discriminated ''over 100 species, varieties, and mutations''), and one brachiopod. There is in the volume, besides this, a wealth of detailed paleontology, all beautifully illustrated.

''Marine sedimentation,'' says Ulrich, ''was not continuous through the Chester epoch. The process was interrupted at least five times before the final withdrawal of the Mississippian sea. Each interruption is marked by evidence of partial or complete withdrawal and more or less extensive shifting of seas.

The first four of the submergent stages are shown in the paleogeographic maps. Comparison of these gives an idea of the kind of sea-shifting that accompanies these breaks in sedimentation" (pp. 197-198).

Unfortunately there is no index to the book, though the two tables of contents will in a way help one to find again what he has read. C. S.

3. *Comanchean and Cretaceous Pectinidae of Texas;* by HEDWIG T. KNIKER. Univ. of Texas Bull. No. 1817, 56 pp., 10 pls., 1918.—In this dissertation for the master of arts degree at the University of Texas, the author describes four new species of *Pecten,* and twelve new and eight old ones of *Neithea.* The work is a revision of the species, but not of the genera. Twenty of the forms are from the Lower Cretaceous, and four from the Austin chalk. C. S.

4. *Decapod crustaceans from the Panama region;* by MARY J. RATHBUN. U. S. Nat. Mus., Bull. 103, pp. 123-184, pls. 54-66, 1918.—The large collections of Tertiary fossils gathered for the United States National Museum in the Panama region and in Costa Rica have netted sixty-one forms of decapods. Of these, forty-seven are specifically named in the work under review, and thirty-nine are new. Of new genera there are *Calappella, Mursilia,* and *Gatunia,* the latter being the basis of a new family. *Gatunia proavita* is one of the finest fossil decapods ever found. In age the species range from the Oligocene to the Pleistocene.

It is not often that so many Tertiary Crustacea are secured from any one area, and yet this collection again illustrates the imperfection of preservation of fossil decapods, as but four species are based on more or less entire individuals. The imperfection of the geological record is also brought out in this collection, as eleven living genera are here recorded as fossil for the first time. The most remarkable occurrence among these fossils is one of the Hexapodinæ, crabs that have lost the last pair of legs. They are represented in the Indo-Pacific region to-day by five genera and eight species, and now the subfamily is carried back to the Oligocene. No one other than Miss Rathbun, with her life-long studies of recent Crustacea, could have made so much of value out of this collection. C. S.

5. *The Radiolarian Cherts of the Franciscan Group;* by E. F. DAVIS. Bull Dept. Geology, Univ. California, 11, No. 3, 1918, pp. 235-432, pls. 25-36, text figs. 1-16.—A thorough study not only of the radiolarian cherts of the Jurassic of California, but of the Miocene as well. In his search through the literature for similar occurrences elsewhere, the author has gone into many lands, and all the evidence which he found is made use of to explain the kind of seas in which the radiolarian cherts of California were deposited. Some of his conclusions are as follows:

"The radiolarian cherts and their associated shale partings do not represent abyssal radiolarian ooze and Red Clay, but were deposited in shallow water or in water of moderate depth. . . They are not pure radiolarian oozes, nor are they siliceous oozes composed in part of radiolaria, and in part of the remains of other siliceous organisms. A portion of their silica is chemically precipitated and the radiolaria are simply incidental fossils, entombed in the precipitated silica.

"It appears that the silica contributed to the ocean by the rivers *may* be precipitated entirely through the intervention of organisms. If it *is* chemically precipitated, it probably comes down in the form of magnesium silicate and not as silicic acid. . . In the absence of another hypothesis, one is forced to the assumption of colloidal segregation of silica from intermixed shaly material" (pp. 353-354). C. S.

6. *La Face de la Terre;* par ED. SUESS, translated from Das Antlitz der Erde with the authorization of the author and annotated under the direction of EMMANUEL DE MARGERIE, TOME III, 4e *Partie* (FIN), with an epilogue by PIERRE TERMIER, Pp. xv, 1361-1724. 2 colored maps, 3 plates, and 114 figures, of which 90 have been drawn especially for the French edition. Paris, 1918 (Librairie Armand Colin).

Also a supplementary volume,—*Tables générales de l'ouvrage,* Tomes I, II, III translated and annotated under the direction of EMMANUEL DE MARGERIE. Pp. 258 (Librairie Armand Colin).—This third volume, part 4 of the French edition of Suess' great work, Das Antlitz der Erde, includes chapters xxiii-xxvii. It corresponds to the last quarter of the fourth volume of the English translation published in 1909, being part 5, chapters xiv-xxiii of the English edition. It is, however, brought up to date and as a manual of the geology of the globe is much more valuable than either the original German or the English edition. The subject matter, comprising 175 pages in English, is expanded to 333 pages in the French edition. The original text is preserved, but four times as many figures are introduced and the annotation in the form of footnotes is for some subjects as voluminous as the original text. Those who have tried to use the original will appreciate the value of de Margerie's contributions and be prepared to confer on him a vote of thanks for the great labor which he has performed so well. Suess was a master of the geological literature of the world beyond any other man in his generation. He condensed and organized it into a great work, but it was so deficient in maps that reading was difficult and many sections could not be clearly understood unless the reader made a search for appropriate maps and often the original articles. This was many times either difficult or impossible. The mantle of Suess as custodian of the world's literature has descended to de Margerie and geologists will find the host of additional references to recent literature one of the most valuable features of the work.

The index volume is made effective by a system of cross references. All figures are classified by regions and also by subjects. All references are classified by locality, by subject, and by author.

The writing of the Face of the Earth covered the last forty years of Suess' life. The part included in the present issue was written in his old age, but shows a youthful power of incorporation and assimilation. The subject matter includes the following parts. First, analyses of the plans of mountain systems and of their transverse sections. Considerable space is given to the newer interpretation of the Alps and of other mountain systems in that light. Second, the interior of the earth and the nature of igneous intrusion. Third, the origin and arrangement of volcanoes. Fourth, a geologist's studies of the moon. Fifth, relations of density to continental relief. Sixth, contraction of the earth's body. Seventh, a concluding chapter on life, the strand, appearance of placental mammals, asylums. J. B.

7. *New graphic method for determining the depth and thickness of strata and the projection of dip;* by Harold S. Palmer, Prof. Paper 120—G, pp. 121-129, figs. 15-19, pls. XIV-XVI, U. S. Geol. Survey, 1918—This paper brings out very simple, rapid, and usable methods for finding the solutions of these constantly recurring and troublesome questions. For example let the dip of a bed be A. Let the strike of the bed make an angle B with a vertical section plane. What will be the dip C of the bed as shown on the section plane? The formula is tan C=tan A sin B. Where many examples of this nature recur, trigonometric solutions by means of logarithmic tables become tedious, gross errors are easily made, and the proper formula must be ascertained for each variant of these problems. Some useful diagrams have been published for the graphic solution, but the present are notable for their simplicity and elegance. Three parallel lines are graduated in the proper manner in each of the three plates. These lines are named. For instance, in the case previously cited, the three lines represent the dip, the projected dip, and the angle of projection. A straight edge is laid across these graduated lines so that it intersects the two known factors at the proper points. The answer is then read off on the third line at the intersection with the straight edge.

The method depends upon a principle related to that of the slide rule. The graduations of the lines are proportional to logarithms and the lines are so arranged that the intercept on one is equal to the sum or difference of the logarithms on the other two, but the reading of the answer gives the product of two functions direct and avoids all use of logarithmic tables. Every scientist should understand and be able to adapt to his own uses this very ingenious method. J. B.

8. *Osteology of the Armored Dinosauria in the U. S. National Museum, with special reference to the Genus Stegosaurus;* U. S.

Nat. Mus., Bull. 89. Pp. 136, 37 pls., 73 text figs., 1914. *A Newly mounted Skeleton of the Armored Dinosaur, Stegosaurus stenops, in the U. S. National Museum;* U. S. Nat. Mus., Proc., **54**. Pp. 383-390, pls. 57-63, 1918.—Two papers by C. W. Gilmore, one of which has just come to hand, amplify our knowledge of this remarkable group of dinosaurs in large degree. In the larger monograph, Gilmore discusses the following topics: Occurrence and history, wherein he tells of the localities in Como Bluff, Wyoming, especially the so-called "Quarry 13," together with the associated fauna. The second section, consisting of about 75 pages, discusses the osteology of the skeleton, placing a modified and more accurate interpretation on the cranial elements. The hyoid elements, thus far unknown, are also described and figured. Of the vertebral column, a very adequate description is given, but little of novel character is mentioned. Sternal elements are also described and figured for the first time. They are paired, and while not so slender, are in a way suggestive of the already known, similar elements in *Trachodon.* The feet show resemblances to those of the Sauropoda in the short, robust form of the metapodials and, in the manus, the reduction of unguals to one or two—those borne on the first two digits. They are of course depressed, as with other Ornithopoda, instead of being claw-like, but are nevertheless possibly indicative of community of habit in the use of the fore limb. The foot is three-toed, all of the digits bearing unguals.

The dermal armor is the most characteristic stegosaurian feature. In the interpretation of the elements and their morphology, Gilmore agrees with his predecessors, Marsh, Lucas, and Lull, but not in their number and arrangement. Of the flat plates, Marsh showed twelve in a single row; Lucas, in two restorations, twenty-four and twenty-two, the former in opposing pairs, the latter alternating; while Lull in the mounting of *Stegosaurus ungulatus* at Yale showed twenty-eight arranged in pairs, with four pairs of terminal caudal spines. Gilmore demonstrates pretty conclusively that in *S. stenops,* at least, there were but twenty alternating flat plates, the largest of which was situated over the base of the tail, while the terminus of the latter bore but two pairs of spines, and such arrangement must be taken as authoritative until disproved.

Following the morphological portion is a taxonomic section in which the genera and species of armored dinosaurs, of which the types are included in the United States National Museum collections, are redescribed. They are:

Stegosaurus stenops Marsh
Stegosaurus sulcatus Marsh
Stegosaurus longispinus, n. sp.
Hoplitosaurus marshi Lucas

A discussion of the several restorations of *Stegosaurus* which have been attempted follows.

In his later paper, Gilmore speaks most interestingly of the new mount of *Stegosaurus stenops* which has just been assembled under his supervision in the National Museum, and which is, now that the Yale specimen is dismantled and in storage pending the erection of the new Peabody Museum, the only mounted skeleton on exhibition. This, together with the articulated skeleton lying *in situ* in the rock and the great life-sized restoration made under Lucas's supervision, makes a very imposing and unique array of these most bizarre forms.

The mounted skeleton is considerably smaller than that at Yale, measuring but 14 feet 9 inches between perpendiculars as against 19 feet 5 inches for the Yale specimen. It is 7 feet 11 inches high to the summit of the highest plate, whereas the latter measured 11 feet 10½ inches. They differ in the relatively shorter hind limbs of the former; in the greater droop of its tail, as shown by the more wedge-shaped form of the caudal centra; in the reduction of unguals of the foot, but two of which Gilmore thinks were visible outside of the fleshy encasement; and in the number and arrangement of the dermal elements, wherein the Yale mount may have been in error. The whole appearance of the animal, with the knees somewhat flexed, and a fuller body, differs from that at Yale, and is suggestive of the mounted *Camptosaurus* erected by Mr. Gilmore some years ago. In part, at any rate, these differences can be specific, the Yale specimen being the type of *Stegosaurus ungulatus,* in part due to age and size, in part to interpretation of material which has been subjected to post-mortem distortion that may not always be recognizable as such.

Mr. Gilmore is to be congratulated on his very real contributions to our knowledge of these enigmatical quadrupeds.

R. S. L.

9. *A Large Diamond from South Africa.*—It has been recently stated in the public press that a diamond of a soft blue color and having the remarkable weight of 388½ carats has been found at the Jagersfontein mine in the Orange Free State, South Africa. This is the largest stone found since the famous Cullinan diamond of 1905, which weighed 3,025 carats (see vol. **19**, 395, 1905).

10. *The Production of Precious Stones in 1917;* George Frederick Kunz. Reprinted from *Mineral Industry,* vol. **26**, pp. 576-601.—The author has given here a very interesting summary of the production of precious stones during 1917. The statistics are particularly valuable as to the production and price of diamonds from South Africa and other localities. It is noted that the output of diamonds increased from 2,246,300 carats valued at $27,133,000 in 1916 to 2,902,400 carats worth $37,527,700 in 1917.

III. Miscellaneous Scientific Intelligence.

1. *Civic Biology: A Textbook of Problems, Local and National, that can be solved only by Civic Coöperation;* by Clifton F. Hodge and Jean Dawson. Pp. viii, 381, with 168 figures. Boston, 1918 (Ginn and Co.).—This is a truly practical book, containing precisely those fact about animals and plants that everyone in a community must know before the highest ideals of civic life are realized. It is only by the coöperation of the whole people in ways similar to those here indicated that a victory can be gained over those greatest enemies of mankind—the animal and plant parasites and destroyers—which render the human existence so precarious and civilized life so difficult to maintain.

The book is intended for the high school pupil, for whom it is well suited, but it might also be read with profit by everyone interested in his own or in the public welfare. W. R. C.

2. *The Rodents of Iowa.* Bulletin No. 5, Iowa Geological Survey; by Dayton Stoner. Pp. 172; Des Moines, 1918 (Iowa Geological Survey).—A popular systematic account of the gnawing animals of the state, with particular emphasis on the economic importance of each species and directions for destroying those which are the most injurious. W. R. C.

3. *Plant Genetics;* by John M. Coulter and Merle C. Coulter. Pp. ix, 214, 40 figures in text; Chicago, 1918 (The University of Chicago Press).—This little volume was designed to meet the needs of students who have had some training in botany but who have no distinct intention of becoming professional geneticists. The various theories and principles of genetics are clearly presented, and the important results which have already been attained are briefly reviewed. A good deal of attention is naturally given to Mendel's Law and to the more modern hypotheses which are based wholly or in part upon that law, and the diagrams illustrating this portion of the book are unusually satisfactory. Of special interest to botanists are the chapters on Parthenogenesis and Vegetative Apogamy, Inheritance in Gametophytes, and the Endosperm in Inheritance; the topics herein treated deal almost wholly with plants and usually receive but scant consideration in general works on genetics. The concluding chapters deal with Sex Determination and the Bearers of Hereditary Characters. A. W. E.

4. *Cellulose, an Outline of the Chemistry of the Structural Elements of Plants with reference to their Natural History and Industrial Uses;* by C. F. Cross and E. J. Bevan. *New impression,* London, 1918 (Longmans, Green, and Co.).—This new impression is distinguished from the third edition (1916) of Cross and Bevan's textbook by the insertion of a supplementary chapter, which gives a résumé and discussion of recent researches.

A striking statement, which will be of interest to investigators in this field, is that any and every treatment with reagents modifies the constitution of cellulose. This is shown to be produced even by contact with water. Consequently, the normal standard of purity is defined as cellulose purified by the ascertained minimum of action upon the cellulose itself. Subsequent paragraphs deal with the production of anhydro-acetates, the decomposition of cellulose by oxidation with ozone and by heat, and the relation of physical properties to internal structure. Recent work on the products of lignocellulose decomposition is taken as confirmation of the lignocellulose complex previously formulated by the authors. The chapter closes with a few brief remarks on technical progress during the war.

H. D. HOOKER, JR.

5. *Board of Scientific Advice for India. Annual Report for the Year 1916-1917.* Pp. 172. Calcutta, 1918.—The work discussed in the numerous brief articles in this volume shows the influence of the war in many directions. It is mentioned that the fall of three new chondritic meteorites have been noted during the year.

OBITUARY.

DR. EDWARD CHARLES PICKERING, professor of astronomy in Harvard University and director of the Harvard College Observatory, died on February 3 at the age of seventy-two years. He had held his position as director of the Observatory since 1876 and, largely through his efforts, its scientific results as well as its financial income had been increased many times. He studied particularly the intensity of light and spectra of the stars, and through the meridian photometer, devised by him, the light of 1,400,000 stars has been measured. An enterprise in which he was also especially interested was the establishment of a Southern station at Arequipa, Peru, thus extending the work from pole to pole. He received many honors in medals and other forms, and was a member of a large number of scientific academies and societies in this country and abroad.

DR. W. MARSHALL WATTS, distinguished for his work in spectroscopy, died on January 13 in his seventy-fifth year.

M. MARCEL DEPREZ, the eminent French electrician, died on October 18 last. He was elected professor of industrial electricity at the *Conservatoire des Arts et Métiers* in 1890, and his contributions to this department were very numerous and of a high order.

DR. HENRI E. J. G. DUBOIS, well known for his important work in magneto-optics, the magnetic circuit and related subjects, died at Utrecht, Holland, on October 21 at the age of fifty-five years.

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[FOURTH SERIES.]

ART. XV.—*On Ripples and Related Sedimentary Surface Forms and their Paleogeographic Interpretation;* by WALTER H. BUCHER.

PART II. FOSSIL RIPPLES AND THEIR PALEOGEOGRAPHIC INTERPRETATION.

TABLE OF CONTENTS. PART II.

In the following pages, a number of deductions concerning the paleogeographical interpretation of ripples are presented which seem to follow from the data presented in the first part of this paper. (See the March number, pp. 149-210, including Bibliography.)

XLVII

Introduction.

The question, why one or the other type of ripples is not found in a certain sediment, recurs frequently in the following discussions. The answer is always: Either it was not formed or not preserved. While the conditions necessary for their formation are different for the various types of ripples, those favoring their preservation are the same for all. They must all, soon after their formation, be sufficiently covered with sediment settling on them from above[1] (see pp. 156 and 185).

1. In the sea, in rivers and in air, most of this sediment is supplied by a local stirring of the bottom through storms and currents, throwing some sediment into suspension which, when carried by upper currents, settles into quieter layers below. In a sediment too coarse to be carried any distance in suspension, when stirred, this process becomes ineffective.
2. The sediment thus thrown into suspension in the air, may settle in the water of the sea, lakes or of rivers.
3. The load carried by rivers and streams into seas and lakes, reaches the bottom in an unceasing rain of particles.
4. Also, in both water and air, the volcanic sands and dust, ejected during an eruption, locally play a rôle.

Thus, if covered soon enough, even the most transient features may be preserved, like the tracks of flitting crustaceans, the marks left by the trailing arms of a jelly-fish, oscillation-ripples formed during still-water between the tides, or current-ripples produced by an exceptional wind-drift on sediments not ordinarily reached by currents. The shorter the time during which the formation of any of these surface marks is possible, and the rarer the recurrence of conditions favorable for it, the smaller is the probability that they will be preserved.

I. Oscillation-ripples.

1. *Description.*

Fossil oscillation-ripples cover the same range of sizes and forms as those found in present waters.[2] The sharp

[1] Page references in the text refer to Part I in the March number. In cases where references to authors are given, see the Bibliography on pp. 209, 210.

[2] Giant ripples, such as suggested by Gilbert (Ripple-marks and cross bedding, Bull. Geol. Soc. Amer., vol. **10**, p. 135-139, 1899), can not be formed directly by wave action. Gilbert's interpretation was refuted on other grounds by Fairchild, (Beach Structure in the Medina Sandstone, Amer. Geologist, vol. **28**, pp. 9-13, 1901).

crests in contrast to the broad, rounded troughs, often with a minor ridge in their center, which, of course, never appears on the crests, render these ripples especially valuable for the distinction betwen the upper and lower surfaces of strata in structural work.—(Cf. p. 184.)

2. *Interpretation.*

The following points bear on the paleogeographical interpretation of oscillation ripples:

1. The presence of oscillation-ripples in a sediment implies complete *absence of horizontal currents* at the time of their formation.

a. Water bodies, in which sediments showing no other but symmetrical ripples were laid down, must have been practically free from currents of any kind. The two types of currents which alone would produce on a larger scale ripples in standing bodies of water, are tides and wind-drifts. The effect of the latter decreases rapidly with depth; it is probably limited to the upper 50 m. of the neritique zone of the sea.[3] The insignificance of the tides in enclosed parts of the sea as well as in lakes is well known. The Baltic, the Black Sea, the largest part of the European and American Mediterraneans have tides negligible for our purposes;[4] some, like the Black Sea, none at all.[5] *Ripples cannot, therefore, be used to distinguish marine and lacustrine sediments.*

A sediment like the Berea Sandstone, which consists largely of fine-grained, almost pure quartz sand and abounds in oscillation-ripples without a trace of current-ripples,[6] may therefore have originated either in a lake or in a sea free from tidal currents.

A study of map No. 20 of Berghaus' ''Atlas der Hydrographie'' shows that, so far as recorded, all epicontinental seas which are in open connection with the ocean have rather great tidal ranges and therefore are agitated by tidal currents. In open bays the range is invariably increased. It is only in landlocked bodies of water that

[3] ''District littoral'' of Pruvot (cf. E. Haug, Traité de Géologie, 1911, p. 87); ''littoral region'' of Schuchert (Historical Geology, 1915, p. 490).

[4] Cf. Kruemmel, Handbuch d. Ozeanographie, vol. 2, pp. 304 ff., 1911.

[5] Kindle, in making the generalization that oscillation-ripples are generally found on lake bottoms and current-ripples on sea bottoms (1917, p. 49; see Bibliography, Part I), overlooked the fact that the coast of Nova Scotia with its strong tides offers by no means typical or average conditions for all marine shores or the sea bottom at large.

[6] J. E. Hyde, Jour. Geology, vol. 19, pp. 258-269.

the tide is sufficiently low or lacking entirely. We are, therefore, justified in concluding that the body of water in which, for instance, the Bedford-Berea sediments were laid down, was not in free communication with the sea. That the Mississippian embayment, farther west, had tides is proved by the presence of very large current-ripples, measuring about 180 cm. from crest to crest, in the lower part of the Burlington in southeastern Louisa County, Iowa.[7] Since sedimentation was probably continuous in this region, the difference in time between the two deposits can not form a serious objection.

b. Occurrence of oscillation and current-ripples in the same formation, on the other hand, indicates deposition alternatingly in quiet water and under the influence of currents (of water or of air). Favorable conditions for such a combination of processes exist:

(1) In shallow seas with tidal currents and wind-drifts[8] alternating with periods of quiet.

(2) On tidal flats, especially on irregular shores with lagoons and pools.[9]

(3) On alluvial plains where floods leave stagnant lakes, and dust and sand are blown about by the wind, especially in arid regions, where the rivers end in shifting, shallow lakes surrounded by dunes (e. g. Lob-Nur in the Tarim Basin).

In general, the last case offers by far the best chances for the preservation of both types of ripples, especially the large flood plains of semi-arid regions, where the wind, at the approach of the dry season, buries the ripples in stagnant lakes and along the water courses under clouds of silt and sand.

There are practically no data on hand for a comparison of the relative frequency of the two types of ripples in different formations. In a quarry of red Triassic "Buntsandstein" in the German Palatinate, 15 of 23 slabs show symmetrical, the others asymmetrical ripples. (Berthology 1900, p. 181.) A terrestrial origin of this part of the Buntsandstein is almost universally assumed.

[7] J. A. Udden, Jour. Geol., vol. 24, pp. 123 ff., 1916.

[8] For a discussion of the effect of wind drifts on tidal currents see W. H. Bucher, Proc. Nat. Acad. Sci., vol. 3, p. 288, 1917 and Chapter III of this paper.

[9] Oscillation-ripples formed on shores where the tides are high and tidal currents strong, were, for instance, described by Brown, 1911 (Coast of Labrador), and Cornish, 1901 (English Coast).

2. The following relations exist between the dimensions of a water-body and the oscillation ripples formed in it:

(*a*) A ripple of a given wave-length owes its formation to an oscillating current of definite velocity. The size of the water wave which sets up the oscillation determines the depth at which this velocity would exist and be effective. The relation is very complex and not known quantitatively. As the orbital velocity of the particles of water decreases with depth, we may state in a general way that the greatest depth at which the velocity necessary for the formation of a given set of ripples is found, is the greater the larger the waves creating it.

Any set of oscillation-ripples may, therefore, have been produced in shallow water by smaller, or in deeper water by larger waves.

As was demonstrated by Kindle's observations (p. 188), there exists also a minimum depth for each size of ripples. For each size of oscillation ripples there must exist, therefore, a range of depth within which it may form. This range is very large for small ripples. I have frequently observed oscillation ripples with 1, 5 cm. wave length on the silt of floodplains of the Ohio and Little Miami Rivers, in places where the water could not possibly have been more than a few cm. deep. Udden[10] observed ripples of 6 mm. wave-length in a small water pool in a hollow of the surface of a rock, at a depth of water of but 1 to 2 cm. Siau found oscillation-ripples of small size at the depth of 188 m. off the island of Bourbon. They may form, and certainly do, at any time at any depth in between. From very small ripples, therefore, no inference of any kind can be drawn concerning the dimensions of the waterbody in which they formed. Of statements based on such insufficient evidence, I quote only that of Zimmermann.[11] He found small ripples of a little less than 2 cm. wave-length on one of the layers of salt separated by very thin laminæ of anhydrite in a drill core from the Zechstein of Hesse. From this he concluded that these ripples could have formed only under a very thin cover of water, perhaps but a few decimeters

[10] J. A. Udden, Jour. Geol., 1916, p. 123.
[11] E. Zimmermann, Steinsaltz mit Wellenfurchen von Schlitz in Hessen, Zs. Deutsch. Geol. Ges., vol. 60, Monatsber., p. 70, 1908.

deep. They might, of course, have formed just as well at a depth of 100 meters or more.[12]

The range of depth at which ripples may form is, on the other hand, limited for the largest ripples, as the minimum depth is rather great and the maximum small. From the scanty data in table V the former seems to measure a few meters, while the maximum depth is most likely to lie within the littoral region or the upper 40-50m. of the neritic zone of the oceans.

(*b*) Owing to the fact that the largest ripples possible in one locality have by far the best chance to be preserved, a gradual decrease in the average wave-length of ripples of a sedimentary series should be expected in the direction towards deeper water. The absence of such a decrease over great distance offers a valuable *evidence of uniformity of depth.*

(*c*) The depth to which the action of waves is felt, that is, the depth of the wave-base, depends on their size, and this, in turn, is determined largely by the fetch of the wind. For each given diameter of a body of water there exists, therefore, a maximum depth to which wave action may extend. For the ratio of *depth* to *width* of the basin, measured along any line, the term "form ratio"[14] might be used. For each basin there exists a minimum and a maximum form ratio, measured along the shortest and the longest diameter. If the latter rises above a certain value, which is different for different widths, a part of the bottom will never be touched by the wave action.[15]

On the other hand, if the area of a bay, lagoon or lake is known to have been small, the possible range of the depth at which the largest ripples found in its sediments may have formed, is reduced considerably.

Along the shores of the small, shallow ponds of our parks, on which but small waves can form, ripples are

[12] The same is true, for instance, of small ripples observed in cannel coal (Upper Stinson coal) in Kentucky; cf. White and Thiessen, The origin of coal, Bureau of Mines, Bull. 38, p. 42, 1913.

[13] Note omitted.

[14] This term is used by Gilbert (1914, p. 36) for the ratio of the *depth of stream* to the *width of channel.*

[15] Systematic observations on the vertical distribution of oscillation-ripples on carefully selected portions of the bottoms of various water bodies, might yield valuable data concerning the depth of wave-action, especially if combined with extended measurements of the waves themselves. The photographic camera could probably be adapted to this purpose and lateral illumination be used to distinguish oscillation-ripples.

commonly found but close to the shore. Within half a meter from the shore they disappear at depths measuring in centimeters. On the shores of Lake Geneva, Forel observed ripples down to a depth of nearly 9 meters, which can represent but a relatively narrow zone, as the mean depth of the lake is 154 m.[16]

In all sediments deposited in basin-shaped depressions, especially in smaller, more or less enclosed arms of the sea, or bays, such as for instance the sea of Azof, or in lakes, we should expect to find the ripples restricted to a relatively narrow marginal zone, because of too large a form ratio. This explains why lacustrine sediments ordinarily do not show any ripples at all.

It is probable that a compilation of numerous observations on presence or absence of ripples in clastic formations in favorable cases might yield positive results concerning the general trend of the shore line. According to Daly, for instance, ripple marks are absent from the very fine-grained quartzites of the Creston formation of the Purcell Mountain System, while "elsewhere within the Boundary belt these markings were found."[17] Cases like this deserve consideration in detailed stratigraphic studies. The stratigraphic position and dimensions of the ripples of many formations deserve as well a place in the field geologist's notebook as fossils.

(*d*) There are two observations of ripples on record, which, so far as I know, seem to imply *true shore conditions*,[18] and therefore are of special interest to the paleogeographer. Dawson[19] figures a "rippled surface in Potsdam Sandstone with marks of worms or molluscs arranged in the hollows of the ripples. The marks are simple trails, of that curious circular or chain-like form sometimes observed, and seem to have been made by animals creeping in the furrows between the ridges of the ripple-marks." It is of no little interest to see very similar if not identical tracks confined in the same way to the troughs of ripples figured by Stuchlik (1906; table 8, fig. 3) from the Oligocene Molasse Sandstone of Lechbruck (foot of Bavarian Alps). The conclusion seems to be unavoidable that the animals were concentrated in

[16] A. Supan, Grundzuege d. phys. Erdkunde, 1911, p. 753.
[17] Geol. Survey, Canada, Memoir 38, Pt. I, p. 123, 1912.
[18] Not necessarily marine, of course.
[19] J. W. Dawson, On burrows and tracks, etc., Q. J. Geol. Soc., London, vol. 46, p. 611, fig. 14, 1890.

the troughs by the receding waters which exposed the crests.

3. The relation existing between the trend of oscillation-ripples and geographical conditions, too, offers a highly complex problem. In practical application it presents itself in this form: Why do the ripples of one formation show a pronounced parallelism, while others do not?

In the case of parallel ripples, others were either not formed or not preserved.

(*a*) That they were not formed might be due (1) to practical absence of winds from other directions, as under trade wind or monsoon conditions; or (2) that only waves from one direction "touched bottom."

(*b*) Of the factors favoring the preservation of ripples, outlined, only one may have a selective effect.

If the form ratio of the waterbody is such that only the largest waves stir the bottom sufficiently so as to provide the sediment with which to cover and preserve ripples, the bottom is, for long periods, exposed to the rippling action of the smaller waves. The smaller ripples formed by them, however, will not ordinarily be preserved, because they are nearly always replaced by the larger ones resulting from the action of the exceptional waves. According to Forel's experiments, these, on the other hand, will not be changed, either in wave-length or orientation, by minor agitations of the sea-bottom differing in direction up to 45° from their own and, consequently, are by far the most likely to be preserved.

Along any coast facing the open ocean, the direction from which the largest waves come will always be more or less at right angles to the shore. Even if the direction of greatest fetch of the wind should differ considerably from that of a right angle, the waves would break so far from the shore as to turn them into such a position in shallower water.

In shallow seas of relatively uniform depth and small form-ratio, the bottom of which is reached practically everywhere by most waves, such as probably yielded the largest part of our marine sedimentary record, this breaking and turning of the wave-front is confined in its effects to but a very narrow zone. Throughout the largest portion of the sediments of such large or small embayments and gulfs the length of fetch of the wind would largely determine the position of the largest water waves and the ripples resulting from them.

4. We are now in a position to discuss the interesting case of the ripples in the Bedford and Berea formations at the base of the Mississippian section of eastern and central Ohio, which were so well described by Hyde.[20]

The facts entering into this discussion may be summarized as follows:

(1) Where the ripples are most typically developed, both formations consist of fine-grained sandstones interstratified with more or less shaly portions.

(2) The beds are from less than one inch to at most two or three feet thick.

(3) The individual layers are not persistent, pinching out and reappearing at different levels, much like the limestones of the limestone-shale series of the Cincinnatian at the type locality.

(4) Where typically developed, almost every layer is rippled.

(5) Only oscillation-ripples are present.

(6) Most of these ripples trend very nearly N 53° W, with subordinate variations in both directions covering an extreme total range of 69°.

(7) Occasionally, smaller ripples intersecting the larger ones at right angles or nearly so, are found.[21] Only one case of typical interference pattern, produced by the intersection of equally large ripples, has come to my knowledge.

(8) These ripples were observed over an area 115 miles long and 20 miles wide.

From observation (5) we have already concluded the absence of tidal or wind-drift currents from the lower part of the water. The former indicates the absence of free communication with the open sea, the latter a depth sufficiently large in proportion to the area to prevent the action of drift on the bottom. That the limestone-shale series of the Ordovician of the Cincinnati region owes its peculiar character to the stirring action of storms on the sea-bottom and subsequent redistribution of the material thrown into suspension through the action of surface drifts, appears highly probable from an analysis of these

[20] Jesse E. Hyde, Jour. Geol., vol. **19**, pp. 257-269, 1911.

[21] Several good specimens are in the collection of Ohio State University.

strata. The similar character of this sandstone-shale series (observations (2) and (3)) suggests a similar origin. In fact, the absence of bottom currents practically necessitates such a process of constant redistribution of the sediments, since the bedding in detail is not regular enough to be interpreted as the sole result of undisturbed sedimentation from above, as, for instance, off the mouth of a large river.

The condition outlined on page 246 explains observation (6), that is, the form ratio of the basin, in which these sediments were deposited, was such as to allow only the larger waves to act vigorously on the bottom, trending NW.—SE. Observation (7) proves that at times waves did form even at right angles of this direction, but they were much weaker than the others. The question then remains: Why were the waves trending northwest to southeast strongest on the Bedford-Berea waters? Either because the wind blew strongest and most frequently from that direction, or because it had by far the greatest fetch in that direction.

Owing to the great difficulties of correlation of the strata involved, no reliable conjectures concerning the geography of that time can be made. One fact, however, will permit us to go one step further in our conclusions. There seems little doubt that a distinct change in the distribution of land and water took place, during Bedford and Berea time. In the north, in Lorain County, Ohio, channels 200 feet deep were cut into the Bedford shale before the Berea sandstone was deposited.[22] Farther south the effect of this erosion interval rapidly diminishes, until south of Fairfield County its trace is lost[23] and sedimentation of the Bedford and Berea formations seems to have been more or less continuous.

From this we conclude that, if the constancy of the orientation of the largest waves was due to topographic causes, the fetch of the wind being greatest in this direction, the wind could have come from the southwest only, because the northeast certainly suffered great topographic changes which would necessarily have affected

[22] W. H. Burroughs, The Unconformity between the Bedford and Berea Formations of Northern Ohio, Jour. Geol., 19, pp. 655-659, 1911.

[23] Jesse E. Hyde, Stratigraphy of the Waverly Formations of Central and Southern Ohio, Jour. Geol., 23, p. 663, 1915. Here also additional references on this question.

the formation of waves and thereby the trend of the ripples in the southern portion of the area.

While not impossible, it seems rather improbable that the topographic changes indicated by the erosion channels of northern Ohio should not have influenced the general shape of the basin and incidentally the direction of waves and ripples during the Bedford-Berea time, especially if there should have been no or as little connection with the sea in the southwest and west as indicated by Schuchert's maps.[24] The weight of this argument would be great if the ripples in the Bedford and Berea formations of northern Ohio should prove to be parallel to those of central and southern Ohio. In that case we should be compelled to look to climatic causes for an explanation, to winds blowing strongest and most frequently in one or two opposite directions. Of course, as was said before, almost on any coast facing the open sea, the onshore winds, having the greater fetch, are most apt to produce the largest waves. In view of the complete absence of currents, however, we cannot assume such a direct connection with the open ocean. Hyde's conclusions, based on this argument, are therefore untenable.

We must turn then to the only alternative, trade winds or monsoons. In the immediate neighborhood of the great North Atlantic continent to the northeast[25] we could not expect to find trade winds in their primitive development. They would necessarily assume the character of monsoons. Monsoon winds blow most frequently and strongest in their typical directions. During the period of reversal, calms are common and the variable winds are much weaker. By way of illustration I reproduce in graphic form (fig. 11) the data contained in a table given by Hann[26] for the Arabian Sea. There the mean wind velocities reach their maxima in the summer and winter months, during the typical northeast and southwest monsoons, while they fall off considerably in the intermediate months.[27] The means of the wind directions, during the months of greatest wind velocities, show a range of 30°

[24] Charles Schuchert, Paleogeography of North America, Bull. Geol. Soc. Amer., vol. 20, pl. 78 and 79, 1910.

[25] Cf. A. de Lapparent, Traité de Géologie, vol. 2, p. 891, 1906. E. Haug, Traité de Géologie, vol. 2, 1, 817, 1911.

[26] J. Hann, Handbuch der Klimatologie, vol. 2, p. 196, 1910.

[27] Comp. especially the description of the winds of the Arabic Sea.

(-60)°,[28] which compares favorably with that reported for the Bedford-Berea ripples. This is equally true of the monsoon off the western side of Africa[29] and especially off the north coast of Australia.[30]

There are two independent facts which lend additional weight to the assumption that the constancy of the Bedford-Berea ripples is due to the action of monsoon winds.

FIG. 11.

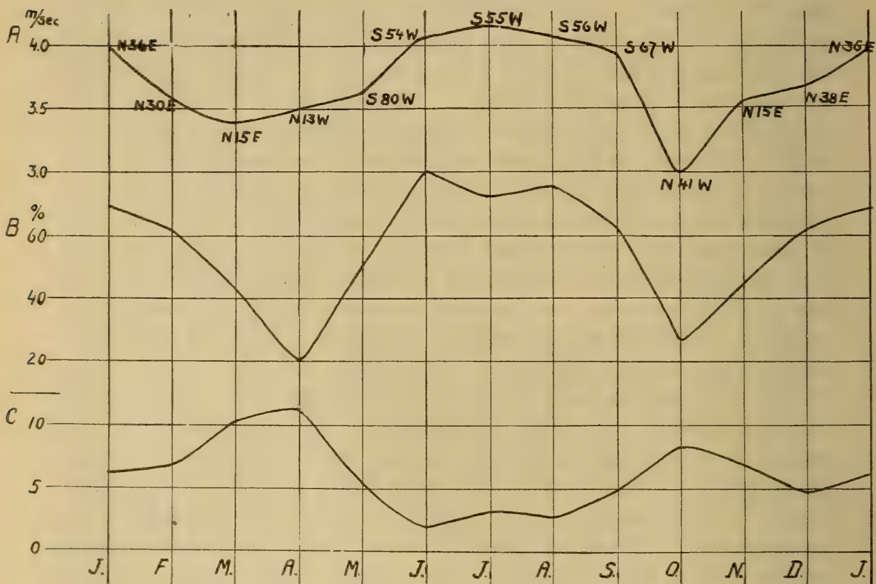


FIG. 11.—Curves showing the relationship between wind velocity and direction of wind for the Monsoon of the Arabian Sea and the northern Indian Ocean.

A = Mean direction and velocity of the wind; B = the number of observations of the mean direction expressed in percent of the total number of observations. C = the number of calms.

(1) The orientation of the ripples (northwest to southeast) harmonizes well with the general assumption of a great land mass, the North Atlantic Continent, to the northeast, and a wide expanse of water in the southwest.

(2) For a later part of Mississippian time Barrell inferred from fundamentally different data a climate of

[28] *Ibid.*, p. 200.

[29] *Ibid.*, p. 76.

[30] *Ibid.*, p. 287; also, J. Barrell, Origin and Significance of the Mauch Chunk Shale, Bull. Geol. Soc. Amer., vol. 18, pp. 449-476, esp. 475 f., 1907.

alternating dry and wet seasons for the region lying to the east of the Bedford-Berea sediments.[31] For the terrestrial sediments in question, the comparison with the monsoon region of the upper Punjab is made, which seems a very happy one. The shallow water marine sediments of our Mississippian seas probably find their closest analogy in the shelf sea north of Australia, where the sea-bottom is largely covered by "a very fine-grained, impalpable, pale olive-green mud, wholly soluble in dilute hydrochloric acid, and therefore essentially carbonate of lime."[32] Along the Gulf of Carpentaria the dry winds from the deserts to the south must carry quantities of sand into the sea[33] during the dry season from April to November, while in the remaining months the great floods produced by the northwest monsoon[34] must furnish considerable amounts of clastic sediment.

Summary:—It is in a relatively small, more or less detached portion[35] of such a gulf that Bedford-Berea sediments were laid down. The parallelism of the ripples formed in it may be due to a peculiar shape, offering the wind a much greater fetch in one direction than in any other. In that case the greater expanse of the water in question must necessarily have been to the southwest, since the north suffered considerable changes during the time of the formation of the ripples.

In view of the distribution especially of the Berea formation and of the improbability attached to the assumption that the waterbody kept its general shape while perhaps as much as one-half of it underwent elevation, erosion, and depression, it appears highly probable that winds of constant direction have caused this remarkable parallelism of ripples. The general trend of these rip-

[31] See preceding footnote.

[32] J. D. Dana, Corals and Coral Islands, 3d edit., p. 142, 1890.

[33] Joh. Walther, Lithogenesis der Gegenwart, 1894, p. 648.

[34] J. Hann, Handbuch der Klimatologie, vol. 2, p. 288, 1910.

The Arafura Sea with the Gulf of Carpentaria and the South China Sea with the Java Sea are the only epicontinental seas of the present geologic period offering close analogies to the warm shallow seas of the Paleozoic. A systematic study of their sediments from the point of view of sedimentary petrography is certainly as necessary to a deeper understanding of the problems involved as that of the rocks of the volcanic islands of the adjoining deep sea is to igneous petrography.

[35] A recent, larger example of such a detached arm of an epicontinental sea practically without tides is offered by the Baltic Sea, which during the Pleistocene, for a time, was even transformed into a freshwater lake. (Comp. E. Kayser, Lehrbuch d. Geol. Formationskunde, 3d edit., p. 650, 1908.)

ples and the testimony of the later deposits of the Mauch Chunk shale, render it probable that they were monsoon winds blowing to and from the large North Atlantic Continent in the northeast.

II. Current-ripples.

1. *Description.*

Current-ripples are much more common in all kinds of sediments than might be judged from the scarcity of the name or its equivalent in geological literature. It is essential that they should, in all cases, be clearly separated in geological reports from oscillation-ripples.

The current origin of some limestone ripples, especially small ones, is not always easily recognized, as their asymmetry often is not pronounced. A study of a cross-section or a careful determination of the position of the line of greatest depth will, however, reveal their true nature. In most cases, broadly rounded crests lacking any indication of a definite crestline, may be taken as evidence of current origin.

Fossil current-ripples cover the same range of sizes as recent ones. In contrast to oscillation-ripples, they are unfit for the discrimination of upper and lower surfaces in structurally complicated regions, owing to the similarity of crests and troughs.

2. *Interpretation.*

The following points are of value to the Paleogeographer:

1. *Eolian versus subaqueous ripples.*—If the observations of Cornish and of Kindle (p. 197) prove to hold true in a great majority of cases, at least, ripples of eolian and subaqueous nature may be distinguished by the ratios of their wave-lengths and amplitudes. The absence of the subaqueous type from arenaceous sediments, especially when combined with the typical rounding of grains and the peculiar cross-bedding characteristic of dunes, should be good evidence of their eolian origin. It appears quite doubtful, however, if eolian current-ripples ordinarily can be preserved at all.[36]

2. *Current-ripples in marine sediments.*—An indication of currents of any kind in marine sediments is always a matter of interest. I have no doubt that, once atten-

[36] Cf. p. 269 (Part II).

tion has been called to this matter, current-ripples will be reported from numerous marine formations.

They are rather common on the surfaces of very fine-grained, bluish limestone layers of the Eden and Richmond Groups of Kentucky and Ohio, in the former especially in the fine-grained sandy limestones of the "Garrard Sandstone" of Kentucky.

Such current-ripples may be formed by the wave of translation on the strand, or by wind-drift or tidal currents down to considerable depths. That no information can be expected from marine current-ripples concerning any systems of currents, is made obvious by an inspection of the results of modern marine current measurements, especially those made on the cruises of the "Michael Sars" during the last fifteen years.[37] These investigations have shown that the system of currents in such seas as the Norwegian and the North Sea is vastly more complex than was anticipated. By interference of wind-drifts and tidal currents, of these again with reflected tidal waves, along the shore with shore-drift, undertow and freshwater surface currents and their counter currents, a great variety of conditions are produced. These are further complicated by the existence of vortical movements with vertical axes, in the open ocean as well as in coastal waters, and by the fact that in the great majority of cases the bottom currents follow their own laws. In the Skagerack, for instance, "the tidal currents are scarcely noticeable in the upper water layers, whereas they have been met with there down at the very bottom at such great depths as 200 m."[38]

This raises the question of the maximum depth at which such current-ripples as are found, for instance, in certain marine limestones, might have originated. It can be answered best by a reference to one of the most interesting measurements made on the "Michael Sars." On the edge of the continental slope, about 80 km. northwest of Aalesund on the Norwegian coast,[39] *in the open ocean,* not in any channel, the Atlantic current was found running, on the average, parallel with the continental slope,

[37] See especially Helland-Hansen, Current Measurements in Norwegian Fiords, the Norwegian Sea and the North Sea, in 1906, Bergen's Museums Aarbog, 1907, No. 15; and Helland-Hansen, and Nansen, The Norwegian Sea, Rept. Norweg. Fishery and Marine Investigations, vol. 2, No. 2, 1909.

[38] Report Norweg. Fishery and Marine Investigations, vol. 2, No. 1, p. 79, 1909.

[39] 62°50′ N. Lat.; 4°47′ E. Long.

at times with a velocity of 0·215 m. p. sec. *at a depth of 250 m.* The lowest velocity observed was 0·059 m.p. sec. "This velocity is so great that the water would move grains of sand, and wash them away from the bottom, which at this place was rocky."[40]

From ripples found in marine sediments, therefore, no other reliable information can be obtained than that there existed currents of some kind which touched the bottom. Since the conditions of preservation are the same for both current and oscillation-ripples, the absence of one or the other type in a sediment must be accounted for in other ways. The Bedford-Berea ripples offered an excellent example for the one case. In the limestone-shale series of the Eden and Richmond Groups of the Cincinnati Anticline current-ripples are common, while I have so far not seen a single case of undoubted oscillation-ripples. While I have no doubt that they will be found, their scarcity is certainly significant and a good evidence of the rather constant current action in these seas, which were shown to have been largely tidal.

3. *Fluviatile current-ripples.*—While in marine sediments the trend of ripples seems of little value to the paleogeographer, its study may yield important results in fluviatile deposits, the true nature and wide distribution of which among the sediments of the past we are just beginning to realize. There are no sediments in which ripples of any kind are of more common occurrence and find better chances of preservation than the sands and muds of alluvial plains.[41]

In the deposits of a river obviously a great majority of all ripples should be found facing approximately in the direction of flow of the river. Locally, of course, they can be found facing even in an opposite direction, as along parts of meanders or under the influence of local eddies. Such cases can not, however, seriously affect the average direction obtained from numerous determinations.

This is also true of the ripples on compound alluvial fans. An analysis of the ripples in sediments which are interpreted as alluvial fillings of rift valleys, as, for instance, the Newark series in Connecticut,[42] should prove especially interesting.

[40] Helland-Hansen and Nansen, loc. cit., p. 155; cf. also table 1 of Part I of this paper.

[41] Cf. also p. 269 (Part II).

[42] J. Barrell, Central Connecticut in the Geologic Past, Proc. and Coll. of the Wyoming Hist. and Geol. Soc., vol. 12, pp. 1-30, 1911.

But even in moist climates very complicated conditions may arise which would call for the greatest caution in the analysis of ample data, without which no positive results could be hoped for. The rift valley of the Rhine, *e. g.*, over 160 miles long between Basel to Bingen, was filled to a depth of over 100 m.,[43] locally even over 150 m.,[44] with silt, sand and gravel by the Rhine and its tributaries. The Rhine flows from south to north, but meandered over a large part of the 20 miles width of the valley, and frequently overlapped widely over the fans built by its tributaries, each of which, upon emerging from the bordering horsts, meandered more or less widely over the confines of its fan. An analysis of the ripples of such deposits might well meet with insuperable difficulties. But it deserves to be attempted and may, when combined with careful studies of the composition of the associated gravels and other data, yield reliable results which would substitute definite geographical conceptions for vague notions.

In the Pottsville series of Kentucky, the author observed at several localities shaly sandstones in which the ripples, covering nearly every layer, showed a gradual and continuous change of direction from one level to the next, reflecting clearly the slow shifting of the current in some part of a meandering stream. One mile northeast of Oil Springs, Johnson Co., Ky., for instance, the following six readings were taken on the best exposed surfaces within a thickness of three feet of very thin bedded shaly sandstone:

S 40 E
S 45 E
S 50 E
S 57 E
S 70 E
S 90 E

A number of intervening layers showed rippling too, which, in all cases, was in harmony with this general arrangement. The wave-length of the ripples varied between 6·5 and 7·5 cm., and all faced southward.

4. *Current-ripples as evidence of exposure.*—The highly characteristic linguoid ripples, described in Part

[43] G. R. Lepsius, Das Mainzer Becken, Darmstadt, 1883, p. 156.

[44] E. g. 160 m. at Blodelsheim, in the Upper Alsace: L. Van Werveke, Uebersicht ü. d. geol. Bau u. d. geol. Entwickelung des Reichslandes Elsass-Lothringen u. d. Grossh. Baden-Strassburg, 1913, p. 45.

I, have always, as far as I know, been found where the depth of running water was rapidly diminished to complete exposure. They are equally common on tidal flats as on floodplains and therefore can be considered as indicators of this special condition. During the G. S. A. meeting at Albany, New York, there were exhibited excellent specimens of negatives of this type, if I remember correctly, from the Portage Sandstone of New York, together with plaster casts showing their true form. Cox and Dake figure a good specimen from the Roubidoux sandstone of the vicinity of Rolla, Missouri,[45] and Kindle one from the Carboniferous Sandstone, Joggins section, N. S.[46] Kindle also called attention to the fact that the laminations of such linguoid ripples, when exposed by erosion, resemble the problematic burrows, described as *Taonurus*. Surfaces like the one figured by him on plate 31 are commonly met with, for instance, in the rocks of the Pottsville group of Kentucky.

The evidence offered by these linguoid ripples is definite and should be used in combination with other data, giving clues to the marine or terrestrial nature of the sediments.

In marine deposits they should be confined to a narrow zone, corresponding to the tidal flats; or they might be found over a wide area in a formation of limited thickness ascending obliquely through the stratigraphic column due to progressive marine overlap pushing the marginal zone forward across the land.

If they are, however, found throughout a considerable thickness of a formation of fixed position in the stratigraphic column, covering a wide area, they offer a strong argument in favor of a terrestrial, fluviatile origin.

III. Large Current-ripples.

1. *Description.*

Large current-ripples were described or mentioned from the lower Ordovician dolomites of Illinois[47] and from the Trenton at a number of localities in New York

[45] Cox, G. H., and Dake, C. L., Geologic criteria for determining the structural position of sedimentary beds, Bull. School of Mines, Univ. of Missouri, vol. 2, No. 4, pl. IIB, 1916.

[46] E. M. Kindle, Recent and Fossil Ripple-Marks, Geol. Survey, Canada, Museum Bull. 25, p. 121, 1917.

[47] Udden, J. A., Jour. Geol., vol. 24, p. 125, 1916.

and Ontario.[48] They are common in the Eden and in parts of the Richmond Group of the Upper Ordovician in the Cincinnati anticline.[49] They occur at a number of localities in the Silurian Brassfield formation of Kentucky and Ohio.[50] They were also reported from younger Silurian limestones in Ohio[51] and New York,[52] from Devonian limestones in Ohio[53] and Ontario,[54] from the Mississippian limestones of Iowa[55] and from Waverly conglomerates of Ohio,[56] and finally from the Comanchean of Texas.[57]

Table VI gives a selected number of measurements for large fossil current-ripples.

In shape they vary from strongly asymmetrical to completely symmetrical; more than half of all large ripples seen in limestones of the Ordovician and Silurian of the Cincinnati Anticline were more or less symmetrical. Their crests are always broadly rounded like the troughs and but rarely show distinct crest lines.

Not one showed any signs of assortment. Shells of *Rafinesquina,* over 5 cm. long and wide, Bryozoans 8 to 10 cm. long and over 1 cm. thick, and, in the Richmond, calices of *Streptelasma,* over 10 cm. long and over 3 cm. wide, are found scattered equally over crests, sides and troughs of the ripples, mixed in almost any proportion with finer shell fragments down to the finest matrix filling the interstices.

It is very important to note that the same utter lack of assortment characterizes the large ripples which are found in the Berne member of the Cuyahoga formation of

[48] Ruedemann, R., Am. Geol., pp. 367 ff., 1897. Cushing, Bull. N. Y. State Mus. Nat. Hist., **77**, p. 34, 1905. Miller, *ibid.,* vol. **135**, p. 36, 1910. Kindle, Jour. Geol., **22**, pp. 703-713, 1914.

[49] See Locke, J. (1838); Orton (1873); Linney, W. M. (1882-1887); Knott, W. T. (1885); Perry, N. W. (1889); Shannon, W. P. (1895); Foerste, A. (1895); Moore, J., and Hole (1902); Culbertson, G. (1903); Prosser, Ch. S. (1916).

[50] Cf. Foerste, Kentucky Geol. Surv., Bull. **7**, 1906. Prosser, Ch. S., Jour. Geol., **24**, 1916, pp. 465-470.

[51] *Ibid.,* pp. 470-472. Foerste, Jour. Cinc. Soc. Nat. Hist., **18**, p. 167, 1896.

[52] Kindle and Taylor, U. S. Geol. Survey, Folio **190**, pl. 25, 1913.

[53] Stauffer, in ''Geol. of the Columbus Quadrangle,'' Ohio Geol. Surv., 4th Ser., Bull. **14**, p. 20, 1911. According to my own measurements, the ripples of the so-called ''smooth layer'' of the Columbus limestone, here mentioned, have a wave-length of 74 cm. and an amplitude of 2-5 cm. Prosser, *loc. cit.,* pp. 472-475 (2 good photogr.).

[54] Kindle, Ottawa Naturalist, vol. 26, pp. 1-3, 112.

[55] Udden, Jour. Geol., vol. 24, p. 125, 1916.

[56] To be described presently.

[57] Udden, *loc. cit.,* p. 126.

TABLE VI.—Data on Ripples observed on limestones chiefly of the Upper Ordovician of Kentucky.

No.	Stratigr. Group.	l[a] cm.	a cm.	$\frac{l}{a}$	$\frac{l_1}{l_2}$	material.	
1.	Richmond	0·4	....	......	....	fine-grained sandy l. s.	C[b]
2.	Richmond (top)	1·6	0·07	23	2·7	dense, light yellow dol. l.	C
3.	Richmond (base)	2·5	0·1	25	....	dense, gray argill. l. s.	C
4.	Richmond	3·0	0·2	15	....	dense, "blue" argill. l. s.	C
5.	Richmond (base)	4·0	0·15	27	....	" "	C
6.	Richmond	7·3	0·25–0·5	14–29	1·8	" "	C
7.	Richmond (top)	8·0	0·3	26	1·9	" "	C
8.	Maysville (base)	12·5	1·2	10	1·0	" "	O?
9.	" "	23–30·0	....	......	....	....	?
10.	Eden (top)	34·3–50·9	7·6 7·0	4·5 7·3	n. s.[a]	coarse-grained fossilif. l. s. no assortment	P
11.	Richmond	40–50	2·5–4·5	15 (av)	n. s.	" "***	P
12.	Eden	60·0	6·5–7·0	9	n. s.	" "	P
13.	Eden	70–79	5·7–8·6	12 9	2·1 ±	" " " "	P
14.	Eden	80·0	8·0	10	n. s.	" "	P
15.	Eden (top)	74–94	7·6–8·9	8–12	1·2–1·5	" "	P
16.	Brassfield	83–100	4·6–6·3	18 (av)	n. s.	oolitic rock passing into iron ore	P
17.	Eden	95	9·2	10	1·1	coarse-grained fossilif. l. s. no assortment	P
18.	Eden	100	10	10	4	" "	P
19.	Eden	100	5·5	18	n. s.	" "	P
20.	Eden	110–120	9–10	12	n. s.	" "	P
21.	Eden	128	7·5	17	n. s.	" "	P
22.	Eden	75–130	6·3–5·7	12–23	2·2–2·5	" "	P
23.	Brassfield	134	11	12	1·5	" "	P
24.	Eden	145	12	12	n. s.	" "	P
25.	Brassfield	105–160	7·5–10	14 (av)	n. s.	oolitic rock passing into iron ore	P
26.	Eden	130–160	11–10	11–15	n. s.–2·6	coarse cryst. no assortment	P
27.	Lower Burlington	180	15	12	....	crinoidal l. s.	P

[a] l = wave-length; a = amplitude; $\frac{l_1}{l_2}$ = horizontal form index (see p. 154, pt. I); n. s. = nearly symmetrical.
[b] C = Current-ripples; O = Oscillation-ripples; P = Para-ripples.

LIST OF LOCALITIES REFERRED TO IN TABLE VI.

No. 1: Ky., Casey Co., near Carpenter's Creek. Nos. 2, 7: Ky., Oldham Co., S of Harrods Creek, Lagrange Rd. Nos. 3, 4, 5, 6: Ky., Lincoln Co., Logan Creek. Nos. 8, 9: Ky., Mason Co., between Marshall and Lewisburg. Nos. 12, 14, 19, 20, 21: Ky., Mason Co., creek W of Maysville. Nos. 10, 11, 15: Ky., Garrard Co., Paint Lick. No. 13: Ky., Shelby Co., between Mt. Eden and Southville. Nos. 22, 26: Ky., Shelby Co., between Waddy and Harrisonville. Nos. 16, 25: Ky., Bath Co., about 3 miles N of Olympia. No. 23: Ky., Bath Co., W of Preston. Nos. 17, 18, 24: Ohio, vicinity of Cincinnati. No. 27: Iowa, SE Louisa Co. (Udden, 1916).

Hyde's definition,[58] who showed me personally two very interesting occurrences in the vicinity of Newark, Ohio, in Quarry Run, south of Newark, and at Toboso, east of it. At the former locality, the broadly rounded, symmetrical crests, 145 cm. apart, have formed on a quartz conglomerate in which pebbles of more or less 0·5 cm.

Fig. 12.

Fig. 12. Asymmetrical para-ripples on limestone in the Eden group, ¼ mile above the bridge across Little Beech Creek, on the road from Mt. Eden to Southville, Shelby Co., Ky. (For dimensions see table VI.)

diameter are uniformly mixed with coarse and fine sand without a trace of assortment. Since in the growth of oscillation ripples, the to and fro motion of the oscillating current produced by waves on the bottom of a water body involves a constant tossing of the grains, a sifting and assorting of the grains is unavoidable.

Its absence in the large ripples in question seems to be sufficient proof of their current origin. Besides, it

[58] J. E. Hyde, Stratigraphy of the Waverly formations of Central and Southern Ohio, Jour. Geol. vol. 23, p. 659, 1915.

appears very doubtful, as was pointed out in Part I (March No.), whether ripples of this size can form at all through the action of waves alone. All experimental and observational evidence seems to speak against it.

In the course of a discussion the objection was raised that a current should be expected to "cut through the

FIG. 13.

FIG. 13. Para-ripples on limestone in the Richmond group, Blue Bank Creek, above Goddard, Fleming Co., Ky. (See table VI.)

Note that the para-ripples cover undulations of a higher order of magnitude, four of which are seen in the figure (Nos. 1-4). The hammer rests on the second one.

rippled layer into the underlying sediment" in places, while no such case is known at present. This should be indeed the case if there existed local differences in velocity or depth of the current. We have, however, in Part I endeavored to show that the establishment of ripples at the contact of sediment and water serves the very purpose to eliminate any such irregular, local differences and to replace them by a uniform system of flow-lines.

These large current-ripples agree in most points with the tidal meta-ripples as described in Part I. The essential difference lies in the great number of symmetrical ripples and in the smaller horizontal form-index of the asymmetrical forms. To what extent this difference is due to the fact that the recent tidal ripples were observed after emergence while most fossil cases probably remained under a water cover, I have no means to judge.

Since a neutral name is desired for the large, nearly or completely symmetrical ripples showing no assortment of grain, I suggest the term "*para-ripples.*"

2. *Interpretation.*

The following discussion of the probable origin of these large ripples of the Upper Ordovician and lower Silurian of the Cincinnati Anticline has already been published elsewhere.[59] The limited distribution of the other publication, however, makes it appear desirable to embody it in this paper.

a. In Kentucky, the Brassfield formation of the Silurian east of the Cincinnati Anticline shows one or two rippled layers within its 18 feet of thickness. West of it, no traces of ripples were found according to Foerste.[60]

The ferruginous oolitic facies of the same formation is also limited to the east side of the anticline, extending over a distance of nearly 120 miles from Madison County, Kentucky, to Clinton County, Ohio, in a belt running roughly north-south (perhaps slightly east of north). On the west side of the anticline nothing but a salmon-brown color of the limestone betrays the (relative) neighborhood of ferruginous deposits.[61] From this the inference appears justified that the shore-line of the Brassfield sea was somewhere to the east with a general north-south trend.

Of the thirteen measured exposures of rippled layers in the Brassfield, ranging over a distance of nearly 50 miles, twelve showed directions of strike between N 50 W and N 110 W, averaging N 76 W, that is, at right angles to the direction of the assumed shore-line (see fig. 14*b*). The current, therefore, must have been parallel to this shore-line. This excludes the undertow and similar currents from discussion.

[59] W. H. Bucher, Proc. Nat. Acad. Sci., vol. 3, pp. 285-291, 1917.

[60] Foerste, The Ordovician-Silurian contact in the Ripley Island area of S. Indiana, this Journal (4), vol. 18, pp. 321-342, 1904.

[61] Foerste's map of the distribution of the facies of the Clinton formation.

b. Large current-ripples are found only on rocks of relatively coarse grain, as conglomeratic sands (Cuyahoga formation) or fragmental limestones, never on fine-grained sediments, that is, on dense blue argillaceous limestones. These are, however, frequently covered with small current-ripples, ranging in wave-length from 1 to 30 cm., and are often interstratified with fragmental limestones of coarse grain covered with large ripples and separated from them only by thin layers of shale. The calcareous layers show delicate tracks of gastropods or trilobites well preserved which practically exclude any current action.

This seems to indicate that the current in question varied in intensity from a maximum to nil, in relatively short intervals. The finer sediments could record only the weaker movements, as stronger currents would have thrown them into suspension.

c. In the Ordovician, I have repeatedly found large asymmetrical ripples on two successive limestones, not more than a foot apart, with nearly the same strike, but with their lee sides facing in opposite directions. The current, therefore, reversed its direction in relatively short intervals.

Observations *b* and *c* exclude ocean currents of larger dimensions, while they point consistently to tidal currents. These, too, are the only marine currents flowing parallel to the shore-line in which velocities of at least 1 m. sec., which seem necessary to produce the effects observed, are found over wide areas.

The great similarity of form existing between these large fossil ripples and some of the tidal para-ripples referred to above goes far to confirm these conclusions. From Cornish's paper on these tidal ripples[62] we know that on open shores, such as at Mundsley (Norfolk, p. 183) above the mouth of Barmouth Estuary (p. 173), or especially on the Goodwin Sands (p. 189), about six miles off the shore of Kent, these tidal ripples invariably trend at right angles to the shore, often at right angles to the waves. On the open shore, too, their wave-length is the same as that of most large Paleozoic ripples, while those observed in estuaries, where the velocity of the tidal current is greatly increased, have a greater wave-length.

The inference, therefore, seems justified that the large

[62] Cornish, Sand Waves in Tidal Currents, Geogr. Jour., vol. 18, pp. 170-202, 1901.

current ripples described were produced by tidal currents. Those of the Brassfield formation in Kentucky offer a direct analogy to those of the English Coast.

The ripples of the Lorraine and Richmond Formations, however, offer an additional problem.

1. They are not limited to a relatively narrow zone in the neighborhood of the shore, but formed (probably more or less synchronously) throughout the area of the Cincinnati Anticline, that is, over an area of at least 15,000 square miles and probably much more.

2. They trend in all directions, although a north-south trend is more common than an east-west trend (see fig. 14, *c-k*).

At first sight this seems to offer a serious objection to my interpretation, since in open waters the direction of the current passes through all the points of the compass in the course of twelve hours, which would render the formation of permanent ripples impossible. The following observations, however, offer a clue to this problem.

In 1881 Hunt[63] visited the broad open gulf of Torbay on the south shore of Devonshire two weeks after a heavy

Fig. 14*a*.

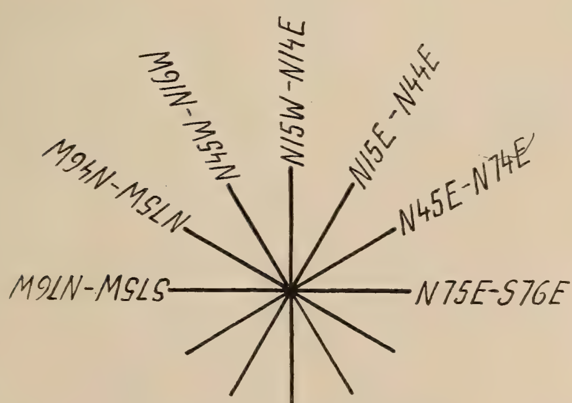
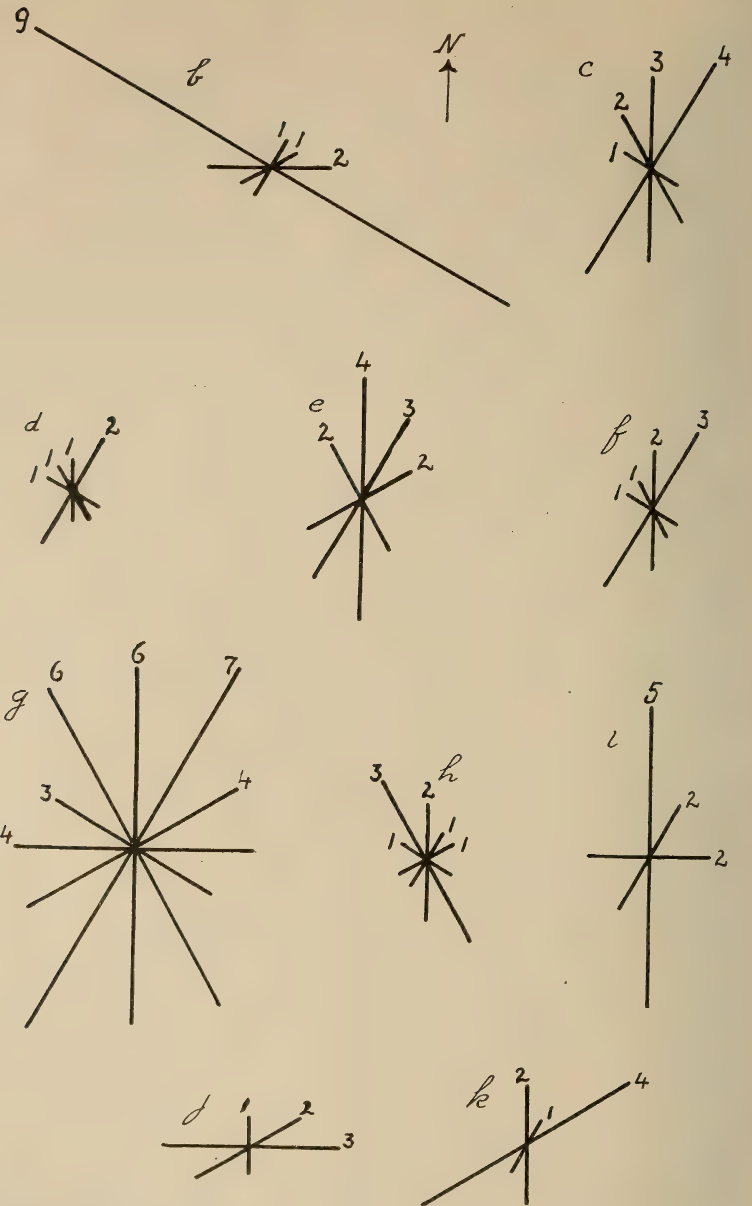


Figure 14, *a-k*. Diagram illustrating the relative frequency of the different directions of strike observed in para-ripples of the Brassfield formation (*b*), Eden group (*c-g*), and Richmond group (*h-k*) of the Jessamine dome. Fig. *a* illustrates the method by which the diagrams were constructed. The directions observed were divided into six groups and plotted on six rays, each representing all the directions lying within 15° on either side. The total number of observations in each group is shown, relatively, by the length of the rays, and, absolutely, by the figures at their ends.

[63] Hunt, A. R., On the formation of Ripple Marks, Proc. Roy. Soc., vol. 34, p. 4, 1882.

FIG. 14*b* to *k*.



Brassfield formation: Fig. *b*, 13 localities in Bath, Fleming, Powell, and Estill counties, Ky.

Eden group: Fig. *c*. Valley west of Maysville, Mason Co., Ky.; Fig. *d*. Paint Lick and tributaries below Paintlick, Madison Co., Ky.; Fig. *e*. Little Beech Fork and tributaries N of Gravel Switch, Marion Co., Ky.; Fig. *f*. Headwaters of Big Beech Creek, W of Waddy, Shelby Co., Ky.; Fig. *g*. Vicinity of Cincinnati, Ohio.

Richmond group: Fig. *h*. Elkhorn Creek, Adams Co., Ohio, after Foerste, 1895; Fig. *i*. Between Poplar Plains and Goddard, Fleming Co., Ky.; Fig. *j*. Tributary of Harrods Creek, N of Lagrange, Oldham Co., Ky.; Fig. *k*. Jefferson and Wayne counties, Indiana, after Moore and Hole, 1901, and Culbertson, 1902.

storm. In Midbay, at a depth of over 12 meters, where the bottom usually is a soft muddy sand that clogs the dredge in a few minutes, he found the ground hard, producing "not a single shell or a particle of the usual muddy sand." Four weeks after the storm "the ground was still very hard, both the dredge and a fishing-lead tied to a line *bumping along as though over ridges.*" Over six weeks after the gale the same spot had returned to its normal state.

Similarly, Cornish (p. 175) found Pegwell Bay (Kent) in which ordinarily the tide never produces anything but small current-ripples, covered with large tidal ripples after a heavy gale blowing into the bay.

These observations indicate that the drift produced by periods of storms may so strengthen the tidal current as to produce large current-ripples. This I suggest as the probable origin of our large Eden and Richmond ripples.

The ripples observed by Hunt formed at a depth of over 12 meters with a tide of over 2 meters. In open waters the range of the tides and the velocity of the resulting currents would be much smaller than in the channel. With gales of similar strength, therefore, the same mechanical effect of the currents would be possible only at a much smaller depth of water. Allowing, however, for extreme conditions, we may safely say that our Ordovician ripples probably were formed in water less than 25 meters deep rather than more. The Persian Gulf offers an interesting analogy. With an area of about 90,000 square miles, it has a mean depth of but 25 meters.[64] The tidal range along all its shores is more than 2 meters.[65]

We may summarize the geographic conditions inferred from the large current-ripples of the Upper Ordovician of the Cincinnati Anticline as follows:

1. A sea having sufficient connection with the open ocean to allow relatively high tides.
2. Sufficient area to permit the formation of strong wind-drifts in most directions during periods of storms.
3. A depth small enough to admit of a strong action on the bottom sediments by wind-drift and tidal current combined, probably 25 meters or less on the average.
4. Atmospheric conditions providing for the occurrence of storms, blowing from all points of the compass,

[64] Supan, A., Grundzüge der physischen Erdkunde, 1911, p. 260.
[65] Berghaus, Atlas der Hydrographie, 1891, pl. XX.

such as tropical cyclones or, more probably, those of intermediate latitudes.

In the paper referred to, considerable emphasis is laid on a sufficient rate of sedimentation as the chief condition for a preservation of the ripples formed. The discussion, which involves an interpretation of the origin of the more or less rhythmic repetition of shales and limestones in the Upper Ordovician of the Cincinnati Anticline, can not be given here.

The fact that at least four independent factors had to combine for the production of these ripples, namely sufficiently strong tidal action, frequent periods of strong storms, a relatively small depth of water, and a sufficient rate of sedimentation to insure their preservation, explains why such large current-ripples are not found commonly over wide areas in the sedimentary record of other seas.

The large ripples produced along the shores by ordinary tidal currents, also have much poorer chances for preservation than smaller ripples, because they require a thicker cover in order to be preserved. This explains their scarcity in shore deposits. The same is true of fluviatile ripples.

In view of the fact that strong tidal currents are found only in waterbodies which are in direct open connection with the sea and not in landlocked seas, whether mediterraneous or epicontinental seas, the presence of para-ripples in marine deposits ranging in age from the Lower Ordovician to the Comanchean, all from the United States west of ''Appalachia,'' is of fundamental interest. Many more will be recorded[66] and will doubtless furnish valuable checks on many lines that will be drawn on future paleogeographic maps.

IV. General absence of Ripples in certain Formations.

One question remains to be answered: Why are ripples entirely absent from certain formations, while they are a conspicuous feature throughout others?

The *formation* of ripples is prevented by:

1. Sediments too coarse or too fine in proportion to

[66] Every occurrence of such large ripples deserves publication. The wave-length, amplitude, degree of asymmetry, direction of trend and a detailed account of the texture of the sediment should be given besides detailed topographic and stratigraphic location.

the existing currents and oscillations. Pure muds can not form ripples at all.

2. The absence of tidal currents, that is, of an open connection with the ocean. (Applies to current-ripples only; cf. p. 243.)

3. A depth too great in proportion to the area of the water body to allow waves and drift currents to touch bottom. (Cf. p. 246.)

The *preservation* of ripples is made impossible by

4. The absence of the conditions favorable for a rapid covering of the ripples, as outlined below.

5. It should be noted especially that in relatively coarse homogeneous sediments, coarse sands for instance, not capable of being carried any distance in suspension and covering extensive areas, the stirring of the sediments does not result in a covering of the ripples formed.

Judging from these points, ripples will be absent from (*a*) sediments deposited in a landlocked sea or lake with too large a form ratio (points 2 and 3), or, if the form ratio were small enough to cause the action of waves on the bottom, with sediment too coarse or too fine to give rise to ripples (points 1 and 2).

(*b*) Also from well assorted, coarse sands or other arenites, accumulated in a shallow water body, with or without strong tidal currents and waves, distant from the mouths of streams and of coasts with sand-laden winds (points 4 and 5).

Not one of these points, on the other hand, applies to terrestrial alluvial deposits. There is no reason why ripples of practically all kinds should not be found in profusion in all fluviatile deposits, especially in such as were accumulated under more or less arid conditions, with clouds of wind-blown silt and sand settling into the shifting waters.

It appears to be very doubtful, however, if ripples will ordinarily be preserved in dune sands, in view of point 5, which certainly is of equal importance in subaërial as in subaqueous sediments. In my own observations of sections of recent dunes, limited to shore dunes, I have never seen ripples preserved in the sands, and they are not mentioned in the descriptions of such typical fossil dune sands as the Sylvania sandstone.[67]

University of Cincinnati,
Cincinnati, Ohio.

[67] Sherzer, W. H., and Grabau, A. W., Michigan Geological and Biological Survey, Geol. Series, 1, pp. 61-86, 1909.

Art. XVI.—*The Rounding of Grains of Sand by Solution;* by J. J. Galloway.

Introduction

The degree of roundness of grains of sand is considered by many geologists as of prime importance in the interpretation of the conditions of deposition of sandstones. A "millet seed," quartz sandstone, that is, one consisting wholly of well rounded grains, is regarded as indicating eolation and the deposition of the sand under desert conditions.

Special importance has been attached to the presence of well rounded grains below one-tenth millimeter in diameter as indicating that such grains were rounded by abrasion in the wind, and could not be rounded in water.[1] This idea evidently originated in Daubrée's statement, "The dimensions of grains which can float in very feebly agitated water appear to be about one-tenth millimeter in average diameter. All finer sand will be without doubt angular."[2]

I have proved by experiment that grains of calcite, dolomite, mica and hornblende, ranging in size all the way down to ·01 mm. in diameter can be rounded by mutual abrasion in water in fifty hours at a velocity of four miles an hour; that the lower effective limit of rounding by abrasion in water is about ·05 mm.; and that the rate of rounding becomes progressively slower after the grains are reduced to a diameter of about ·2 mm., below which size the time taken to round grains is greatly lengthened. I believe these results would apply to quartz grains if the time were sufficiently lengthened, that is to at least 800 hours at four miles an hour. The smallest spherical grain of quartz I was able to produce in 150 hours at four miles an hour measured ·2 mm. in diameter.

The fact, however, that fragments of minerals are rounded by solution, and that this process may be of corresponding geological importance, seems to have escaped the attention of most students of sands. Sorby, almost the first and one of the closest observers of the characteristics of sands, recognized the factor of corrosion in the production of rounded grains of quartz. He says,[3]

[1] Grabau, Principles of Stratigraphy, pp. 226, 253, 553, 1913.
[2] Literal translation from Daubrée, Géologie Experimentale, p. 256, 1879.
[3] Quart. Jour. Geol. Soc. London, vol. 36, Proceedings, p. 47, 1880.

"The quartz in quartzose felsites is often of much more truly crystalline form, the planes being sometimes very perfect; but very often there is a remarkable rounding of the angles, which might easily lead any one to think that they were waterworn. Even the grains of quartz derived from granite sometimes show this character to a less extent, but the rounding is usually accompanied by small surface ridges, which clearly show that their rounded form was not due to mechanical wearing. In the specimens of decomposed granite which I have examined in greatest detail, the larger grains of quartz have a somewhat opaque surface, as if corroded, and the angles are rounded. This rounding is relatively much greater in the case of the smaller grains, which is the reverse of what is met with in worn sand. On the whole the facts seem to indicate that the quartz has been more or less corroded and dissolved by the action of the alkaline silicates set free by the decomposition of the feldspar. The contrast between its corroded surface and the glassy fractures of broken quartz is very great."

A few simple experiments will demonstrate that crystals or mineral fragments of any shape tend to become round in the process of dissolving.

If a pinch of sodium chloride, potassium chloride, sugar or any other finely granular material, which is readily soluble in water is put into a few drops of water on a slide and observed under a microscope, the angular grains will be seen to change to rounded ones by the more rapid dissolving of the corners. The smaller the grains become the more nearly spherical they become. If ground calcite, or any other finely granular, pure, crystalline material is partially dissolved in acid, the grains will be rounded by solution. Fig. 1 shows the forms and character of surface produced when grains of Iceland spar are partially dissolved in warm hydrochloric acid.

As is well known, all the minerals occurring in sands are soluble in natural waters. The process is accelerated when the water contains appreciable quantities of alkalis or acids. The feldspars and ferromagnesian minerals dissolve fairly readily. Quartz, magnetite, rutile, zircon, apatite, garnet, muscovite and monazite are extremely resistant to solution, but even these may be dissolved naturally in water when the amount of water and time are great enough.[4]

The physical process involved in the rounding of small

[4] See Clarke, Data of Geochemistry, U. S. G. S., Bull. 616, pp. 478-483, 1916; Merrill, Rocks, Rock Weathering and Soils, pp. 189-194, 236-238; Van Hise, Treatise on Metamorphism, U. S. G. S., Mon. 47, pp. 516, 848, 1904.

grains by solution is similar to the formation of rounded bowlders by exfoliation of granite, by weathering of basalt, the rounding of bowlders and mineral fragments by abrasion, and the tendency of chunks of ice to become round in melting, differing mainly in the size of particles

Fig. 1.

Fig. 1. Grains of crushed Iceland spar rounded by solution in warm hydrochloric acid. Note that the smallest grains are the most nearly round. Transmitted light. Magnified 70 diameters.

removed from the respective surfaces. In all these methods of rounding, the larger amount of material is removed from the corners.

The surfaces of grains rounded by rapid solution, or solution accompanied by motion of the grains, are smooth like glass, though sometimes minutely pitted or corroded, but never "frosted" like ground glass. When solution is very slow, as in the case of weathering of quartzite pebbles in conglomerates, or vein quartz, or the corrosion of quartz grains in decomposed granite and residual soils, glacial till and clays which I have examined, the surfaces are dull, giving an effect easily mistaken for that produced by strong abrasion. The solution surfaces of minerals containing impurities or other lack of homogeneity are pitted or develop other irregularities, especially if the rate of solution is slow.

Factors in Rounding by Solution

Several factors enter into the rounding of grains of sand by solution, the most important of which are:

FIG. 2.

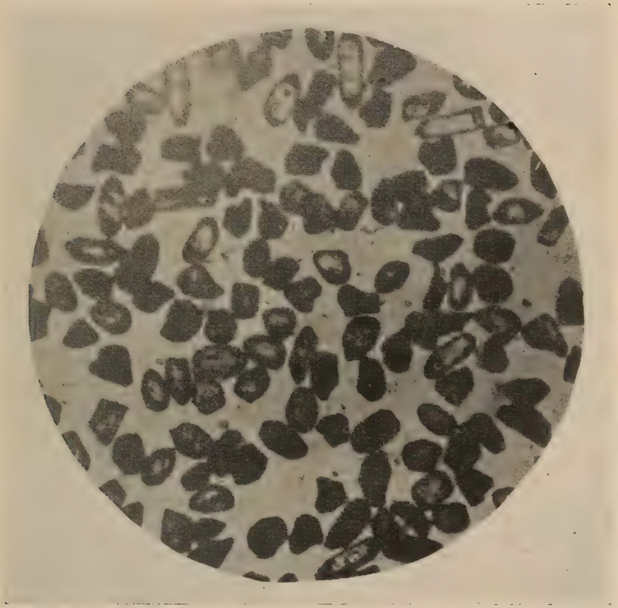


FIG. 2. Grains sifted from beach sand from Rockaway, L. I., about half of which may be considered as well rounded. These grains vary in size from ·05 to ·1 mm. Transmitted light. X 50.

(1) rate of solution, (2) time, (3) size of grains, (4) original shape of grains, (5) motion of grains and solvent, (6) cleavage, and (7) purity of the mineral.

Rate of solution.—The more soluble a mineral is the more rapidly grains of it will approach roundness until the saturation point of the solvent is reached. A balance is then obtained between mineral and solvent, and the grains tend to assume their crystalline outlines. When the solvent becomes supersaturated, as by evaporation, the grains are built up into more or less perfect crystals.

Garnets, feldspars, magnetite, hornblende, tourmaline, zircon and apatite are more soluble in water than pure quartz, as proven by the fact that quartz remains when every other mineral is removed, and should more often occur in rounded forms. I have seen rounded grains of these minerals and of smoky quartz varying from ·05 to ·1 mm. in diameter in young beach sand from Rockaway, L. I., the smallest grains of which are shown in fig. 2.

Fig. 3.

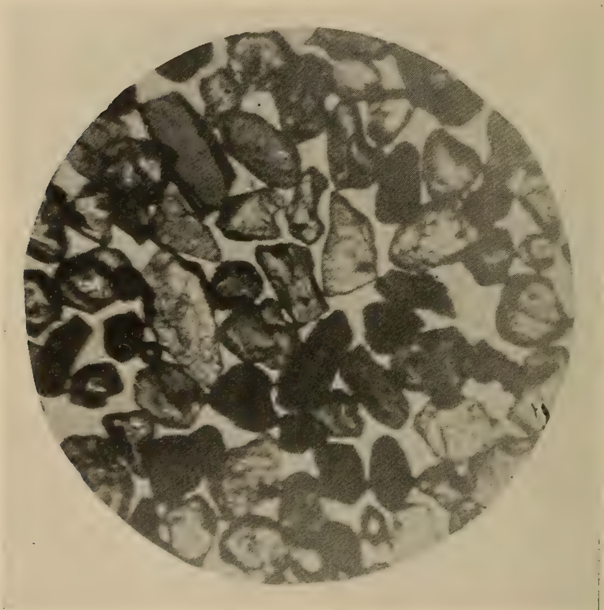


Fig. 3. Grains from the same sand as that shown in Fig. 2, varying from ·1 to ·2 mm. in diameter. Note that fewer of the grains are rounded than in the finer sand. Transmitted light. X 50.

Grains of the same minerals from ·1 to ·2 mm. in diameter are much less rounded in the same sand, as illustrated in fig. 3. The smallest grains were probably mostly rounded by solution, for the larger the grain the more the abrasion both in water and in wind, although abrasion and the original roundish form partly account for the present outlines. The surfaces of the rounded grains have a dull, corroded appearance when seen by reflected light, probably indicating their production both by solution and abrasion. The smallest perfectly round grain of quartz in this sand was ·06 mm. in diameter.

When grains of calcite have been rounded by solution in warm acid and which have brilliant, smooth surfaces, are subjected to solution in a very weak, cold acid, the surfaces are etched and become dull in appearance, showing that the rate of solution has more effect on the character of the surfaces produced than on the shape of grain produced by solution.

Time.—All minerals are soluble in water if sufficient time is given, and especially if alkalis or acids are present in the water. Quartz can be dissolved in a few hours in hot water under pressure. The temperature and pressure of water in which sands are accumulated, however, are not high enough to be important factors in solution. Just how rapidly solution takes place in nature is not known, but it probably requires hundreds, perhaps thousands, of years to produce any noticeable effect on the roundness of a grain of sand.

When the surface exposed remains constant, and the solute far from the saturation point, the rate of solution varies directly with the time. When other factors remain constant, the longer solution acts the more nearly round the grains become.

The brilliant, glistening surface of the grains of most beach sands is no doubt partly due to solution. The surfaces of quartz grains which I mechanically rounded in water were pearly, not glassy like freshly broken quartz, nor ''frosted'' as in old, wind-worn sands, nor like old beach sands like that noted by Merrill from Santa Rosa Island, Florida,[5] whose history seems to be complex.

Size of grains.—The smaller the grains the more rapidly and the more completely they are rounded by solution. Grains of sodium chloride and of calcite ·2 or ·3 mm. in diameter partially dissolved experimentally are subround and retain some of their original form, while grains of the same materials under otherwise identical conditions but less than ·1 mm. in diameter were mostly subspherical. Fig. 4 shows the forms assumed by common table salt undergoing solution in water.

The rate of solution varies with the area of surface acted upon, hence finely divided substances dissolve more rapidly than the same quantity in larger pieces. The

[5] Merrill, Rocks, Rock Weathering and Soils, p. 243, 1904.

same law accounts for the dissolving off of corners, for the more irregular the shape the greater the surface in proportion to volume.

A sample of very fine sand from a bubbling spring at Dayton, Maine, consists of quartz, fresh feldspar, hornblende and biotite grains, all between ·04 and ·15 mm. in diameter, many of which are round or subround. The

Fig. 4.

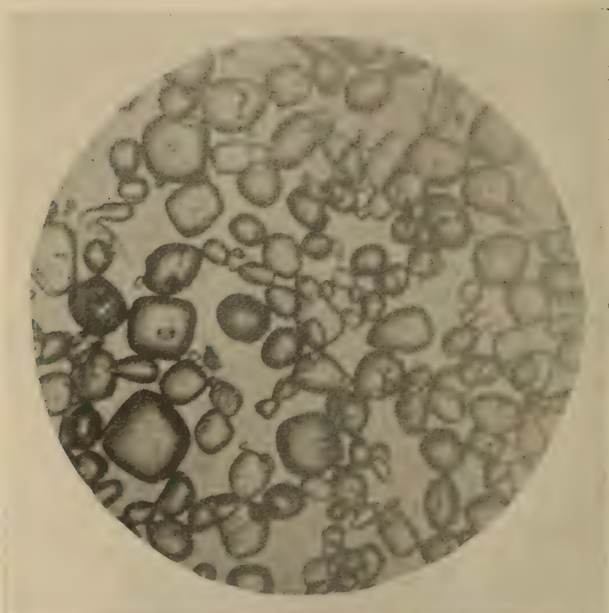


Fig. 4. Grains of common table salt rounded by solution in water. The smaller grains are the most nearly round. Grains seen in water by transmitted light. X 50.

smallest grains are the most nearly round, which shows that solution was the main factor in the process of rounding them. The smallest perfectly round grain measured was of quartz which was ·04 mm. in diameter. If the rounding has been due entirely to mechanical action, either by wind or water, the largest grains would have been rounded most. Flakes of biotite ·1 mm. and over were also round and were undoubtedly so formed by abrasion in the feeble spring. The surfaces of the rounded grains of quartz and feldspar were perfectly smooth, with an oily luster, the most brilliant surfaces I have ever seen on rounded sand grains. Such surfaces can be produced either by polishing in a liquid, as glass is polished, or by solution, but solution seems clearly to be the main factor in this case.

The sand seems to be of glacial origin, which shows that it is geologically young. The time it was acted upon by

Fig. 5.

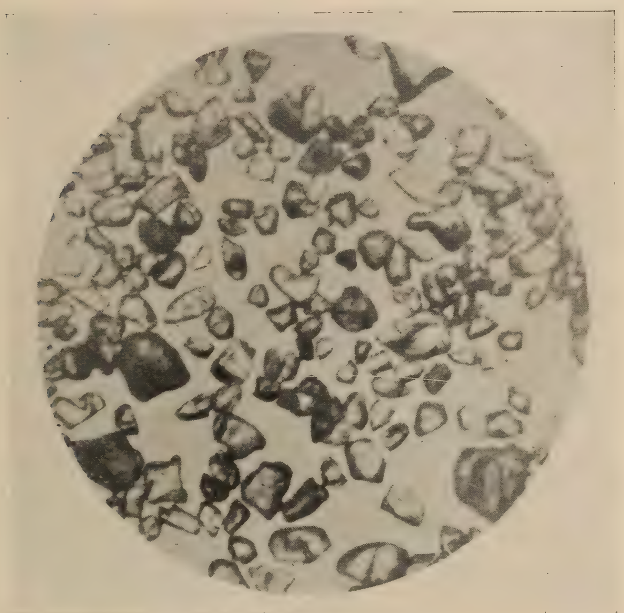


Fig. 5. Sand from a bubbling spring, Dayton, Me. All the grains are somewhat rounded, the largest ones the least. The surfaces of the quartz and feldspar grains are perfectly polished. Transmitted light. X 50.

the waters of the spring are to be measured in a few thousands of years at most, probably a much shorter time, which would indicate that noticeable effects of the solvent action of water upon quartz can be accomplished in a short time geologically, especially where the water is changed continually and the grains are in motion.

Original shape of grains.—The more angular and irregular the shape of grains the more rapid the solution, but the more regular the shape the more nearly spherical the grains become. Thus cubical and rectangular grains of common salt rapidly assume rounded forms, while grains of ammonium chloride, consisting of aggregates of acicular crystals, dissolve into bizarre forms bounded by curved surfaces. Long crystals or rhombohedral fragments as of calcite, produce oval, roller shaped or very prolate spheroids. Grains of garnet, magnetite, zircon, apatite, monazite and others which have a comparatively equidimensional crystalline form to start with, more rapidly assume or reach a better rounded form than more angular crystals, as those of hornblende and feldspars. Mineral grains, including quartz, are often more or less round as they occur in the parent igneous or metamorphic rock from which sands are derived. These could scarcely be distinguished from grains rounded by abrasion or by solution.

There is a tendency in nature for large objects to become round due to gravity and for small plastic particles to take such form by surface tension, the effects of which are universally present in drops or particles of liquids. Snow flakes change from flat, radiating crystals to subround pellets or ''snow sand'' without melting, probably due to sublimation, as suggested by Cornish.[6] The molecular attraction in minerals of ordinary sands is so much greater than surface tension in the same minerals that grains of sand do not tend to become round in any of these ways.

Motion of grains and solvent.—Grains are more perfectly and more rapidly rounded by solution when they are moved about in the liquid, thus allowing the unsaturated solute to come into contact with the grain on all sides, and eliminating the factor of diffusion and corrosion. When the grains are not moved, as in the decomposed granites, residual soils, clays and loess which I have examined, or in experiments on solution rounding, corrosion produces a peculiar texture of the surface not like that of abrasion but easily mistaken for it.

Quartz grains washed from Cretaceous clay from New Jersey, varying in size from ·06 mm. down to ·001mm., are not transparent like ordinary quartz but are translucent, due to the corroded surfaces. The grains are not sharply angular but somewhat roundish in form, and the surfaces are not smooth like glass, nor have an even curve and ''frosted'' surface like abraded grains, but have a minutely rough surface like rusted iron or weathered feldspars. I believe these features were due to slow

[6] Cornish, Waves of Sand and Snow, pp. 117-121, 1914.

solution unaccompanied by movement of the grains. The same features were noted in quartz grains ·1 to ·04 mm. in diameter from residual clay from Brick Haven, Va., and in decomposed granite from the District of Columbia. In so-called loess from Muscatine, Ia., most of the quartz grains are round or subround, especially those between ·05 and ·01 mm. in diameter, and the surfaces are all corroded. I do not believe that such small grains could be rounded by abrasion in either air or water, but solution would account for the form. In glacial silt from Ithaca, N. Y., the quartz grains ·1 mm. and less in diameter are only slightly corroded and all are noticeably rounded, differing strikingly from the perfect angularity of crushed quartz grains of the same sizes with which I compared them. In fuller's earth from Whigham, Ga., there are quartz grains ·05 mm. and less in diameter, and most of them are smoothly round, the surfaces are brilliant and show no corrosion, and they certainly were not produced by abrasion.

Streams, beaches and springs are favorable places for the rounding of minute grains by solution, on account of the more or less continual motion of the water and sand. Moreover, since the smaller grains are more often and longer in motion than the larger grains, the smaller ones would have the best chance of becoming rounded both by abrasion and by solution. It is possible also that water softens the surfaces of grains and makes abrasion more rapid and polishing more complete than when the grains are dry.

Cleavage.—Cleavage has little effect on the shape of grain produced by rapid solution, even when so pronounced as in calcite or halite, except as it influences the shape of the grain before solution begins. The patterns produced on crystals by etching with acid is due to molecular arrangement rather than to cleavage. When the cleavage planes have separated, solution and disintegration are favored, and flat or irregular forms are produced as well as round grains of silt or clay size. Under continued solution grains become almost perfectly round just before they disappear. When solution is slow, cleavage and twinning planes are attacked more rapidly than other parts of the crystal, causing disintegration and favoring decomposition rather than solution.

Purity of the mineral.—Grains consisting of more than one chemical substance, such as impure salts, calcite, dolomite and feldspars, which are not usually simple crystals but are twinned and vary in composition in the same crystal, dissolve according to the solubility of each constituent, producing somewhat rounded forms with numerous irregularities. Included gas bubbles and crystals of other minerals, and distorted crystals also interfere with regularity of surface produced by solution. In the case of complex grains, such as those composed of interlocking crystals or other lack of homogeneity, the attempt to form rounded grains experimentally by solution is not usually successful.

Conclusions

Grains of sand of any mineral makeup can be rounded by solution, and the process is especially competent on those of very small size, i. e., grains below one-tenth millimeter in diameter.

Four types of sand grains are produced by solution, depending upon the factors discussed above. They are: (1) sharply angular grains with brilliant surfaces, as in rock flour from glaciers with practically no solution; (2) angular grains with corroded surfaces, as in Pleistocene glacial silt and Cretaceous clays; (3) round grains with corroded surfaces, as in the Rockaway Beach sand and the loess from Iowa; and (4) round grains with brilliant surfaces, as in the spring sand described above and in fuller's earth from Georgia. These four types usually occur together, one or the other predominating.

While it is probably always true that a sandstone consisting wholly of well-rounded grains, many of which are less than ·1 mm. in diameter, was deposited by and owes its roundness of grain to the wind, the presence of a small percentage of minute, round grains is of itself not a safe criterion for assigning the origin of a sandstone to wind action. It rather points to water action.

Any reliable set of criteria for the genesis of a sedimentary rock are more complex than is usually assumed. All available data, the physical form and mineralogical character of grains, the structure of the rock, the stratigraphy and field relations, the fossil evidence and paleogeography, must be weighed before the origin of doubtful rocks can be correctly determined.

Columbia University,
New York City.

ART. XVII.—*Co-operation in Advanced Geologic Instruction;* by HERBERT E. GREGORY.[1]

During the past two years the country has witnessed a remarkable example of co-operation—a submergence of individual desires and the abandonment of cherished work and opportunities—all for the general good. To be of service has become the controlling motive of men and of institutions. The desire to serve has led educational institutions seriously to consider their ability to serve and the relative usefulness of the service they are able to render.

In particular, graduate and professional schools are undergoing a searching review. Are these institutions capable of providing an adequate number of investigators, or must specially designed research institutions, supported by private or government funds, be provided? At present few universities are acknowledged leaders in any branch of science. By general agreement one institution stands first in engineering, one in medicine and one in forestry. Students of agriculture from abroad find little difficulty in choosing an American college, but the choice of an institution for the study of chemistry, physics, geology, history, economics or languages, rests on incidental factors. Among graduate schools of the country there are many good departments, some strong departments, but no department which sets the pace and exerts a commanding influence in the advancement of science. The reason appears to be that pre-eminence of an institution in one department pre-supposes relative weakness in others. Under modern conditions, large endowments, a large group of able men associated with a large group of carefully chosen students are required to make a department of first rank and these essentials are difficult to procure. There seems to be a fairly widespread opinion that the standing of a university is somehow measured by the number of departments represented, that the only excuse for failure to offer advanced instruction in a subject represented in another institution is lack of funds. It is the present practice of universities to give graduate instruction leading to the doctor's

[1] Read at the Baltimore meeting of the Geological Society, Dec. 27, 1918.

degree in many branches of science. Of 563 institutions listed by the Bureau of Education as universities, colleges and technical schools, 220 of these enrolled graduate students in 1915. Of this large number of institutions the degree of Doctor of Philosophy was conferred in 1915 by only 43, and of the 546 doctorates in all subjects conferred in 1915 80% were given by 13 institutions and approximately 40% by 3 institutions. Even in the larger universities the number of graduate students is small compared with the faculty and in most institutions the teaching force in a subdivision of a subject consists of one man. Is it not feasible to develop a plan whereby a man of pre-eminent ability may guide the investigations of 20 men in his particular subdivision of study instead of 1 or 2 as at present, and whereby a student may have the advantage of association with a group of instructors and research fellows interested in his particular field of study? Is it not likely that funds would be saved, students receive better instruction and science advanced if there were 10 institutions adequately manned and equipped to deal with graduate students in geology instead of 38 institutions now offering advanced instruction in this subject?

If such a condition seems desirable it can be brought about by co-operation among universities—by a sort of "gentlemen's agreement" among a group of universities to develop strong departments in certain branches even at the expense of other departments. A university entering into this scheme would frankly admit that it gave no particular attention to advanced instruction in chemistry or anthropology, for example, and would advise prospective students to enroll at another institution. As its funds increased the university would strengthen its strong departments rather than build up those which were relatively weak.

Such an understanding does not imply that geology should be taught at only a few institutions. Departments like those at Williams, Amherst and Oberlin, which offer no graduate work, but which have introduced many strong men into the profession and which have exerted a profound impression on geologic thought, should be multiplied until they include all of the 563 colleges in the United States.

This broad scheme seems perhaps Utopian because of present endowments and of regional and administrative rivalries, but hopeful signs are appearing. Not a few institutions are complaining of the burden of weak departments which cost much money and contribute little. One institution discouraged the establishment of a Forest School because a neighboring institution had one. A generous donor who proposed to establish a School of Irrigation in an unfavorable locality was induced to reconsider. Another institution refused a large endowment for a School of Education. In this connection the effort of Harvard to divert a very large bequest for applied science to the Massachusetts School of Technology is significant.

Without interfering with the administrative policy of universities it is possible if thought desirable to enlarge the facilities for geologic research and study by co-operation between existing departments, to the end that a relatively large group of teachers, investigators, and students in a given branch of geology should be brought into close contact. To illustrate: Harvard, Massachusetts Institute of Technology, Yale, Columbia are neighbors who have geological departments of high standing. Their faculties are relatively large, the number of students small. In ordinary years the number of *bona fide* graduate students in geology is less than the number of instructors giving graduate courses in that subject. Furthermore, a student in these institutions who is specializing in a particular branch of geology receives the ideas and direction of one man. Would it not make for progress if in this group of neighboring institutions future developments were directed to the end that, for example, Harvard should stand pre-eminent in one branch of geology and Massachusetts Institute of Technology, Yale, and Columbia in other branches? Similar grouping of institutions might be made in other parts of the country. Perhaps a better scheme would be to form a single group of a dozen strong institutions covering the United States. Each institution would be under obligations to maintain a faculty, equipment, and fellowships ample for the needs of a body of advanced students and research workers in its chosen field. Some place might develop such semi-geological subjects as paleobotany and seismology, for which no adequate provision exists.

Without adopting either of these plans or disrupting existing departments, much more, I think, can be done for graduate students, and for research, by interchange of students, by interchange of information and by joint field courses.

The generous interchange of students is to my mind a matter of large importance. No institution has a monopoly of inspiring and suggestive teachers or of men who conduct significant research or men with the same code of ethics. Institutions are not uniformly equipped with library, laboratories and collections, and the geology surrounding institutions differs widely. It is highly desirable that students during their three or four years of advanced study should come into contact with a number of strong men, especially of men other than their undergraduate teachers, and that they should learn at first hand the salient geologic features of different parts of the country. No complicated machinery is necessary to provide these opportunities. Students may enroll and receive their degrees at the university of their choice and be guests or paying guests at other institutions. It would, however, involve an agreement to organize one-term courses and to make more liberal expenditure of fellowship funds, perhaps even to the extent of pooling funds now available in different institutions.

The interchange of information regarding problems in hand, of areas under investigation, and of materials collected is desirable. The duplication and wasted effort resulting from the disregard of friendly conference may be illustrated by cases which have come under my observation. Without consulting the State Geologist a student was assigned for a thesis, involving a summer's field work, a problem which was supposed to be untouched but on which two able men had spent two years and had prepared a report for the press. Another student spent a season collecting material for study and prepared an inconclusive paper, ignorant of the fact that a complete collection of material from the same locality was available in a neighboring museum. Three trained workers with no knowledge of each other's plans worked on the same problem for at least a year and reached substantially the same conclusion. One paper was published under the proper title; one was disguised and used to pad out an article on another subject; the third paper went to the waste basket. Illustrations of similar mishaps discouraging especially to young workers could be multiplied.

By co-operation, systematized field courses could be given—the lack of which constitutes a serious defect in American geologic instruction. Eleven institutions offer summer field courses regularly or intermittently, and field courses are advertised by 44 institutions. The requirement of field work is common, but makeshifts are equally common, and there is general agreement that the present situation is unsatisfactory. Not a few holders of the doctor's degree are strong in their criticism of the institution which failed to teach them methods of field investigations. A near approach to a suitable field course is an assistantship on the Federal or State surveys or employment with an oil company, where the training though valuable is offered to few men and furthermore is unsystematic and unrelated to the students' stage of advancement.

The difficulty in organizing field courses is threefold: (1) There are not enough graduates in each institution to warrant the considerable expense involved. (2) Fellowship funds are lacking. Geologic students are proverbially poor: they must make money during the long vacation. (3) Some teachers of geology unfortunately place little emphasis on systematic field work carried throughout a course. In my opinion at least two seasons of field work, summers or half years, should be required of candidates for the doctorate, and specific courses covering the work should be outlined in the catalogues. The work should be in charge of the best field teachers obtainable from any source at any price and the field should be located with regard to graded instruction. A summer field school which changes its location each year or one or more field schools open all the year are feasible. Among the less obvious advantages to students of well organized field instruction are: 1. Personal acquaintance with the minds and methods of geologists other than their own instructors. 2. Education that comes from association and competition with students of diverse types and interests. 3. Experience in working with other men and dealing with non-technical assistants—farmers, ranchmen and business men. 4. Familiarity with the classic geological literature of various parts of the country—the lack of which is much more serious than lack of acquaintance with French and German.

By co-operation, ample funds could, I think, be secured for a plan approved by a group of geological departments.

It appears that the money annually expended by educational institutions for field instruction amounts to approximately $24,000, and if the cost of training field men by the Federal and State surveys were added the figure would be much larger. Once started, the proposed field school might expect contributions from many sources. Universities and surveys and scientific societies might feel justified in supporting such a school even if not continuously used by them. About 40 institutions subscribe to the Marine Zoological Laboratory at Woods Hole. Many of them use it regularly; some rarely. A number of institutions contribute annually to the maintenance of the American School of Classical Studies at Athens and a similar school at Rome.

Geological instruction has received little attention from organizations and individuals interested in research, but to my mind it is a matter of large importance. Progress in science involves an increasing supply of thoroughly trained workers.

Yale University,
New Haven, Conn.

Art. XVIII.—*Anglesite from The Coeur d' Alene District, Idaho;* by Earl V. Shannon.

Although the Coeur d' Alene District has been a prolific source for fine crystallized lead minerals, anglesite has always, heretofore, been a rarity in the ores. In this connection, it may be well to quote Ransome[1] who, after an examination of all of the mines of the District in 1904-5, writes as follows:

"Anglesite, the sulphate of lead, has not been recognized in the District. That the galena should for the most part change to cerussite is easily understood in light of the fact that the accompanying conversion of the siderite gangue to limonite sets free an abundant carbonic anhydride which probably goes into solution, partly free and partly combined with calcium, magnesium, and where oxygen is deficient, with some iron, in the form of bicarbonates. The direct oxidation of galena should give the lead sulphate, anglesite, and in districts where the oxidizing waters are deficient in carbonates or rich in sulphuric acid or sulphates, as for example the San Juan district in Colorado, anglesite is a common alteration product of galena. Penrose states that the oxidation of the lead sulphide to sulphate is a necessary step in the formation of cerussite from galena and Emmons found at Leadville that chemical tests showed the occurrence of a thin crust of anglesite between the galena and cerussite. In the Coeur d' Alene District, however, no anglesite has been detected, the sulphide and carbonate being directly in contact. The galena, however, does not pass into compact cerussite but is replaced by loose bunches of crystals, many of which are of large size. As a rule, masses of galena in process of oxidation show irregularly etched or corroded cavities upon the walls of which are planted crystals of cerussite. It is clear that in the formation of these large free-growing crystals considerable molecular or ionic migration must have taken place, and it is quite possible that under such circumstances and in the presence of abundant carbonates in solution the anglesite may have formed and been immediately changed to cerussite, the process being such that no visible quantity of anglesite could accumulate. Even where the ore contains bunches of almost completely oxidized pyrite, as in the Last Chance mine, and where sulphates or sulphuric acid were presumably more than usually abundant, the galena, directly in contact with the porous limonite resulting from the oxidation of the pyrite, has altered to cerussite with no visible anglesite.

[1] Ransome, F. L., Geology & Ore Deposits of The Coeur d' Alene Mining District, Idaho. U. S. G. S., Prof. Paper 62, p. 132.

It is not quite clear why, under these conditions, some smithsonite or calamine has not formed from the sphalerite. The latter mineral, however, was not abundant in the ores subjected to oxidation and it is by no means certain that special chemical investigation would not reveal a corresponding small quantity of zinc in the oxidised ores.''

Since the above was written, anglesite has been identified in four mines in the district: the Highland-Surprise Mine on Pine Creek, the Last Chance and Tyler Mines at Wardner, and the Hypotheek Mine at Kingston.

Fig. 1.

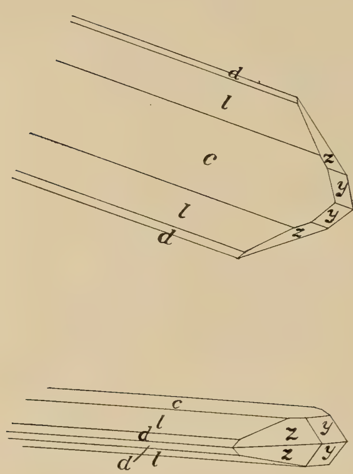
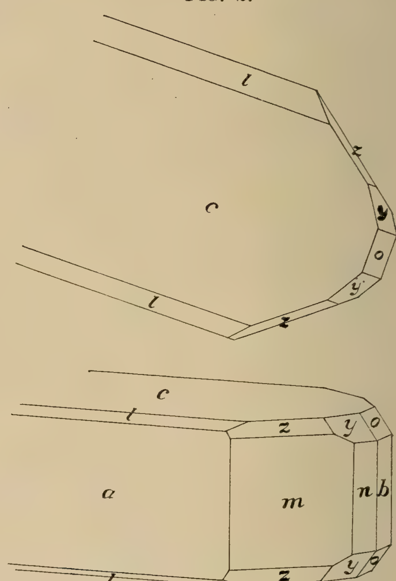


Fig. 2.



In the Highland-Chief tunnel of the Highland-Surprise mine, anglesite occurs as a compact massive ash-gray coating around lumps of galena, the anglesite in turn being coated with limonite. The mineral is similar to massive anglesite from many other western mining districts and warrants no special description.

In the Last Chance mine, prismatic crystals, elongated parallel to the *b*-axis, were occasionally found in cavities in galena. Some of these reached an extreme length of two inches, the general appearance being similar to fig. 1. These were commonly smoky gray to black from included unoxidised galena. In the adjacent Tyler mine, anglesite formerly was frequently found in cavities in galena and associated with decomposing pyrite. The notable feature of most of the crystals from this mine is their extreme simplicity, many of them simply consisting of the unit prism *m* (110) and the basal pinacoid, *c* (001); *o* (011) and *d* (102) are also seen. A common form shows notched edges due to parallel growth (*o*). A crystal now in the Brush collection showing *c, m, o,* is perfect in form and transparency and nearly half-an-inch in diameter. Frequently these crystals are coated on the prism and pinacoid faces with limonite while the dome faces are clear and brilliant.

The Hypotheek mine near Kingston has produced the finest crystals of anglesite that have been found in the state. Indeed it is doubtful whether any locality in the United States has equalled this mine in the size and beauty of its crystals. The ores of the mine are oxidized to an unusual depth and consist largely of cerussite. Large bunches of pure granular galena occur surrounded by soft ocherous material that consists mainly of oxides of iron and manganese, and contains bunches of cerussite, pyromorphite, malachite, covellite and bindheimite. It is in cavities in the residual lumps of galena that the fine anglesite crystals occur. These crystals are colorless, perfectly transparent, and exceedingly brilliant. With two exceptions the crystals obtained by the writer in September, 1916, were from a small mine car of ore beneath the surface ore bins. This ore had been shot down, shoveled into a chute, and probably handled a half-dozen times through cars and bins, yet after this prolonged abuse, the protected cavities and interiors of the lumps contained crystals equal to the finest specimens from Sardinia at present visible in American collections. In the possession of Mr. Thomas Strick, a foreman at the mine, was seen a lump of galena having a cavity several inches across, lined with ideally perfect doubly-terminated crystals an inch or more in length, having the form shown in fig. 7. Two smaller specimens from the same cavity were obtained at the time. One of these is now in the Brush Collection and the other is in the collection of Col. Roebling. In commenting upon the latter specimen, Col. Roebling writes as follows:—"Although I have at least thirty anglesites, the crystal you sent is the best of its class. . . . The Broken Hill specimens are different in habit and more orange in color . . . Yours is like those from Monte Poni, Sardinia—imbedded in galena, frequently with a black heart of unchanged galena. Occasionally there has been too much sulphur for the lead to absorb, leaving a cavity with a perfect little crystal

Fig. 3.

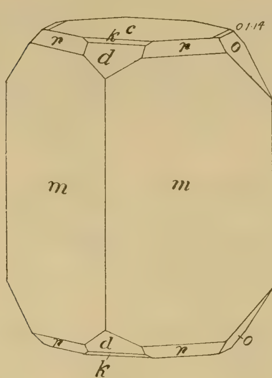
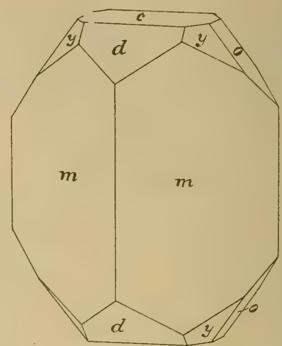


Fig. 4.



of sulphur in it." The largest crystal observed at the mine was about an inch and a half in diameter but some as large as a hen's egg are said to be frequently obtained. Cavities lined with crystals up to one half-inch in diameter occur everywhere in the galena. Where a little work with a hack saw and a light hammer would yield a

Fig. 5.

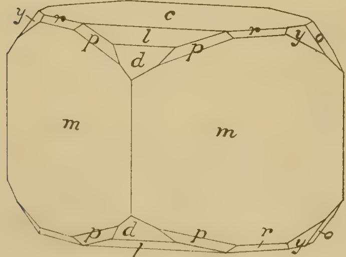
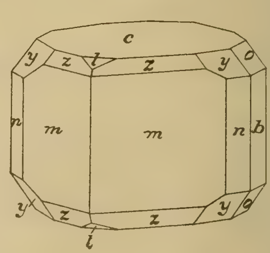


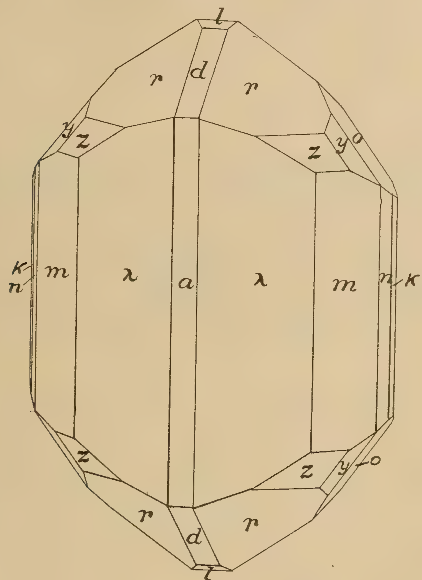
Fig. 6.



beautiful specimen, the lumps of galena are struck, by the miners, with a heavy hammer. If a fairly symmetrical group of crystals breaks out it is preserved, but when, as commonly happens, the anglesite flies to pieces or the crystals break loose from the matrix, the whole are thrown away.

The crystals from the Hypotheek mine are ideally suited for measurement on the reflecting goniometer. The accompanying figures show the predominant habits observed on the specimens obtained by the writer. As will be seen, the habit is exceedingly varied and on no two specimens are the crystals exactly alike. The most common type is that shown in fig. 7, although a number of crystals like fig. 5 were observed.

FIG. 7.



Most of the forms observed on the anglesite crystals from this mine are of common occurrence. Only two undescribed forms were seen on the crystals measured and these were represented by very narrow line faces. These are a prism (910) observed on a crystal resembling fig. 5, and a brachydome (0·1·14) shown on fig. 3.

The forms observed on ten crystals measured are listed below:

Form.	Symbol.	Times observed.
a	100	3
b	010	2
c	001	8
m	110	9
n	120	3

Form.	Symbol.	Times observed.
	130	1
	210	1
–	910	1
r	112	5
z	111	7
y	122	8
p	324	4
	221	1
l	104	6
K	106	2
d	102	7
o	011	8
–	0·1·14	1
s	132	1

The observed angles of the previously undescribed forms are compared with the calculated angles below

	Calculated.	Measured.
$0{\cdot}1{\cdot}14 : 0{\cdot}\bar{1}{\cdot}14$	10°38′	10°36′
$910 : 9\bar{1}0$	9°58′	9°40′

Springfield, Mass.

ART. XIX.—*The Proper Name for the Fossil Hydroid Beatricea;* by CHARLES SCHUCHERT.

The object of this article is in the main to point out the correct generic name for the singular late Ordovician (Richmondian) fossil long known as *Beatricea*. Doctor Plummer, of Richmond, Indiana, in 1843 described these fossils as cephalopods under the generic name *Aulacera*. In 1857 Billings published his *Beatricea* as marine algæ, while others thought that they were rugose corals most closely related to *Cystiphyllum*. In 1865, Hyatt, also unaware of Plummer's work, concluded that *Beatricea* was a cephalopod, and most closely related to *Endoceras*, but in 1885 he gave up this conclusion and then referred it to the Foraminifera. H. A. Nicholson was the first to point out its true relationship, referring it to the Stromatoporoidea in the family Labechiidæ, and this is where it is left by the specialist in these fossils, W. A. Parks.

In 1857, Billings published in the Report of Progress for the years 1853-1856, Geological Survey of Canada, the following:

> "Plantæ. Genus *Beatricea*. The above generic name is proposed for certain tree-like fossils collected in the Lower and Middle Silurian rocks of Anticosti. They consist of nearly straight stems from one to fourteen inches in diameter, perforated throughout by a cylindrical and nearly central tube, which is transversely septate. Outside of the tube, they are composed of numerous concentric layers resembling those of an exogenous tree. No traces of roots or branches have been distinctly observed. There appear to be two species, distinguishable only by the characters of the surface."
>
> These two species are *B. nodulosa* and *B. undulata*.

These fossils are now known to have a wide distribution in the higher Ordovician of Anticosti, Quebec, the Manitoulin Islands of Lake Huron, Manitoba, Ohio, Indiana, and Kentucky.

It is curious that the only fossil named by Doctor Plummer should so long have remained unnoticed, and all the more so since he described and figured in a recognizable manner these long puzzling organisms. It is true that he designated no genotype, nor did he name the species in hand, and yet his illustration shows that he had the widely distributed form described later by Billings as

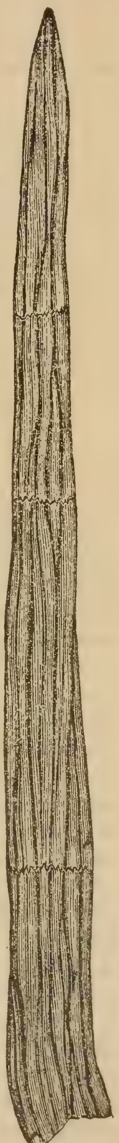
B. undulata. This, therefore, becomes the genotype of *Aulacera.* Plummer, under the caption of Univalves, speaks of

"A fossil which I venture to place here, and call for present convenience, *Aulacera.* . . . The largest species I have always found in the 'marlite'; one specimen, which as usual is not perfect, is upwards of two feet long, and another eighteen inches long; some have a diameter of but one-fourth of an inch, while the larger ones, which instead of being cylindrical are elliptical, have a long diameter of five inches and a transverse diameter of three inches. The siphuncle of these large specimens is lateral, and varies from two to two and a half inches in diameter . . .

"As none of my scientific friends, who on visiting this place, have seen it, and none who have received casts of it appear to have been acquainted with it, it is probably not common, and perhaps is new. The *Aulacera,* as I have provisionally named this fossil, is a long, somewhat cylindrical body, coarsely and unequally fluted throughout its whole length, and having a tubular cavity passing through it longitudinally. The specimen in my possession, though evidently imperfect, is about three feet in length, and tapers gently to one end, which is almost entire. The larger extremity presents a fractured surface of an oval form, two and three quarter inches by two inches in diameter. Being broken into several pieces, the fossil exhibits the large siphunculoid cavity, either filled or lined with calcareous spar, and a light colored interior, while the whole surface of the specimen is of a darkish brown and resembles an extremely thin cuticle. I have repeatedly, but in vain, sought for a multilocular structure in this probable nondescript; not the slightest indication can be detected of any kind of structure, besides what I have already mentioned, unless I may add two sharp lines which run along opposite sides of the fossil, as if they were the sutures of a long pod. The sketch [fig. 1] on the preceding page will give you a tolerable idea of its appearance. . . ."

In 1861, A. E. Verrill, N. S. Shaler, and Alpheus Hyatt, then students of Louis Agassiz, spent two months on the island of Anticosti, and among other fossils collected an abundance of *Beatricea.* One specimen is 13·5 feet long by 8·5 inches in diameter, and Hyatt estimated that the original length "was certainly not less than 20 feet." In the summer of 1908 the writer also collected on this island, and saw, many specimens of *Beatricea.* Almost all of them are prostrate in the strata, having been broken away from their basal attachments, but the latter are often seen, and some are quite large expansions, still stuck to the places where they grew. We must, therefore, always think of these fossils as attached, vertical, colonial organisms, never as free individuals, and especially not as swimming animals.

Fig. 1.



In 1865 Hyatt, having returned from the Civil War, published a paper in this Journal, entitled "Remarks on the Beatriceæ, a new Division of Mollusca." In it he says that *Beatricea* constitutes "a distinct order of cephalopods," for which he proposed the name of *Ceriolites,* being "most closely allied to the genus *Endoceras.*" We see here that he regarded their "internal vesicular structure" as of the nature of the endocones of *Endoceras.* On the other hand, Hyatt was not certain whether these fossils were internal skeletons or external shells, but upon the whole thought they were external. His view is very like the one held by Doctor Plummer much earlier, and differs only in being analyzed in far greater detail. In 1885, however, Hyatt saw that *Beatricea* was not a cephalopod and referred it to the Foraminifera.

Nicholson in 1886 referred *Beatricea* to the order Stromatoporoidea of the Hydrozoa, and this is where Parks also places it, under the family Labechiidæ.

To understand these fossils the student should also study P. E. Raymond's paper entitled "A *Beatricea*-like Organism from the Middle Ordovician." Here in the basal portion of the Mohawkian series occurs commonly *Cryptophragmus antiquatus* Raymond, and comparisons are made between it and *Beatricea.*

It is also interesting to note here that another Richmondian fossil, and one of wide distribution, known as *Girvanella richmondensis,* was described by Doctor Plummer as pisolitic concretions, the nucleus of which is often a fragment of shell (283). They occur, he says, in strata from two to ten feet in depth, and he thinks that they are of inorganic origin, being formed around shells due to carbonated waters bubbling up through the beds of deposition.

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SCIENTIFIC INTELLIGENCE.

I. Chemistry and Physics.

1. *A New Physico-chemical Method for the Determination of Alkali Carbonates in the Presence of Free Alkalies.*—Dubrisay, Tripier and Toquet have devised an analytical method which deserves particular mention on account of the fact that it appears to be a novel application of miscibility for such a purpose. They have shown that the alkaline bases augment the reciprocal coefficient of miscibility of water and phenol, while the carbonates act in the opposite direction. They prepared 2-normal solutions of both sodium hydroxide and sodium carbonate, and taking 50 cc. of these solutions, as well as various mixtures of them, together with 50 g. of phenol, they heated the resulting mixtures until they were clear and then determined the temperatures at which a turbidity appeared upon cooling. From these data a curve was drawn from which the amount of carbonate in any mixtures of this normality could be determined experimentally. Similar curves were formed for alkaline solutions of ½, ¼ and ⅛ the strength previously mentioned. It was found that the temperature of turbidity could be determined easily within about 1/10°C., so that the method is very accurate. The process was applied to the determination of carbon dioxide in chimney gas by allowing a known volume of the gas to bubble through a solution of sodium hydroxide of known strength, and applying the method for determining the amount of carbonate produced. The results thus found were very satisfactory. Similar determinations have been made by the measurement of the electric con-

ductivity of such solutions, but the method under consideration has the advantage of greater simplicity of apparatus.—*Comptes Rendus,* **168**, 26. H. L. W.

2. *The Complexity of Liquid Sulphur.*—Previous investigators have been unable to make satisfactory observations upon the surface tension of molten sulphur on account of its viscosity, but recently ALEX MITCHELL KELLAS has succeeded in overcoming the difficulty by proper purification of the material, and has determined the surface tension by means of capillary tubes from its melting-point, 115°, to its boiling-point, 445°. The purification from such impurities as sulphuric acid, sulphur dioxide and hydrogen sulphide was effected by distillation, then boiling in an atmosphere of dry nitrogen and pumping off the gases. From the results, assuming the validity of the method of calculation of Ramsay and Shields, the more mobile liquid existing between 115° and 160° is composed of S_6 molecules to the extent of at least 95%. Molecular complexity increases at about 160°, and it appears that an endothermic, trimolecular polymerization occurs near that point, forming the aggregate S_{18}, which seems to be stable up to near the boiling-point.—*Jour. Chem. Soc.* (*London*) **113**, 903. H. L. W.

3. *Beverages and their Adulteration;* by HARVEY W. WILEY. 8vo, pp. 421. Philadelphia, 1919 (P. Blakiston's Son & Co.). —This book appears to be a worthy successor of Dr. Wiley's important previous work dealing similarly with foods. It is intended for the use of the general public rather than for the scientific investigator, so that the treatment of the subject is decidedly popular, and it is a book that any reasonably educated person can read without encountering any serious technical difficulties.

The first part deals with water, the most important of beverages, discussing its varieties, pollution, purification, etc. Mineral waters are dealt with very satisfactorily in the second part, while "soft drinks," including the exceedingly important soda water, as well as ginger ale, root beer, etc., are discussed in Part III. The next four parts are devoted to fruit-juices, coffee, tea, and cocoa and chocolate, giving a great deal of interesting information about these things. The remainder of the book, comprising more than one-half of its contents, deals very fully with alcoholic beverages—wines, brewer's products, distilled liquors, cordials, and alcoholic remedies. It may be observed that, in view of the impending national prohibition, this part of the book bids fair to become of greater historical than of practical interest in this country.

There is no doubt that the book can be recommended as a source of much reliable and interesting information in regard to a subject of very great practical importance. H. L. W.

4. *Rapid Methods for the Chemical Analysis of Special Steels,*

Steel-making Alloys and Graphite; by CHARLES MORRIS JOHNSON. 8vo, pp. 437. New York (John Wiley & Sons, Inc.).—In recent times the analytical problems of steel-works chemists have become more difficult on account of the large number of elements requiring determination in their materials and products. The present book gives the methods of analysis recommended by the author as the result of extensive experience in this work. The descriptions give full details and show many points of originality and improvement on the part of the author. The second edition of the book, now under consideration, has been re-written in regard to iron and steel and its alloys, while it contains added chapters on the testing of lubricating oils, coal, iron ores, fluorspar, limestone, sand and fire-brick. In the preface to this last edition an interesting generalization is made: "If iron be combined by fusion with notable quantities of an element whose melting point is very much below that of iron, the tendency is to produce a metal of inferior physical properties, but if iron be combined with an element whose melting point is nearly that or higher than that of iron, then the tendency is to produce a metal of superior physical properties." In confirmation of this view it is a striking fact that the beneficial ingredients of steel, carbon, manganese, tungsten, vanadium, chromium, titanium, molybdenum, nickel and cobalt, all have high melting points, while the low melting sulphur, phosphorus, tin, bismuth, arsenic, antimony and even copper are harmful. The book is a particularly useful one for specialists in this branch of analytical work, but it should give useful suggestions to other analysts. H. L. W.

5. *A Practice Book in Elementary Metallurgy;* by ERNEST EDGAR THUM. 8vo, pp. 313. New York, 1917 (John Wiley & Sons, Inc.).—This book has been prepared particularly for the use of students at the Engineering College, University of Cincinnati, in connection with a course of laboratory work. Very full directions are given concerning the apparatus required for the experiments and the manner in which they are to be performed, while at the end of each group of experiments a series of questions is presented to test the student's understanding of his work and his knowledge of the subject. The course appears to have been well selected, as it embraces a large variety of important and instructive topics. It includes work with various kinds of furnaces, the measurement of high temperatures, a considerable amount of metallography, especially in connection with steel, the heat-treatment of steels, hardness, photomicrography, etc. As appendices there is a good chapter on elementary metallurgical calculations and another on foundry practice with a glossary of its technical terms, many of which, as is well known, are peculiar.

There is no doubt that the book is well suited for giving an excellent course of laboratory work. H. L. W.

6. *The Thermal Conductivity of Air.*—The specific thermal conductivity, k, of a gas is connected with the specific heat at constant volume, C', and the coefficient of viscosity, η, according to the relation $k = f\eta C'$. The value of the constant f, derived from purely theoretical considerations, varies from 1·25 to 2·5 according to the law of force assumed to act during a molecular collision. The above equation shows that if k, η, and C' could be determined experimentally, and to a sufficiently high degree of accuracy, then f could be calculated at once, and a choice between the various theoretical hypotheses might be made. Satisfactory experimental data for η and C' have been obtained, but the values of k, found for the same gas by different observers, are very discordant. For example, the value of k for dry air at 0°C. ranges from $4{\cdot}47 \times 10^{-5}$ (Eckerlein) to $5{\cdot}86 \times 10^{-5}$ (Müller), the dimensions being gram calories per cm. per sec. per degree C. The chief cause of the wide variations seems to lie in the fact that nearly all of the investigations have been carried out in such a manner as to permit convection to introduce relatively large and indeterminate errors. On the other hand, the researches of Eucken (1911 and 1913) on the *relative* thermal conductivity of a fairly large number of gases with respect to air as standard led to values which are generally accepted as accurate and reliable. It is thus evident that a redetermination of the absolute value of k for air is highly desirable.

The solution of this experimental problem has been recently undertaken by E. O. Hercus and T. H. Laby. In order to eliminate convection currents, these investigators took advantage of the method suggested by Poynting, which consists in using a horizontal layer of gas the upper plane boundary of which is maintained at a higher temperature than the lower surface. The fundamental parts of the apparatus may be briefly described as follows: There were three parallel circular discs of copper each 1 cm. thick. The middle disc, which was surrounded by a guard ring, had a diameter of 23·148 cm. The outside diameter of this ring had the same value, 30 cms., as that of the bottom and top discs. The radial width of the air gap between the central disc and the guard ring was 0·605 cm., half of this number being used in computing the effective area of the central disc, that is, 443·1 cm^2. The average distance between the central and bottom discs was 0·6280 cm. The air under investigation occupied the cylindrical space between the effective central disc and the bottom disc. The central disc and the guard ring were maintained at the same temperature (about 35° C.). The bottom disc was kept at a constant temperature, lower than that of the central disc, by the circulation of water through a spiral channel in the zinc base of the apparatus. Good thermal contact between the under surface of the bottom disc and the top of the zinc cooler was effected by an intermediate layer of Wood's metal. Heat passed through the air by conduction and radiation from the central disc to the bottom disc. Since the discs were horizontal, convection currents were absent, the density of the gas being constant in every horizontal plane and decreasing from the cool bottom disc upward to the warm central disc. All the discs consisted of two plates 0·5 cm. thick. Spiral grooves were cut in the upper surfaces of the lower halves of the discs so that the insulated manganin heating-coils and the constantan thermo-couple wires could be embedded in paraffin before the plates were assembled. The object in the top disc—which was kept at a temperature slightly higher than that of the central disc—was to minimize the net passage of heat from the upper surface of the central disc. All of the surfaces were silver plated and highly polished. All sources of error were thoroughly investigated and the corresponding corrections were so obtained as to give an accuracy of one part in 500 in the final value of k. The formula representing the exchanges of heat may be written

$$E^2/R = kS(\theta_2 - \theta_1)/x + R' + C(d\theta/dt) + L,$$

where E^2/R = energy supplied electrically per second to the central disc, S = effective area of central disc, θ_2 = temperature of this disc, θ_1 = temperature of bottom disc, x = distance between central and bottom discs, $kS(\theta_2 - \theta_1)/x$ = heat passing per second by conduction from the central disc to the bottom one, R' = heat transferred by radiation from the central disc, $C(d\theta/dt)$ = heat absorbed per unit time by this disc if its temperature changes with time, and L = heat passing from the central disc to the top disc and to the guard ring.

The final value of k, for 22°C., is given as $5{\cdot}74 \times 10^{-5}$ C.G.S. units. Assuming that the relation $k_\theta = k_o(1 + \gamma\theta)$ holds, and taking $\gamma = 0{\cdot}0029$ $(1°\text{C.})^{-1}$, the specific thermal conductivity of dry air at 0° C. is found to be $k_o = 5{\cdot}40 \times 10^{-5}$. By weighting the values of k_o derived from the present and thirteen earlier investigations, the mean value comes out as $5{\cdot}22 \times 10^{-5}$ cal./(cm. sec. deg.). The average departure from this mean is 0·38 or 7 per cent., showing that the agreement between different observers is very poor. Nevertheless the average of the nine results obtained by the "cooling method" is 5·24, of the three by the "hot-wire method" is 5·26, and of the two by Poynting's method is 5·18; hence the general weighted mean given above is probably fairly close to the true value.

The last part of the paper deals with the constant f. The necessary numerical data from many sources have been collected, properly weighted, and, apparently for the first time, presented in a single table. The numbers following the symbols for the gases are the newly computed values of f: He 2·31, A 2·47; H_2 1·76, N_2 1·76, O_2 1·79, air 1·76, NO 1·73, CO 1·72; CO_2 1·45, N_2O 1·47, H_2S 1·34, SO_2 1·35; Cl_2 1·50, NH_3 1·23, CH_4 1·45, C_2H_4 1·27. Finally, it was found that $f = 2{\cdot}816\gamma - 2{\cdot}2$, i. e. f

is a linear function of γ, the ratio of the specific heat at constant pressure to that at constant volume.—*Proc. Roy. Soc.*, **95** A, 190, 1919. H. S. U.

7. *Absorption of X-Rays.*—It has been found by Bragg and Pierce that the atomic absorption coefficient for X-rays is equal to $CN^4\lambda^{\frac{5}{2}}$, where N = atomic number of absorber, λ = wavelength, and C = a coefficient that is constant over ranges outside the region of selective absorption. "The atomic absorption coefficient expresses the proportion of the energy of an X-ray pencil which is absorbed in crossing a surface on which lies one atom to every square centimetre." The ordinary mass absorption coefficient can be calculated from this quantity by dividing it by the mass of the absorbing atom. The more recent work of Auren on a fairly large number of solutions led to the conclusion that the atomic absorption coefficient is not proportional to the fourth power of the atomic number, but that the elements may be divided into groups, for each of which the atomic absorption coefficient is directly proportional to the atomic number. The cause of the lack of agreement between the results just stated has been successfully investigated by E. A. Owen.

This experimenter began by determining the values of μ/ρ for filter paper, water, magnesium, aluminium, nickel, copper, and zinc. The data obtained showed excellent agreement with the values derived from the work of Bragg and Pierce, and of Hull and Rice. Having thus obtained reliable mean values of μ/ρ Owen brought order out of chaos by the following considerations.

The total absorption coefficient is equal to the sum of the fluorescent absorption coefficient and the scattering absorption coefficient, or, in customary notation, $\mu/\rho = \tau/\rho + \sigma/\rho$. It is shown that, for elements having atomic numbers less than (and equal to) that of bromine, the scattering coefficient σ/ρ has the constant value 0·2. The fluorescent coefficient τ/ρ, when due allowance for scattering has been made, comes out approximately equal to $C'N^3$. Greater accuracy is given by the relation that the atomic fluorescent absorption coefficient equals CN^4. Owen then calculates the molecular total absorption coefficient relative to water for thirty-three of the solutions which had been studied by Auren. The table shows practically perfect agreement between the numbers computed by Owen and the data obtained experimentally by Auren. The formula for the atomic fluorescent absorption coefficient is $f_a = CN^4\lambda^3$. "This relation is independent of the scattering coefficient; it deals only with the loss of energy of X-radiation by the production of corpuscular radiations and the fluorescent X-radiations that accompany them." It may be remarked incidentally that the recalculation by Owen of Aurēn's data involved the following hypothesis: "The molecular total absorption coefficient of a complex molecule is additively determined from the atomic total absorption coefficients of its constituent atoms.'' The excellent agreement obtained indicates that this additive property must be quite exact for elements from hydrogen to bromine.—*Proc. Roy. Soc.,* **94** A, 510, 1918.

H. S. U.

8. *The Nature of Sun-Spots.*—A recent paper (in abstract form) by G. E. HALE contains an interesting summary of the most important results obtained from three lines of experimental attack which were begun at the Kenwood Observatory in 1891 and which have been continued at the Yerkes and Mount Wilson Observatories.

It has been found that the spectral lines in sun-spots are split into components and polarized in precisely the same manner as in laboratory experiments on the Zeeman effect. Accordingly, the evidence that sun-spots are electric vortices is very strong. ''The magnetic polarities and field-strengths of all sun-spots are now recorded daily at Mount Wilson with a 150-foot tower telescope, affording data for the determination of the law of solar storms.'' A large proportion of all sun-spots are double, the two members exhibiting opposite magnetic polarity. The preceding members of such pairs in the northern and southern solar hemispheres are of opposite polarity, indicating opposite directions of whirls, as in terrestrial cyclones. A comparison of the polarities of spots preceding the sun-spot minimum, which occurred in 1912, with those of spots studied after this mimimum, shows that the polarity of homologous spots of groups in the same hemisphere has been reversed. ''Thus the polarities seem to be intimately connected with the cause of the sun-spot cycle.'' Investigations of the Zeeman effect in sun-spots give the direction of the lines of force of the magnetic field, and hence also of that of the axis of the electric vortex. This axis is found to be approximately normal to the sun's surface. A fruitful guide in the study of sun-spots has been the working hypothesis that the oppositely polarized doublets represent the extremities of semi-circular vortex rings, extending beneath the photosphere and lying in planes normal to the general solar surface. ''A search for direct evidence of the existence of electric fields in the sun has hitherto yielded negative results.''—*Proc. Roy. Soc.,* **95** A, 234, 1919.

H. S. U.

9. *Surface Tension and Surface Energy and Their Influence on Chemical Phenomena, Second Edition;* by R. S. WILLOWS and E. HATSCHEK. Pp. viii, 115. Philadelphia, 1919 (P. Blakiston's Son & Co.).—''The object of the work is to give the student of chemistry an adequate idea of the fundamental laws of surface tension and surface energy . . . and then to deal at some length with the relations between surface energy and such constants and phenomena as are likely to be of interest to the chemist and biologist.'' The second edition has been very appre-

ciably enlarged as compared with the first. An entire chapter has been added in which many complex phenomena of great technical importance are discussed. The additional matter includes Whittaker's work on the relation between surface energy and internal latent heat, a summary of recent theories on the structure and properties of metals, Ferguson's equation connecting surface tension and absolute temperature, a number of short paragraphs on adsorption, etc. Certain mathematical proofs are given in two appendixes which are followed by both author and subject indexes.

The manner of presentation is simple and clear, and the text should be useful to students of colloidal chemistry and of biology. There is, however, much room for improvement in two respects, (*a*) the units involved are, in some cases, incorrect in the sense of being incomplete, and (*b*) the number of typographical errors is excessively large for a second edition. H. S. U.

II. Geology.

1. *Líneas generales de la estratigrafía del Neocomiano en la Cordillera Argentina;* por Anselmo Windhausen. Bol. Acad. Nac. de Ciencias de Córdoba, vol. **23**, pp. 97-128. Buenos Aires, 1918.—The Lower Cretaceous faunas and deposits of southern South America have long been of interest to geologists. Darwin when on the voyage of the Beagle collected a few fossils of that age near the Strait of Magellan, and since that time scientific travelers and explorers have proved that the Lower Cretaceous is well developed in the Argentine Cordillera and distributed through many degrees of latitude. The collections thus accumulated have furnished material for many descriptive papers by Behrendsen, Steuer, Burckhardt, Stanton, Favre, Douvillé, Stolley, and others, and for discussions of the general relations of the fauna by Uhlig, Burckhardt, and others. These collections were usually small and obtained at widely separated localities, with insufficient study of local stratigraphy and usually no study of intervening areas. Even such fragmentary studies in connection with Burckhardt's work in Mexico brought out resemblances in Upper Jurassic and Lower Cretaceous faunas which led Uhlig to speak of a "south Andean realm" extending from northern Mexico to the southern point of South America and even to South Africa, because what he called the "austral fauna of Trigonias" is found in all these regions.

During the last few years the government of Argentina through its "Direccion general de Minas, Geologia e Hidrologia" has been carrying on more systematic investigations in the cordillera of Mendoza and Neuquen (S. lat. 32°-41°) in connection with which Windhausen is preparing a monograph of the Neocomian cephalopod fauna—especially the Upper Neocomian.

The present paper is a preliminary statement of his conclusions concerning the stratigraphy, correlation, and general faunal relations of the Lower Cretaceous of Argentina, issued in advance of the complete monograph, which may be delayed in publication. It should be noted in passing that Windhausen uses the term

Stratigraphic Summary of the Neocomian in the Argentine Cordillera

	Northern region (neritic facies)	Southern region (bathyal facies)
Aptian	Variegated sandstones	Variegated sandstones (Discordance) Strata with Ancyloceras patagonianus Stoll., Silesites desmoceratoides Stoll., Neohibolites cf. semicanaliculatus Blainv.
	Partial discordance	
Barremian	Gypsum deposits, in part replaced by ferruginous sandstones Dolomitic beds and layers Calcareous beds Zone of Holcodiscus gastaldianus (d'Orb.)	Slates with Ancyloceras cf. simplex d'Orb. in Brunswick Peninsula ? Strata with Crioceras deeckei Favre and C. sarasini Favre
Hauterivian	Zone of the aff. Spitidiscus, Desmoceras, and Lytoceras Zone of Kilianella pseudoregalis (Burckh.) and Acanthodiscus radiatus (Brug.) Barren littoral or continental deposits S. of Lat. 38° (Pilmatué, Covunco, and Cerro Lotena Facies (of bivalves and gastropods. (Southern Trigonia fauna)	Belgrano beds with bivalves and gastropods ? Belgrano beds with Hatchericeras
Valanginian	Zone of Astieria Zone of Thurmannia cf. boissieri (Pictet) Zone of Steueroceras transgrediens (Steuer) Zone of Neocomites and Acanthodiscus Zone of Spiticeras damesi (Steuer)	? ? Strata with ammonites of the group of Steueroceras wilckensi (Favre) Strata with Steueroceras (Leopoldia) belgranensis (Favre)
Beriasian	Zone of Beriasella fraudans (Steuer) Zone of Steueroceras koeneni (Steuer) Zone of Beriasella calistoides (Behr.) Zone of Beriasella koellikeri (Opp.) and B. mendozana (Behr.)	Strata with Beriasella (Leopoldia) paynensis (Favre) Strata with Beriasella patagoniensis Favre (Transition beds)
Upper Tithonian	Zone of Aspidoceras steinmanni Haupt and Aulacosphinctes colubrinoides Burckh.	Strata with Streblites patagoniensis (Favre) and Himalayites hoplerhillensis (Favre) Mayer River beds Hatcher | Porphyritic tuffs Hauthal

Neocomian in a broad sense to cover everything from the Beriasian to the Aptian inclusive, so that it is practically synonymous with Lower Cretaceous.

The Lower Cretaceous of the Argentine Cordillera is found in two separate areas which show distinct characteristics. The northern area, which has been more thoroughly studied, is in the provinces of Mendoza and Neuquen where a belt of Lower Cretaceous rocks extends almost without interruption from the neighborhood of Espinazito and Aconcagua to the Collón Curá River, or S. lat. 32° to 41°. The southern area, in which fossiliferous rocks of Lower Cretaceous age are known at scattered localities, extends from Lake Pueyrredon to Terra del Fuego, or about S. lat. 47° 30′ to 54°. Little is known about the stretch of over 400 miles between these two areas but there are reasons for believing that Lower Cretaceous deposits are lacking there.

The faunas of the two areas mentioned appear to have no species in common, though the genera represented, especially among the pelecypods, are largely the same in both. Windhausen believes that the same general divisions of the Lower Cretaceous are present in both areas and attributes the differences in faunal facies to differences in depth, classifying the northern region as neritic facies and the southern region as bathyal facies. He presents the stratigraphy of the northern region and the tentative correlation and stratigraphic succession of the southern region in the accompanying table.

The stratigraphic position of the Belgrano beds, which are found in the neighborhood of Lake Pueyrredon, is conjectural because their characteristic ammonite genus, *Hatchericeras,* is not known outside of the southern area.

The author discusses in some detail the ammonite faunas of the different divisions of the Neocomian and points out the importance of the southern Trigonia fauna, or "fauna of bivalves and gastropods," which includes forms similar to those found in the Malone formation of Texas and in the Uitenhage formation of South Africa. Concerning the south Andean Lower Cretaceous fauna as a whole, he finds that its closest relationship is with the faunas of the Mediterranean-Caucasian and Himalayan region which Haug has combined under the term equatorial fauna. He questions the identification by R. Douvillé and others of true boreal types in the Argentine Lower Cretaceous but sees independent (autochthonous) elements in such forms as *Steuerocerus, Beriasella, Hatchericeras,* and others which with additional evidence from future investigations may justify the recognition of an austral faunal province. These independent elements may have developed off the northern coasts of Archinotis, as Ihering has named the ancient Antarctic continent. The coasts of Archinotis may likewise have been the route of migration connecting the southern parts of the earth and thus aiding in the interchange of faunas between the Himalayan and south Andean regions during the Tithonian and Neocomian.

T. W. STANTON.

2. *The Permo-Carboniferous Ammonoids of the Glass Mountains, West Texas, and their stratigraphical Significance;* by EMIL BÖSE. Univ. of Texas, Bull. **1762,** pp. 241, 11 pls.—The date of this publication is given as November 5, 1917, evidently to comply with the postal laws, yet we note a date on the inside

of the back cover as recent as January 1919. The author completed the writing of the report in August 1918, and the book was received at New Haven February 10, 1919. In a previous notice we called attention to this matter of antedating by the Texas Survey, and yet it goes on without reform.

The present memoir is of great importance in stratigraphy and paleontology in that it describes sixteen genera (new ones being *Perrinites, Uddenites, Prothalassoceras, Marathonites, Vidrioceras*) and twenty-eight new species of Permian ammonites. It is the result of an important paleontologic discovery, and the author makes full use of his great find, discussing the fossils not only in respect to their evolution and faunal interrelations, but their significance in stratigraphy as well. His correlations have to do both with the fixing of the strata in the Permian system and the synchronizing throughout the world of the Texas formations that yield ammonites. Clearly there is in Texas a well developed Lower Permian system.

The more ancient of these ammonites are the oldest known Permo-Carboniferous forms. Aside from the cephalopods, the fauna has many species with ''decidedly Pennsylvanian characters,'' but these fossils are not treated in this work. Böse's chief stratigraphic results in tabular form are as follows:

Permian system

(1) Thuringian, and (2) Saxonian series. Not present in America. The Bellerophon limestone of the Alps and the Hungarites-Otoceras beds of Armenia are of Thuringian time. The Chideru group and the Upper Productus limestone of India, along with a part of the Virgal group and the Middle Productus limestone, equal the Thuringian and Saxonian.

Upper Permo-Carboniferous series, or Upper Artinskian. At the top of the Texas section occur the Tessey, Gilliam and Vidrio formations, devoid of ammonites, and equivalent to the Capitan limestone of Texas. Below these comes the Word formation, or zone of *Waagenoceras,* having also *Medlicottia, Gastrioceras* (2 spp.), *Paraceltites* (2), *Agathiceras, Adrianites,* and *Stacheoceras* (2), and correlated with the Delaware division of Texas, the Sosio beds of Sicily, and the Amb and Lower Productus limestones of India.

Leonard formation, or zone of *Perrinites* (2), having also *Medlicottia, Gastrioceras,* and *Paralecanites,* and correlated with the Double Mountain and Clear Fork divisions, and with the upper part of the Hueco series of Texas.

Lower Permo-Carboniferous series, or Lower Artinskian. Hess limestone, or zone of *Prothalassoceras* and *Marathonites.* Also correlated with the Wichita and Albany formations of central Texas. Then follows an unconformity, below which is the Wolfcamp formation, or zone of *Uddenites* (2), having also

Daraelites, Gastrioceras, Schistoceras, Paralegoceras, Agathiceras, Marathonites (3), and *Vidrioceras* (2).

Pennsylvanian system

Cisco formation. There appears to be no physical break with the Permian. C. S.

3. *Lower Cretaceous age of the limestones underlying Florida;* by JOSEPH A. CUSHMAN. Jour. Washington Acad. Sci., **9**, pp. 70-73, 1919.—On the basis of Foraminifera brought up in deep-well borings, the author shows that the later Eocene rests directly upon middle Comanchian formations. These Comanchian deposits are apparently the floor for the Cenozoic of the entire peninsula of Florida. There appears to be no Cretaceous present. The paper is therefore very significant in paleogeography. C. S.

4. *A fossil Isopod belonging to the freshwater genus Phreatoicus;* by CHAS. CHILTON. Proc. Roy Soc. N. S. Wales, **51**, pp. 365-388, 13 text figs., 1918.—The author described in 1883 a subterranean primitive isopod living in New Zealand, giving it the name of *Phreatoicus typicus,* and now he describes a new fossil form of this genus from the Upper Triassic of Newtown, New South Wales. In Tasmania, *Phreatoicus* lives in the same fresh waters with the other primitive shrimps, *Anaspides* and *Paranaspides,* and they are nearly related to *Palæocaris* of the Paleozoic. For this group Calman has erected the name Syncarida. Chilton says: "*Anaspides, Paranaspides* and *Koonunga* are the living representatives of a primitive and generalized group of Crustacea, the Syncarida, and similarly the members of the Phreatoicidea, a primitive group of Isopoda, have continued to exist in the fresh waters of Australia, Tasmania, New Zealand and South Africa from early Secondary times."

It seems that the radiation of these forms was from the northern hemisphere into the terminal continents of the southern hemisphere before Mesozoic time, and in these asylums they have been preserved ever since. C. S.

5. *Triassic insects of Australia.*—Many years ago some insects were found at Denmark Hill, Ipswich, Queensland, but their abundance and great significance remained undiscerned until recently. Mr. R. J. Tillyard, an English entomologist now resident in Australia, has taken up the study of these specimens and, due to this stimulus, Government Geologist B. Dunstan has reworked the original insect-bearing beds, and now more than 230 specimens are available. "Most of these, however, are either coleopterous elytra, blattoid tegmina, or fragments of wings that do not merit a name; so that the number of recognisable new forms will be very much smaller." Even so, the kinds are many times more than all the other Triassic insects of the northern hemisphere. The horizon is Upper Triassic. This is, then, the

grandest vista we have of Triassic insects. Some of the specimens are described in publication 253 of the Queensland Geological Survey and in several papers published in the Proceedings of the Linnean Society of New South Wales for 1917 and 1918. Nearly all the species and most of the genera are of course new to science, and there are even new orders described.

Some of the most interesting material has now been discussed. The commonest forms are Coleoptera, of which 14 forms are named. Of Blattoidea there is 1 species, Protorthoptera 2, Protodonata 1, Odonata 3, Mecoptera 1, Prothemiptera 1, Hemiptera 4, Neuroptera 1, Trichoptera 2, and Protomecoptera 1. The oldest known dragon-fly is here named *Mesophlebia antinodalis*. The panorpid *Mesochorista proavita* stock has lived on until to-day almost unchanged, and is a relic just as is *Ceratodus* among the fishes.

The author remarks that *Austromylacrites* and *Mesogereon* "are little removed from certain Carboniferous and Permian insects of the northern hemisphere. Others are scarcely distinguishable from forms existing in Queensland at the present day." "The Ipswich fossils show that it was the same in Australia in the Trias as it is to-day, and that the Australian fauna then, as now, combined numerous archaic types with certain highly specialized forms peculiar to the continent." Upon the whole, the Ipswich Triassic insects are more specialized than those of the Paleozoic and more archaic than those of the lower Lias.

These Triassic insects are of fair size, and some are even large, but in the clay pits of Jurassic age at St. Peter's, near Sydney, New South Wales, the fossil insects are much larger. From this locality Tillyard describes, among others, a protorthopterid, *Mesotitan giganteus,* about 20 inches across the wings, and seemingly related to the largest of all known insects, from the Coal Measures of Commentry, France. C. S.

6. *Notes on the Geology of Rhode Island;* by A C. HAWKINS; *Correction.*—The paper upon the above subject, published in this Journal for August, 1918, pp. 437-472, represented a summary of a thesis submitted to the Faculty of Brown University in partial fulfillment of the requirements for the degree of Doctor of Philosophy 1916. Reference to this fact should have been made in connection with the article, but was omitted through an oversight. A. C. HAWKINS.

III. MISCELLANEOUS SCIENTIFIC INTELLIGENCE.

1. *National Academy of Sciences.*—The annual meeting of the National Academy of Sciences will be held at the Smithsonian Institution in Washington on April 28, 29, and 30. Members are invited to present brief announcements, not exceeding ten minutes in length, of new discoveries and of the results of cur-

rent research work, somewhat similar in scope and character to the announcements regularly made in the Proceedings. Titles, accompanied by an abstract of 100 or 200 words, should be sent to the Chairman of the program committee, Dr. J. C. Merriam. In addition to the usual Scientific Sessions, the programs for which will be published later, it is stated that two William Ellery Hale lectures will be delivered by James Henry Breasted, professor of Egyptology and Oriental History in the University of Chicago. The general subject is the Origin of Civilization, and the first covers the period from the Old Stone Age to the dawn of civilization; the second carries the subject on to the transition of civilization in Europe.

2. *The Elements of Animal Biology;* by S. J. Holmes. Pp. x, 402, with 249 illustrations. Philadelphia, 1919 (P. Blakiston's Son & Co.).—The first half of this well-written text-book for high school pupils consists of the natural history of the various groups of animals presented in such a way as to give the reader a comprehensive survey of the animal kingdom. The second part is devoted to the elements of physiology, with a chapter on bacteria and disease, while the third part deals with reproduction, adaptation and evolution, with a final, and very important, chapter on heredity and human improvement.

The book will adequately supply the needs of those high school teachers who find it necessary to divide the work in biology into distinct courses dealing separately with plants and animals.

W. R. C.

3. *Tables and other Data for Engineers and Business Men;* compiled by Professor Charles E. Ferris. Pp. 230. Knoxville, Tenn. (The University Press; price fifty cents.)—This little vest-pocket manual has now gone through twenty-two editions, which fact alone is sufficient evidence of the general appreciation of its value to those for whom it has been prepared. Aside from the usefulness of the many tables included, repeatedly revised and extended, it is interesting to note that the compiler has had in view in its preparation "the desire to promote technical education in the South as a means of developing its undeveloped resources."

4. *Annual Report of the Superintendent, United States Coast and Geodetic Survey,* for the year ending June 30, 1918. R. L. Faris, *Acting Superintendent.* Pp. 133, with 37 illustrations, chiefly folded maps, Washington, 1918.—In addition to the usual extended routine work, the Survey, with other national organizations, has been called upon to do a large amount of work connected with the recent war. It is significant that seventy per cent of the personnel were so engaged, while thirty per cent were on active duty with the Army and Navy.

5. *De Wijsbegeerte der Wiskunde van theïstisch Standpunt;* by H. Th. Vollenhoven. Pp. xv, 444. Amsterdam, 1918

(Wed. van Soest).—This dissertation, presented to the Faculty of the Free University of Amsterdam in candidacy for the degree of Doctor of Philosophy, has for its other object to prove that Christian theïsm requires in the study of mathematics an intuitionistic standpoint, which ranks it as a symptom of the tendency among a group of modern mathematicians to metaphysical speculation. In his preface the author defines his position by calling theïsm the ideal philosophy ordained by God and therefore the pre-eminent one to become proficient in. To make the drift of his argument perfectly clear, he undertakes furthermore to emendate, by way of conclusion, the Augustinian query, "*Quid Deus est tempus?*" proposing as a happier expression of its imminent thought, "*Quid Deus est successio?*" One feels tempted to counter his effort with a quotation, from the Pelagian controversy: *Causa finita est.* J. F. S.

6. *A Century of Science in America.* New Haven, Conn. (Yale University Press.) *Correction.*—In the statement in regard to the reproduction of the Willard portrait of Benjamin Silliman on p. 58 of *A Century of Science in America,* the reference to the "Lowell lectures" has been shown to be a mistake. Silliman lectured in Boston and *Lowell,* Mass., in 1835, at the time the Willard portrait was painted, but the "Lowell lectures" were not opened until several years later (1839) by Edward Everett. The same erroneous statement is made on p. 44 of the Centennial number of this Journal for July, 1918. The editor is indebted to Professor W. T. Sedgwick of Cambridge for the opportunity to make this correction.

7. *All-American Time*—In a recent publication of the University of Cincinnati, the director, Dr. Jermain G. Porter, proposes a new *uniform time-system* for this country with the ninetieth meridian as the standard; this method has some obvious advantages over that now in use. Briefly stated, a uniform time for the whole country would be gained by establishing the time of *legal noon* for the different zones. If half-hour zones were adopted, legal noon would everywhere fall between 11:30 and 12:00 o'clock solar time.

The daylight saving plan could be adapted to this system by shifting the time of legal noon half an hour earlier in summer.

It is added that the hours, beginning at midnight, should be counted up to twenty-four.

The Cincinnati Observatory has also recently issued Part IV of No. 18 of *The Catalogue of Proper Motion Stars* by Jermain G. Porter, Director, and E. I. Yowell, first astronomer, and Elliott Smith, second astronomer. This final part of No. 18 gives the collected results as derived in Parts I, II and III. The corrections indicated in the errata in II, III and IV have been applied.

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[FOURTH SERIES.]

Art. XX.—*The Hydrated Ferric Oxides;*[1] by Eugen Posnjak and H. E. Merwin.

Contents.

Introduction.

Our knowledge of the hydrated oxides of iron, notwithstanding the extended number of publications on this subject, is still very meager. Of the large number of supposed hydrated oxides to which at one time or another definite compositions have been assigned, the text-books usually describe the following series as minerals:

Turgite	$Fe_2O_3 \cdot \frac{1}{2} H_2O$
Goethite and lepidocrocite	$Fe_2O_3 \cdot H_2O$
Hydrogoethite	$Fe_2O_3 \cdot 4/3 H_2O$
Limonite	$Fe_2O_3 \cdot 3/2 H_2O$
Xanthosiderite	$Fe_2O_3 \cdot 2 H_2O$
Limnite	$Fe_2O_3 \cdot 3 H_2O$

Of these goethite alone has been well defined physically and chemically. Descriptions of lepidocrocite (rubinglimmer) leave a doubt as to its identity with goethite,

[1] This work was begun in connection with the secondary enrichment investigation pursued by this Laboratory in 1913-1915 in co-operation with Professor L. C. Graton and his colleagues.

although Lacroix[2] makes a definite optical distinction. Hydrogoethite has been supposed to contain more water than goethite but in its optical properties is said to be similar to lepidocrocite. The other names in the list have been given because of certain indefinite physical differences associated with plausible but not well established chemical formulas.

Below we have attempted to bring together the significant results of synthetic chemical work already done on the hydrated ferric oxides.

Work previously done.

Early investigations were brought to a conclusion by Tomasi[3] who summarized the synthetic researches of his predecessors and his own by classifying the hydrated ferric oxides in accordance with their color in two series, differing in their properties: the red and the yellow hydrates. For each series a number of definite hydrates and their methods of preparation were described. Generally, according to Tomasi, the red hydrates were formed by precipitation of ferric salts with alkalies, while the yellow hydrates were produced by oxidation of ferrous oxide or carbonate.

More recently, van Bemmelen[4] investigated such synthetic hydrated ferric oxides in respect to their water content. He came to the conclusion that the reddish-brown substance is a colloid and not a hydrate (or hydrates) as previously described. This substance he says "may undergo various changes and therefore has no definite composition but always comes to an equilibrium depending upon the surrounding vapor tension." The yellow substance is also a colloid. However, "it is not a variety of the brownish-red substance, since it is from the time of its formation in a denser and more stable, though variable condition." He found that between 50° and 200° the yellow colloid retains its water much more tenaciously than the brownish-red, but above 200° both colloids attain the same composition and become identical.[5]

[2] Minéralogie de la France, 3, 360.

[3] Ricerche sulle formule de constituzione dei compositi ferrici, Florence, 1879; Ber. deutsch. chem. Ges., 12, 1929, 2334, 1879.

[4] Van Bemmelen's collected papers, published under the title, "Die Absorption," pp. 70-77.

[5] In a later paper (Zs. anorg. Chem., 20, 185, 1899; Die Absorption, p. 370), which deals with the hydration and dehydration of the reddish-brown

In another paper[6] van Bemmelen tried to verify statements found in the literature dealing with the preparation of crystallized ferric hydrates. He proved all of them to be erroneous, though he claimed to have prepared a crystallized ferric oxide monohydrate. It was formed when hexagonal plates of sodium ferrite were leached with water at 15°. His belief that a true hydrate was formed is based on the fact that this substitution did neither destroy the form nor the transparency of these crystals and that they were not hygroscopic. However, he found that they begin to decompose and lose their water below 100°, while the known natural hydrated ferric oxides are apparently perfectly stable at that temperature. Retention of transparency in cases of pseudomorphism are well known and it seems quite evident, therefore, that his crystals were not crystals of a definite hydrate but were pseudomorphs.

In view of the insufficiency of previously used methods to produce the hydrates of ferric oxide, O. Ruff[7] determined to employ high pressure for that purpose. This, according to him, gave the desired results for "the red colloid immersed in water changed in the course of a few days under pressure, and a temperature of 30-42·5°, into the yellow hydrate $2Fe_2O_3{\cdot}3H_2O$ corresponding to limonite; above 42·5° and up to 62·5° into the yellowish-red hydrate $Fe_2O_3{\cdot}H_2O$ corresponding to goethite, and above 62·5° into the brick-red hydrate $Fe_2O_3{\cdot}\frac{1}{2}H_2O$ corresponding to turgite. The upper temperature limit of stability for the latter was not discovered." These products according to Ruff were so fine-grained that even under a magnification of 600 times, crystallinity could not be rec-

substance, van Bemmelen apparently changed his opinion, as he describes the yellow colloid belonging to the same class as the reddish-brown: "das gelbe, wasserhaltige Eisenoxyd . . . bindet das Wasser etwas staerker als das braunrote gel . . . muss jedoch diesen zugezaehlt werden." Only in the first-mentioned paper did van Bemmelen investigate the yellow substance and even then most of his attention is given to the reddish-brown substance. This statement is, therefore, based not on new facts but rather, we think, on his conception of colloids defined by him as follows: "Ich betrachte die kolloiden Verbindungen der Elemente, Oxyde, Sulfide, Salze u. s. w. mit Wasser nicht als chemisch bestimmte Individuen, sondern als unbestimmte Verbindungen in einem besonderen Aggregatzustand." (Die Absorption, p. 38.) This definition of colloids does not agree with our present knowledge; however, the fact stands, and is of interest, that van Bemmelen found certain differences in the properties of the brownish-red and yellow hydrated ferric oxides, although he was unwilling to give them sufficient consideration.

[6] Die Absorption, p. 145; Journ. f. prakt. Ch. N. F. **46**, 497, 1892.

[7] Ber. deutsch. chem. Ges., **34**, 3417, 1901.

ognized. The compositions of these products, however, agreed remarkably well with the formulas given for hydrates of ferric oxide, and the density determined upon this material was almost exactly as given in text-books for the corresponding minerals. The yellow colloid did not change under the pressure applied by Ruff in the temperature interval of 40-70° and he therefore assumes that it is "not a colloid but a true hydrate" which he suspects is xanthosiderite. But specimens of the two hydrated mineral ferric oxides, investigated under similar conditions,—"limonite" at a temperature of 70-75° and turgite at 40-50°,—did not show any change whatsoever (turgite and "limonite," respectively, should be formed if the two foregoing stability relations were true). This, however, did not deter Ruff from assuming that the problems of composition and the stability relations of the hydrated ferric oxides were thus satisfactorily solved, and he discusses on that basis the formation of natural deposits.[8]

Another investigation was undertaken by H. W. Fischer.[9] By hydrolyzing ferric chloride solutions he came to the conclusion that at least three entirely different substances exist among the colloidal hydrated ferric oxides: the yellow, reddish-black and van Bemmelen's reddish-brown colloids.[10] Now Fischer found that limonite has a characteristic dehydration curve; water is lost rapidly below 100°, then sparingly, although continuously, up to about 165°; above that temperature the loss is very large and is accompanied by a change in color from yellow to red. Just before the substance is heated above 165° it has approximately 1 mol. of water. This behavior of limonite corresponds, according to Fischer, to that of a colloidal hydrate,[11] and as the synthetic yellow colloid shows a similar dehydration curve he concludes that they are identical. The reddish-black colloid he thinks is identical with hematite and the reddish-brown colloid he believes (no experiments made) is identical

[8] As a result of the present investigation the "data" presented by Ruff concerning the compositions and densities of the hydrated ferric oxides can only be considered accidental.

[9] Zs. anorg. Chem., 66, 37, 1910.

[10] Fischer defines colloids as "chemical individuals whose total energy depends besides the variables of state (Zustandsvariablen) on an additive quantity K, which may be interpreted as a function of time."

[11] Hintze, in his "Handbuch der Mineralogie," vol. 1 (2), p. 2008, draws the conclusion that limonite is the colloidal form of goethite.

with the substance of the composition $2Fe_2O_3 \cdot 3H_2O$ prepared under pressure by Ruff,[12] which however he thinks is unstable and therefore does not occur as a mineral. Among the minerals he doubts the existence of xanthosiderite and believes turgite to be a dehydrated limonite.

As seen from this short review little definite knowledge exists in respect to any of the hydrated ferric oxides. except goethite, and many contradictory conclusions have been drawn. Chemically as well as mineralogically the problem presents many difficulties and up to the present apparently no systematic investigation had been undertaken involving the *correlation of different properties.* In view of the abundance of hydrated ferric oxides in nature and the widespread interest in the processes of formation of ore bodies, more definite information about the nature and properties of the hydrated ferric oxides was thought desirable.

The plan of this investigation was, on the one hand, to examine chemically and microscopically a large number of hydrated iron oxides and to determine their physical properties; on the other, to synthesize them, if possible, by the study of a chemical system in which they were likely to occur. As such the system Fe_2O_3-SO_3-H_2O was chosen. The results of the study of this system were, however, disappointing, as only "amorphous" and no crystallized hydrated ferric oxide was formed. Similarly various single experiments aiming at the formation of crystallized hydrated ferric oxides were unsuccessful. This led us to resort to thermal methods which, combined with the chemical examinations and the measured physical properties of the hydrated ferric oxides, yielded some of the desired information.

Analyses.

A large number of analyses of hydrated ferric oxides is found in the chemical and mineralogical literatures. However, most of them, except those of crystallized goethite, were made on materials not sufficiently defined physically, and accordingly show unaccountable variations to such an extent that from them no definite conclusions as to the hydrated form which they represent could safely be drawn. Most analyses are also comparatively old and for that reason probably unsatisfactory in respect

[12] Loc. cit.

TABLE I.

Analyses of Crystalline Hydrated Ferric Oxides.

No.	Locality.	Fe_2O_3	FeO[a]	Al_2O_3	Mn_2O_3	CaO	MgO	SiO_2	CO_2	H_2O	Total.	$\frac{H_2O}{Fe_2O_3}$	Name of mineral as received.
1	Germany	97·83	......	......	......	......	......	0·73	......	1·30	99·86	0·12	Hematite
2	New York (No. 18330)[b]	93·68	0·49	......	trace	......	......	0·68	0·30	4·12	99·27	0·39	Turgite
3	Missouri (No. 65269)	92·64	0·70	......	0·10	......	......	0·90	0·43	4·68	99·45	0·44	Turgite
4	Rockingham Co., Va. (No. 17968)	......	......	......	......	......	......	......	......	5·39	......	......	Turgite
5	El Paso County, Colo.	89·65	......	......	......	......	......	0·36	none	10·19	100·11	1·01	Goethite
6	Cornwall, England	89·03	......	......	......	......	......	0·70	......	10·22	99·95	1·02	Goethite
7	Harz, Germany (No. 84270)	86·39	......	......	......	......	......	3·05	none	9·92	99·46	1·02	Xanthosiderite
8	Diamond Hill, Rhode Island (No. 17879)	88·24	......	......	......	......	......	1·07	none	10·54	99·85	1·06	Limonite
9	Brazil (No. 80862)	87·19	0·34	......	......	......	......	1·17	0·21	10·95	99·86	1·09	Goethite
10	Michigan	86·55	......	......	......	......	......	2·42	......	10·80	99·77	1·10	Goethite
11	Easton, Pa.	85·80	1·47	......	trace	......	......	0·91	0·90	11·02	100·10	1·14	Goethite (Lepidocrocite)
12	Easton, Pa. (No. 81909)	82·67	1·82	0·24	1·24	none	0·12	0·92	1·09	11·68	99·78	1·25	Goethite
13	Salisbury, Conn. (No. 17302)	82·12	1·73	0·27	1·27	trace	0·16	1·58	1·06	11·78	99·97	1·27	Limonite
14	(No. 13973a)	83·47	0·89	0·30	0·36	trace	......	2·75	0·55	12·20	100·52	1·30	Limonite
15	Urals, Russia (No. 40352)	80·67	2·09	0·18	0·89	0·08	0·09	1·82	1·28	12·00	99·10	1·32	Limonite
16	Specimen A	82·44	1·44	......	0·19	......	......	3·18	0·70	12·47	100·12	1·34	Limonite
17	Pennsylvania	81·15	1·50	0·10	0·55	0·06	0·40	2·26	0·92	12·80	99·74	1·40	Limonite
18	(No. 46746)	80·13	0·29	0·29	......	......	0·12	4·92	0·18	13·85	99·78	1·53	Limonite

[a] The amount of ferrous oxide was calculated from the determined amount of carbon dioxide on the assumption that the latter was derived from ferrous carbonate.

[b] The National Museum's number of specimen.

to water determination. Water was usually determined by ignition loss and may, therefore, have included other volatile compounds. As the proposed hydrated ferric oxides differ only slightly in their water content an exact estimation of water is essential.

The analyses in Table I were made on carefully selected material[13] examined microscopically in respect to its homogeneity. The iron was determined by titration with permanganate, manganese was determined colorimetrically. In cases where aluminum, calcium, etc., were to be determined, the iron was first removed by electrolysis. The water determinations were made according to Penfield's method,[14] for some of the hydrated ferric oxides contained considerable amounts of carbonate which increase the value for water if the latter is determined by the ignition loss. In what form the carbonate is present could not directly be ascertained, for microscopically the analyzed hydrated ferric oxides appeared practically homogeneous. According to the analyses the carbonate might either be present as ferrous or as manganese carbonate. However, the corresponding amounts of manganese and carbon dioxide directly determined do not show any regularity whatever, though small amounts of ferrous iron could be detected (in No. 11 about 0·5%). It seems, therefore, that the carbonate present must be siderite, while manganese is present in a peroxidized condition which when the mineral dissolves oxidizes the ferrous iron and thus renders the direct determination of the latter impossible. Manganese is probably present as manganite ($Mn_2O_3 \cdot H_2O$) which is isomorphous with goethite.

That carbon dioxide was probably derived from ferrous carbonate finds some confirmation in the following observation. The ignition loss determined in some of the hydrated ferric oxides gave a certain excess compared with the amount of water found by the direct method. Assuming this to be due to the presence of ferrous carbonate, which reacts on ignition thus: $2FeCO_3 + O = Fe_2O_3 + 2CO_2$, the amount of carbon dioxide corresponding to

[13] We wish to express our thanks to Dr. G. P. Merrill of the National Museum for the privilege of selecting these specimens; and to Dr. E. T. Wherry, formerly of the National Museum, for help in making the selections, and for specimens from his own collections; also to Professor R. J. Holden of the Virginia Polytechnic Institute for about 20 fine specimens.

[14] See W. F. Hillebrand, Analyses of silicate and carbonate rocks.

this difference can be calculated. Table II shows the agreement of carbon dioxide calculated in this way with the amount directly determined.

TABLE II.

No.[a]	% ignition loss	% H_2O	Difference[b]	% CO_2 calculated	% CO_2 determined
13	12·71	11·78	0·93	1·13	1·06
15	12·99	12·00	0·99	1·21	1·28
16	13·08	12·47	0·61	0·74	0·70
17	13·60	12·80	0·80	0·98	0·92

[a] The numbers refer to Table I.
[b] This shows that the determination of water by the ignition loss, even on apparently homogeneous material, may easily be as much as 8% too high.

Some "amorphous" hydrated ferric oxides were also analyzed. The term "amorphous" is used here not to distinguish a special form of hydrated ferric oxide but only to indicate that the separate particles of the substance were of such fineness that their aggregates were essentially isotropic. They are primarily of interest in showing what influence the structure may have on the composition of the mineral. The results are given in Table III.

TABLE III.

Analyses of "amorphous" hydrated ferric oxide.[a]

No.	Locality	Fe_2O_3	FeO	CuO	SO_3	SiO_2	H_2O	Total	$\frac{H_2O}{Fe_2O_3}$
19	Cananea, N. M.,	83·34	...	1·23	1·34	1·73	13·26	100·90[b]	1·41
20	Shasta Co., Cal.,	81·03	0·64	0·46	1·27	1·20	14·97	100·50[c]	1·64
21	Shasta Co., Cal.,	76·29	0·25	0·15	0·35	5·67	17·41	100·12	2·02
22	Bisbee, Ariz.,	76·18	0·19	1·22	2·90	1·59	17·83	100·11	2·08
23	Shasta Co., Cal.,	74·95	0·25	0·50	1·67	1·50	17·76	100·67[d]	2·10
24	Synthetic,	84·72	...	...	1·82	...	13·91	100·45	

[a] Except No. 24 they are gossan ores received from Prof. L. C. Graton in connection with the investigation of the secondary enrichment of copper sulphide ores.
[b] With trace Mn_2O_3. [c] Includes 0·93 MgO, trace Mn_2O_3. [d] Includes 4·04 Al_2O_3.

Discussion of Analytical Results.

In the last column of Table I is given the name under which the mineral was received. It is seen that with the sole exception of Nos. 5 and 6, which were definite crystals of goethite, the compositions of the hydrated ferric oxides differ considerably from their supposed formulas.

Thus a hematite (fibrous) is found to have as much as 1·3% water; two turgites considerably less water than is called for by the formula, while on the other hand goethites may have too much water. "Limonites" in most cases were found to be too low in water for the type of hydrate they supposedly represent, as was also the only specimen of xanthosiderite which we were able to obtain.[15]

The ratio of water to ferric oxide for the various hydrated ferric oxides is given in Tables I and III. The values of this ratio lie between 0·1 and 2·1 and embrace, therefore, with one exception—$Fe_2O_3{\cdot}3H_2O$—all the supposed hydrated ferric oxides usually described as minerals, and mentioned in the beginning of this paper. However, this ratio shows practically a continuous variation instead of sudden changes as should be expected for a series of hydrates. It was rather surprising to find that the limited number of specimens which we analyzed presented such a gradation, as the selection of specimens for the analyses in Table I was made entirely on the basis of optical homogeneity and optical differences.

It may further be stated in respect to these analyses, that probably not all of the water determined in these substances belongs to the hydrated ferric oxide, but that some of it belongs to the "impurities," chief among which is silica. Usually the water content is higher the larger the amount of such impurities (see Tables I and III). The ratios of water to ferric oxide given in Tables I and II are, therefore, somewhat too high to be representative because the total amount of water was taken. It is noteworthy that even after this fact has been taken into account, the respective ratios of most "limonites" and turgites are not sufficiently high for the hydrates they supposedly represent. It seems, therefore, that on the basis of analytical data there is little foundation for the series of hydrates of ferric oxide, which is commonly assumed.

Optical and Crystallographic Study, with Synoptic Descriptions.

In order that the terms used in the latter part of the paper may have as definite a significance as can be given before those parts of the paper have been read, short descriptions including microscopical characteristics will be given at once.

[15] Fischer, loc. cit., makes similar statements in respect to the last two minerals.

Goethite:[16]—$Fe_2O_3 \cdot H_2O$; orthorhombic with $a:b:c =$ about 0·90-0·92: 1: 0·600-0·605;[17] density $4·28 \pm 0·01$; prismatic, bladed, fibrous;[18] elongation parallel to *c;* cleavage perfect *b,* good *a;* refractive indices[19] are $\alpha = 2·26$, $\beta = 2·394$, $\gamma = 2·400$; fine powder is dull orange-yellow (16″ *i* to 16′ *i* Ridgway); thicker grains show slight pleochroism in orange-yellow browns (16 *l*), thinner grains are not perceptibly pleochroic and are clear yellow; for red $\alpha = b$, $\beta = a$, $\gamma = c$, and for blue $\alpha = b$, $\beta = c$, $\gamma = a$; $\beta = \gamma$ at 610-620$\mu\mu$. Grains lying on the best cleavage face show a very characteristic green interference color, while colors of grains slightly tilted from this position pass through red and green without extinguishing. In white light the absorption formula is $a > c > b$.

The foregoing description applies to well-crystallized goethite, the following to *fibrous goethite.*

Aggregates of thin blades and fibers, subparallel with respect to the axis *c,* vary considerably physically and chemically. They usually appear microscopically homogeneous but their refractive indices are low; they contain water, silica, etc., as impurities, and they show confused interference figures, or are uniaxial at shorter wavelengths than is goethite owing to lack of parallel orientation with respect to *a* and *b.* The optical properties of these aggregates are best explained by the following considerations.

If very fine (diameter 0·5μ or less) fibers or blades of goethite—elongation *c*—could be packed without pore space and with random orientation with respect to *a* and *b,* then slivers of the apparently parallel-fibrous aggregates would have a maximum refractive index parallel to the elongation equal to 2·40, and a minimum[20] throughout the plane perpendicular to the elongation equal to 2·33. Absorption would be slightly greater in the direction of the elongation.[21]

[16] More complete descriptions appear near the end of the paper.

[17] Crystallographic irregularities limit the accuracy. See p. 342, also G. Cesàro and A. Abraham, Bull. Acad. R. Belg., 1903, 178.

[18] See next section.

[19] Dr. E. S. Larsen, of the U. S. Geol. Survey, has found $\alpha_{Li} = 2·21$, β_{Li} and $= \gamma_{Li}$ 2·33-2·35 (unpublished).

[20] That is the maximum would equal γ of goethite and the minimum $\frac{\alpha + \gamma}{2}$ approximately, and the aggregates would be essentially uniaxial positive with $\omega = 2·33$ and $\epsilon = 2·40$.

[21] The diffusion of light at boundaries between differently refracting surfaces may affect the apparent pleochoism of fibrous substances. Grains should be observed in a medium having a refractive index midway between the refractive indices of the differently absorbed rays.

If instead of the random orientation there is a tendency toward parallelism, then there will be, for any bundle of fibers considered as a unit, three principal refractive indices: $\gamma = 2{\cdot}40$, β variable between 2·40 and 2·33, and α variable between 2·26 and 2·33. For example $\gamma = 2{\cdot}40$, $\beta = 2{\cdot}35$, $\alpha = 2{\cdot}31$; or $\gamma = 2{\cdot}40$, $\beta = 2{\cdot}34$, $\alpha = 2{\cdot}32$.

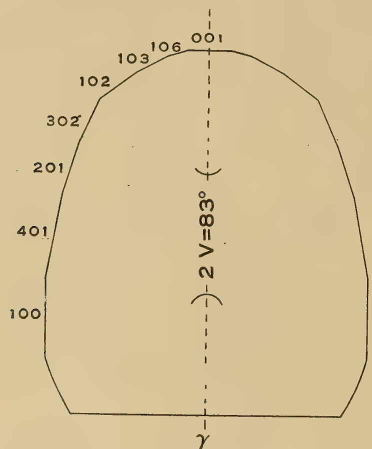
The presence of variable amounts of impurities in, and the physical behavior of, all our analyzed samples of bladed or fibrous goethite indicate that the fibers are not so tightly packed as just supposed but that the impurities (excess of water, silica, etc.) are in thin films among the fibers. By calculating as nearly as possible the volumes of the various impurities and assuming the additive relation for refractive index, the calculated mean refractive indices for several analyzed specimens have been found. Comparison of them with the observed values is found in Table IV. Most of these specimens were called limonite by the collectors.

TABLE IV.

No.	Mean refractive index calculated from analyses	Mean refractive index measured
9	$2{\cdot}28_6$	2·30
10	$2{\cdot}27_2$	2·28
13	$2{\cdot}22_5$	2·21
14	$2{\cdot}22_2$	2·19
15	$2{\cdot}20_2$	2·19
16	$2{\cdot}17_8$	2·17
17	$2{\cdot}16_8$	2·17
18	$2{\cdot}11_7$	2·12

Limonite:—When $Fe_2O_3{\cdot}H_2O$ is precipitated and hardened under natural conditions which do not permit definite crystallization, a porous mass is formed containing considerable excess of water, besides other impurities. So indefinite is the material that it cannot be characterized very satisfactorily. Its color in fine powder is scarcely distinguishable from that of fibrous goethite. Although often occurring in compact layered or botryoidal forms it does not possess decided fibrous fracture. The earthy varieties consist of minute loosely agglomerated spheroidal grains. Air-dried material possesses some pores of such size that, although microscopically invisible, they readily fill with such liquids as are used to immerse the grains for microscopic study. Thus, refractive-index determinations cannot be definitely interpreted; air-dried material does have observed apparent refractive indices within the rather narrow limits of about 2·00 to 2·10 when saturated with a liquid of corresponding refractive index. Such material, which has often been called limonite, will be referred to as limonite here.[22] Double refraction is common in such material, usually it is indefinite and not strong, but occasionally it reaches 0·04 and is almost as definite as in fibrous goethites. For example, in the cylindrical crusts around stalactites and in the spheroidal grains the ray vibrating along the radius is most strongly refracted as in fibrous goethite. In rare

FIG. 1.



cases a decided tendency for minute fragments to be splintery makes this material look somewhat like fibrous goethite.

Lepidocrocite:—Optical studies of the reddish, scaly crystals called rubinglimmer and lepidocrocite, led Lacroix to propose that they be classed together as lepidocrocite and separated from goethite, with which they had formerly been identified.[23] Crystals supposed to contain more water than goethite and which from later[24] descriptions were seen to be optically similar to lepidocrocite, were called hydro-goethite by Zemjatschensky.[25] Crystallographic measurements, mostly with the micro-

[22] See A Review of the Amorphous Minerals, A. F. Rogers, J. Geol. 25, 528.
[23] Minér. d. France, III, 360.
[24] J. Samojloff, Zs. Kryst. 34, 701 and 35, 272, abs.
[25] Zs. Kryst, 20, 185 abs.

scope, were made by Cesàro and Abraham.[26] They used a different optical orientation from that of either Samojloff or Lacroix and classed their crystals as a special type of goethite.

Our determinations of refractive index and density have confirmed the idea that these crystals are entirely distinct from goethite; on the other hand their composition is like goethite.

By adopting the name and optical orientation proposed by Lacroix, and by combining our own crystallographic data with those of Cesàro and Abraham, we can write a fairly complete synoptical description of the mineral. For more details see fig. 1 and the description of specimens, p. 345.

Lepidocrocite, $Fe_2O_3{\cdot}H_2O$, orthorhombic, $a:b:c = 0{\cdot}43:1:0{\cdot}64$. Density $4{\cdot}09 \pm {\cdot}04$. Habit, single thin scales {010}, slightly elongated *c,* or in scaly to compact bladed aggregates. Cleavage, {010} perfect, {001} less perfect, {100} good. Streak dullish orange. Color of fine powder 13′ *i* (Ridgway). Refractive indices: $\alpha = 1{\cdot}94$, $\beta = 2{\cdot}20$, $\gamma = 2{\cdot}51$, $\alpha = b$, $\beta = a$, $\gamma = c$. Therefore $-2V = 83°$, axial dispersion very slight. Pleochroism: in thicker grains α is clear yellow, β dark red-orange, γ darker orange-red; in thinner grains α is nearly colorless (yellowish), β and γ orange to yellow according to thickness.

Turgite:[27]—The fibrous red oxide of iron containing variable amounts of water cannot be definitely characterized. Some specimens have primary structure, others are pseudomorphic. The primary structure is divergent-fibrous. Detached splinters have parallel extinction, negative elongation and negative (apparently uniaxial) optical character. The refractive indices thus far observed[28] range between $\alpha(\text{or } \epsilon) = 2{\cdot}3$ to $2{\cdot}6$, β and $\gamma(\text{or } \omega) = 2{\cdot}5$ to $2{\cdot}7$. The color in fine powder is distinctly lighter and more inclined toward orange than hematite. The corresponding density is about 4·7, and the water content about 4 to 6 per cent.

Pseudomorphic turgite appears to result from the partial dehydration of fibrous goethite and primary turgite, and from the oxidation and slight hydration of magnetite

[26] Bull. Acad. Belg., 1903, 178.

[27] See p. 347.

[28] These include unpublished values kindly furnished by Dr. E. S. Larsen of the U. S. Geological Survey. Mixtures containing sulphur, iodine, arsenic, selenium and tellurium are suitable for making such measurements.

into martite.[29] Properties thus far observed indicate that pseudomorphic turgite is intermediate between hematite and primary turgite. The character of the filling of the space from which water has escaped affects the properties.[30]

These observations together with studies of density and thermal properties (p. 337) indicate that turgite is probably a solid solution of goethite and hematite, often containing considerable but minor amounts of capillary and adsorbed water.

Thermal Study.

The identification of hydrates is usually accomplished by the study of the relation between their vapor pressure and composition under definite conditions. The vapor pressure can either be measured directly with a gauge or according to a method suggested by van Bemmelen by placing the substance in a series of known water vapor pressures. These methods require prompt reversibility, so that equilibrium can be reached from both sides. However, as in many other cases,[31] this is impossible to do with the hydrated ferric oxides, because ferric oxide under ordinary conditions cannot be hydrated. The question whether such irreversibility is simply due to the extreme slowness of the rate of reaction, or whether dehydration causes a more stable molecular rearrangement, is still an open one.[32]

For irreversibly hydrated substances Le Chatelier[33] suggested a method which is based on the fact that in general the velocity of such reactions increases according to an exponential function of the temperature. It consists in measuring the temperature at definite intervals while the substance in question is heated at a fairly uniform rate. In this way temperature-time curves are obtained which show a heat effect similar to those of melting or inversion temperature-time curves.

[29] Some martites studied contained 0·6 to 0·9% of water, and had decidedly lower indices of refraction than hematite. See Trans. Am. Inst. Mining Engineers, 58, 431, 1917.

[30] See p. 347.

[31] Johnston, Zs. phys. Chem. 62, 330, 1908.

[32] The difference in the behavior of irreversibly and reversibly hydrated substances is often explained by assuming that the former contain constitutional water while the latter contain water of crystallization. This, however, does not explain anything, as the two words have no exact physical meaning.

[33] Zs. phys. Chem. 1, 396, 1887.

FIG. 2.

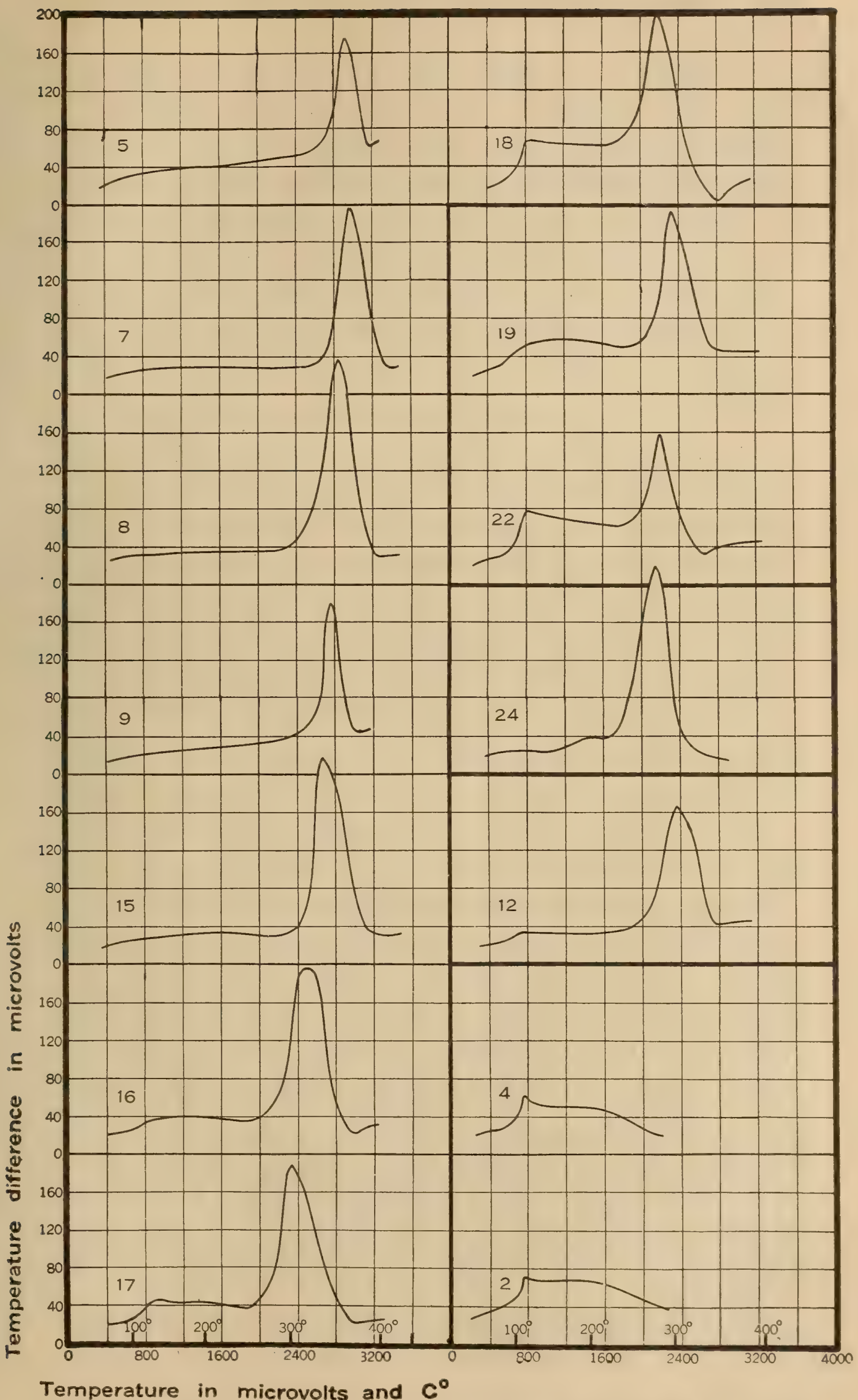


FIG. 2. Temperature-time dehydration curves. Numbers refer to analyses in Tables I and III.

According to Le Chatelier[34] the rate of heating influences the decomposition temperature but little. This, however, is true only for the comparatively rapid heating such as is used in making temperature-time curves. Only under such conditions are reproducible results obtained. These, however, give much higher temperatures for the decomposition than those obtained by heating the substance to constant weight at definite temperatures, as will be stated later. Such higher decomposition temperatures are probably caused by such factors as rate of reaction and physical character of substance, including the size of grains.

While, for that reason, the decomposition temperature found by this method could not be relied upon for the definite identification of hydrates, the curves obtained are quite valuable for a first orientation and quick information as to the way water is held. Water which enters into composition of such substances in a definite ratio, is readily distinguished by these curves from dissolved or adsorbed water. The former gives a curve with sharp heat effects due to rapid decomposition, while the latter, passing off gradually, produces fairly smooth curves.

The results for a number of decomposition curves are given in fig. 2. The substance was heated by means of an electric resistance furnace. The curves were taken by Roberts-Austen's differential device[35] against copper oxide as a neutral body and the temperature was measured with a platinum-rhodium thermoelement. The numbers of the curves refer to analyses in Tables I and III.

Except turgite, all the specimens of hydrated ferric oxide which have been investigated gave a strong heat effect. This was due to the decomposition of the substance, and no heat effect was produced on reheating. Some of these substances also show a slight heat effect just above 100°. This effect gradually increases with the total amount of water held by the hydrated ferric oxides and is undoubtedly due to adsorbed water, the greater part of which would come off at about this temperature. The temperature at which decomposition takes place can be reproduced for each sample very closely. However, as seen from the curves in fig. 2, there is a continuous gradation in the decomposition temperatures of the

[34] Loc. cit.

[35] See G. K. Burgess, Bull. Bureau of Standards, 5, p. 210, 1908; W. P. White, this Jour. 18, 453, 1909.

hydrated ferric oxides (except turgite). Crystalline goethite (No. 5) shows the highest decomposition temperature, while the "amorphous" hydrated ferric oxide (No. 22) decomposes at the lowest temperature. No definite identification of hydrated ferric oxides is therefore possible on the basis of these curves.

As has been stated, the curves for turgite differed greatly from those of the other substances. A slight heat effect is shown at about 110°, which, however, is not sharp and the curve falls off gradually; no other heat effect was observed between this temperature and 600°. The shape of the curve plainly signifies that the water in turgite is held in a different way from that in the other hydrated ferric oxides.

It has been previously mentioned that Fischer[36] attempted the identification of "limonites" by determining their decomposition temperature by slow dehydration at fixed temperatures. The choosing of the decomposition temperature for purposes of identification is rather unfortunate as this temperature may be influenced by the physical character of the substance. The rate of reaction also has to be considered. The longer the substance is kept at each temperature, the more, in all probability, would the influence of the rate of reaction be reduced. However, the irreversibility of the reaction leaves no definite criterion and the exact decomposition temperature must remain uncertain.

Fischer found that only above about 160° did "limonite" decompose (the decomposition curve however was not completed), although an appreciable amount of water was lost at lower temperatures. Just before decomposition his samples contained between 8·5 and 10·8% water which is much less than required by the formula usually assigned to "limonite." However, no definite conclusion could be drawn from these data as the substance was not sufficiently defined (only the amount of water determined by ignition loss is given).

In view of the sharpness of the curves obtained with Le Chatelier's method it was thought that slow dehydration at fixed temperatures might be made to yield valuable results. In principle both are identical; however, as the amount of water lost by the substance at each successive step is determined by the latter method, the resulting

[36] Loc. cit.

curve (extended considerably beyond the decomposition temperature) together with exact analytical data, should give definite information about the nature of the substance in question.

The hydration experiments were carried out at as slow a rate as practicable and the heating at all the temperatures required over four months. The substance was ground, placed in a small weighing glass and heated in an electric furnace which was kept constant within ±5°. A slow stream of air, dried over sulphuric acid, was passed through the furnace. For weighing, the substance was quickly placed in a desiccator over sulphuric acid and, when sufficiently cooled, was covered and weighed. Before putting it back in the furnace the substance was slightly shaken up. At least twenty-four hours elapsed between successive weighings and the substance was treated at a different temperature only if no change occurred after two more days heating.

Most of the time required by the dehydration experiments was consumed for the decomposition of the substance. Before decomposition begins and after it is practically completed, the substance comes very rapidly to constancy under the conditions of experiment. Decomposition proceeds, however, at an exceedingly slow rate at the temperature at which it is first discovered and it was necessary to raise the temperature considerably to dehydrate the substance within a reasonable period.

The results of the dehydration experiments are given in figs. 3 and 4. With the exception of turgite, all the hydrated ferric oxides examined show similar dehydration curves which consist of three distinct parts. The decomposition of the substance takes place in the middle portion of the curve and is accompanied by the color change from yellow to red. It should probably take place at a single temperature, but owing to the practical irreversibility of the reaction and its slowness this temperature can not be fixed and decomposition therefore is determined within the temperature interval between the point at which continuous loss was first observed and the somewhat higher temperature at which for practical reasons the dehydration was carried out.[37]

[37] In the drawings this interval is indicated by the broken line. The line connecting the upper and lower portion of the curves is drawn at the point at which continuous loss of water was observed, which however does not represent the exact decomposition temperature.

Fig. 3.

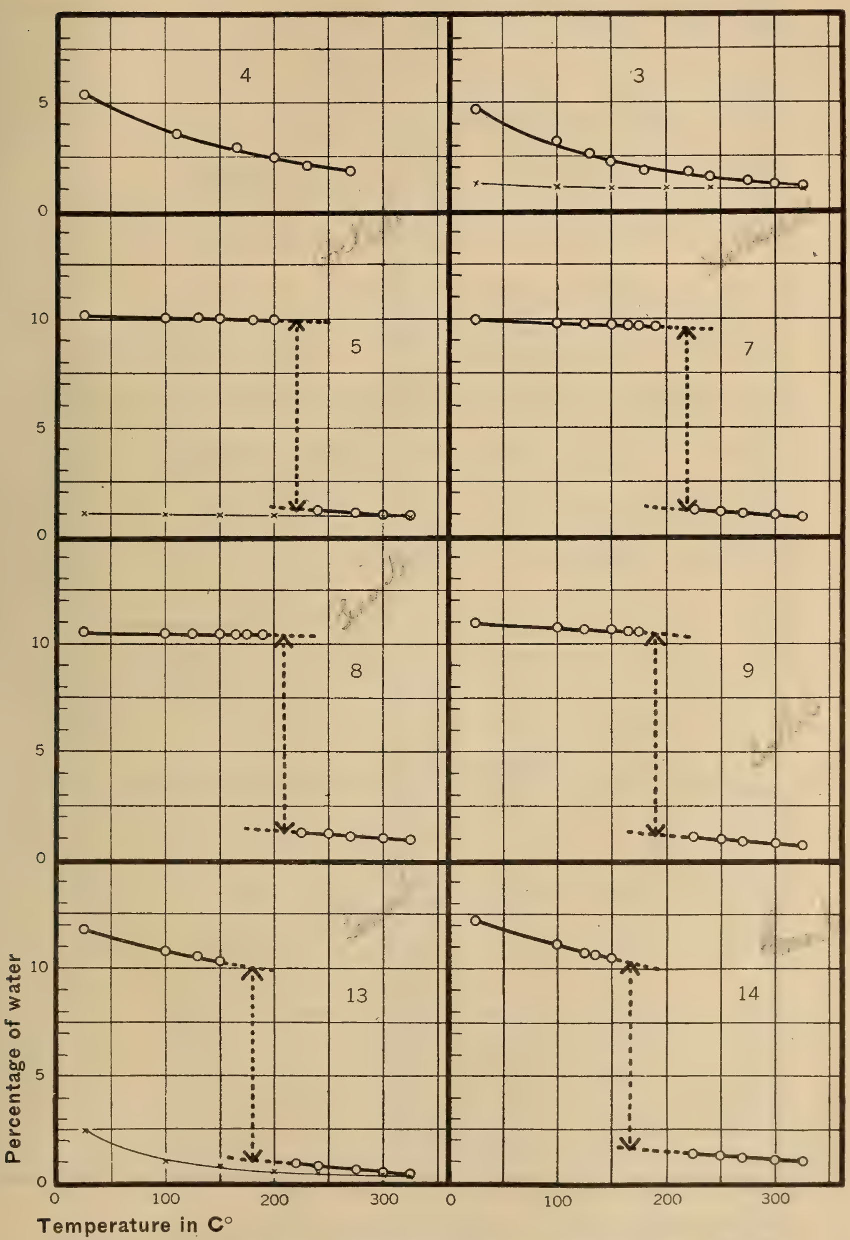


Fig. 3. Dehydration to constant weight at fixed temperatures. Numbers refer to analyses in Table I: 3 and 4—turgite; 5 and 8—bladed goethite; 7, 9, 13 and 14—fibrous (crystallized) goethite.

FIG. 4.

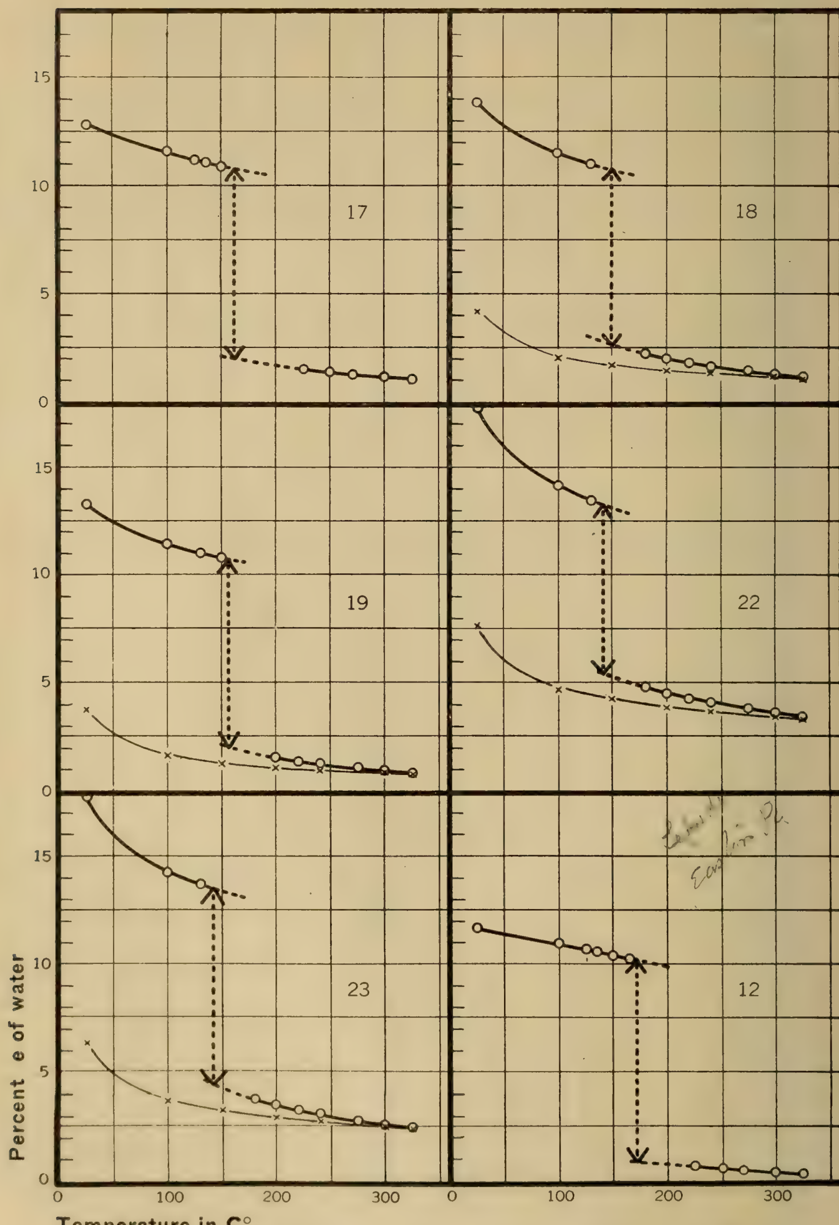


FIG. 4. Dehydration to constant weight at fixed temperatures. Numbers refer to analyses in Tables I and III: 17 and 18—fibrous (crystallized) goethite; 19, 22 and 23—limonite (''amorphous''); 12—lepidocrocite.

The temperatures of the dehydration intervals are considerably lower than the corresponding decomposition temperatures obtained by the rapid heating. This difference is probably caused by the slowness of the rate of reaction. In a comparative determination of the decomposition temperatures of several specimens, other factors, such as physical structure, size of grains, etc., will also prove of considerable influence, and it seems certain, therefore, that for purposes of identification the determination of decomposition temperatures is wholly unreliable.

As is seen from the figures, the dehydration curves consist of three distinct parts. The middle portion is formed by loss of water due to decomposition of the substance. The upper and lower portions of the curves show the losses in water not combined in a definite ratio. This is in all probability adsorbed and capillary water and the amount held will depend largely on the structure of the material. Comparison of curves for coarsely crystallized material with those for the more fibrous specimens strongly supports this view. It is also confirmed by rehydration experiments.

The results of rehydration are indicated by thin lines in a number of curves given. These experiments were carried out as follows: after the first dehydration up to the highest temperature the substance was left to come to constancy in the room;[38] then it was dehydrated in the same manner as before. The amount of water taken up in the room by the different samples was roughly equal to the amount lost in the first portion of the curves. Apparently dehydration did not appreciably change their original gross structure: thus the formerly crystallized goethite took up very little, while the originally fibrous and especially the "amorphous" samples took up correspondingly larger amounts.

The second dehydration gave perfectly smooth curves, which in the beginning approximately parallel the first portions of the corresponding original dehydration curves and later are practically identical with the third portion. The slight deviation is probably accounted for by shrinkage.[39] These experiments strongly suggest that a single cause must be responsible for the character of the first

[38] The humidity of the air was taken into account and the data refer to a relative humidity of approximately 40.

[39] Silica probably originally holds some of the water, which after heating is not so readily taken up again.

and third branches of the original dehydration curves. Judging from the smoothness of the curves, the quick adjustment, and the reversibility of the water contents, it is probable that it is due largely to adsorption. That adsorption of moisture to a considerable extent would take place could readily be foreseen from the fibrous (crystalline) and aggregated structure of most hydrated ferric oxides.

The part of the dehydration curve which gives information about the chemical nature of the substances in question, and is therefore of greater interest, is the middle portion. It is formed by the decomposition of the substance, and the amount of water lost in this portion serves for the chemical identification of the substance. These amounts may be approximately estimated[40] in the graphic way from the plots of the dehydration curves as follows: a parallel to the ordinate is drawn from the point at which decomposition begins and the lower branch of the dehydration curve is continued in the direction indicated by its curvature to the intersection with that line. The distance between the upper point and the intersection below indicates approximately the percentage of chemically combined water. Comparison on a mol basis of this amount of water with the amount of ferric oxide determined will indicate the chemical nature of the compound.

TABLE V.

No. of analysis in Tables I and III	% Fe_2O_3	Graphical estimation of % of combined H_2O	Mol. ratio Fe_2O_3: H_2O	Name of mineral as received
5	89·65	9·1	1 : 0·90	Goethite
7	86·39	8·2	1 : 0·84	Xanthosiderite
8	88·24	9·0	1 : 0·91	Limonite
9	87·19	9·4	1 : 0·96	Goethite
12	82·67	9·4	1 : 1·01	Lepidocrocite
13	82·12	9·0	1 : 0·97	Limonite
14	83·47	8·8	1 : 0·94	Limonite
15	80·67	8·8	1 : 0·97	Limonite
17	81·15	8·9	1 : 0·97	Limonite
18	80·13	8·2	1 : 0·91	Limonite
19	83·34	8·8	1 : 0·94	"Amorphous" hydrated ferric oxides (gossan ores)
22	76·18	8·0	1 : 0·93	
23	74·95	9·0	1 : 1·06	

[40] These estimates may not represent the exact amount of water lost by the substance on decomposition. Decomposition somewhat changes the physical structure and thus through ab- or adsorption may influence the position of the lower branch of the curve. However, this probably would not cause a large enough error to change the results.

As seen from Table V this ratio in all cases is practically one. The fact that in most cases a slightly smaller value was obtained is probably caused by adsorption, due to the increase in surface on decomposition.

Slow dehydration of turgite confirmed the earlier conclusion, derived from the rapid curves, that this substance differs essentially from the other hydrated ferric oxides. The curves are given in fig. 3 (No. 4 and 3). They are smooth and show that water is given off gradually with every increase in temperature. No sudden decomposition takes place anywhere and it would seem that turgite, unlike the other hydrated ferric oxides, is not a definitely hydrated compound. The water this substance contains must either be adsorbed or in solid solution, or both. Some indication as to the way in which the water is held may be found in a rehydration experiment. But little water was taken up by the dehydrated substance on standing in the room for over two weeks, and on the subsequent dehydration up to the highest temperature it had the same composition as formerly. This could not very well be the behavior of adsorbed water, for reversibility in water content is characteristic in such cases provided no change of gross structure takes place (see p. 331). It appears, therefore, more likely that the water in turgite is largely held in solid solution. Support of this view was found later in some other observations (see density and microscopical descriptions).[41]

Considering the evidence presented by the dehydration experiments, we come to the conclusion that no series of hydrates of ferric oxide exists. According to the evidence presented the only definite compound actually in existence is ferric oxide monohydrate. Goethite has long been recognized as such a compound and the present study definitely established lepidocrocite as another substance of the same composition. As previously mentioned, Hintze[42] concluded on the basis of Fischer's work that "limonite" is the "colloidal form of goethite." In view of the facts brought forward in the present paper such a conclusion seems rather hasty and, using the same terminology, it seems that "limonite" could just as well be the colloidal form of lepidocrocite. However, as the term colloidal does not imply anything about the modification of the substance (it can properly be used only to

[41] Support of this view may also be found in the dehydration of the specimen from Germany (Table I, No. 1). This substance contained 1·3% water but lost less than 0·2% on heating to 300°.

[42] Handbuch der Mineralogie, I (2), p. 2008.

describe properties caused by some general physical condition) it is still possible that "limonite" could also be a distinct polymorphic form of ferric oxide monohydrate. To decide this question some further study was necessary (density, optical properties, etc.).

Densities of the Monohydrates of Ferric Oxide.

Information about the number of polymorphic monohydrates of ferric oxide in existence was sought by means of density determinations. Available data for the supposed hydrates show considerable but irregular differences. Thus Dana gives in his "System of Mineralogy" the density of goethite (and lepidocrocite) as 4·0-4·4 and the density of limonite as 3·6-4·0. The density of hydrogoethite is given by Zemjatschensky and Samojloff as 3·5-3·7.

In view of the fibrous character of many of our specimens great care had to be taken, in determining this constant accurately, to drive out all the air. The substance to be examined passed a 100 mesh and was held by a 200 mesh (per linear inch) sieve. The pycnometer described by J. Johnston and L. H. Adams[43] for specific gravity determination was used and the air carefully boiled out under reduced pressure. Repeated determinations were in good agreement differing only in the third decimal. Comparative density determinations in xylol to determine whether complete filling of pores took place in our experiments were also attempted. However, only in cases where little excess water was present were these determinations successful and the values then obtained were identical with those in water. Where more water was present some was easily liberated in boiling out the air and small drops of it were observed in the xylol. The values for the specific gravity were accordingly considerably lower than in water and the latter probably essentially correct.

The specific gravities given in Table VI show the wide variation usually found in these substances. However, we know from the analyses that they contain a considerable amount of impurities and the result is therefore not surprising. Comparison of these data is possible only after the proper corrections are made for these impurities.

[43] J. Am. Chem. Soc. 34, 563 (1912).

TABLE VI.

No.	Specific gravity in water	$\frac{\text{mineral } 25°}{\text{water } 25°}$ in xylol	Name of mineral as received
5	4·263	4·266	Goethite
6	4·250	....	Goethite
8	4·172	....	Limonite
9	4·107	(4·093)	Goethite
10	4·091	(4·087)	Goethite
13	3·970	....	Limonite
14	3·895	....	Limonite
15	3·951	(3·878)	Limonite
17	3·822	....	Limonite
11	3·854	....	Lepidocrocite
12	3·841	....	Lepidocrocite

The corrections of the specific gravity determinations were made on the basis of the analyses and in accordance with the evidence presented by the dehydration experiments that the specimens were monohydrates of ferric oxide. The analyses, as will be remembered, indicated as chief impurities silica (amorphous except in No. 5 and No. 6) and probably ferrous carbonate and manganite. For water in excess of the amount required to form the monohydrate with the ferric oxide a correction was made on the assumption that the water was free. The value taken for the specific gravity of amorphous silica was 2·3; for quartz 2·65; for ferrous carbonate 3·88, and for manganite 4·4. The approximate composition of the minerals and the specific gravities of the monohydrates of ferric oxide corrected on that basis are given in Table VII.

TABLE VII.

	Approximate composition of mineral					Sp. gr. at 25° for	
No.	% $Fe_2O_3 \cdot H_2O$	% $FeCO_3$	% $Mn_2O_3 \cdot H_2O$	% SiO_2	% H_2O	$Fe_2O_3 \cdot H_2O$	Name as labeled
5	99·65	...	...	0·36	0·10	4·29	Goethite
6	99·08	...	...	0·70	0·17	4·29	Goethite
8	98·15	...	...	1·07	0·63	4·30	Limonite
9	97·44	...	...	1·17	1·08	4·28	Goethite
10	96·28	...	...	2·42	1·07	4·32	Goethite
13	91·38	2·79	1·42	1·58	2·37	4·34	Limonite
14	92·88	1·44	0·40	2·75	2·75	4·36	Limonite
15	89·76	3·37	0·99	1·82	2·81	4·35	Limonite
17	90·25	2·42	0·61	2·26	3·60	4·34	Limonite
11	95·44	2·37	...	0·91	1·38	4·07	Lepidocrocite
12	91·96	2·91	1·38	0·92	2·25	4·12	Lepidocrocite

As seen in the table (Table VII), lepidocrocite has a considerably lower specific gravity than goethite. The value 4·07 derived from No. 11 is probably the better value of the two given, since the substance was purer. The wide variation and difference of the observed specific gravities of goethite and the "limonites" have practically disappeared, but the corrected values of the "limonites" are now slightly higher than the value for goethite. However, it would not be safe to place much reliance on that difference as the corrections applied to most "limonites" are very large (about six times that difference). The assumed mineral compositions are also somewhat uncertain and the correction may therefore not be exact. It would be preferable for that reason to consider that the observed difference in the corrected values of goethite and "limonites" is caused by such errors and, as long as there is no other evidence in favor of their polymorphy, to assume that they are identical. The optical study furnishes much in favor of that assumption (see Table IV).

Specific Gravity of Turgite.—It will be remembered that the dehydration experiments indicated that turgite, on account of the gradual loss of water on heating, could not be a definite chemical compound. Analysis and optical observation showed the variability of this substance and thus supported this conclusion. These facts led to the view that the water in turgite must either be adsorbed or dissolved. Rehydration experiments, however, indicated that this water in all probability was mostly not adsorbed, and this finds further support in specific gravity determinations of turgite. These are given in Table VIII. The values corrected for the small amounts of silica and ferrous carbonate are also given, as well as the corresponding specific volumes.

Table VIII.

No. (Tab. I)	% H_2O	Sp. gr. mineral 25° water 25°	Sp. gr. corrected for SiO_2 and $FeCO_3$	Sp. volume	% hematite	% goethite
1	1·30	4·978	5·050	0·198	87	13
2	4·12	4·607	4·648	0·215	59	41
3	4·68	4·670	4·730	0·211	53	47

If the water is adsorbed the specific volume of turgite should be very nearly the sum of the specific volumes of its components, *i. e.*, ferric oxide and water. In fig. 5 the broken line connects the specific volume of hematite (specific gravity 5·2) and water, and it is seen that this line greatly deviates from the points experimentally found. The solid line in the same figure, which connects the specific volumes of hematite and goethite, however, approaches these points very closely.[44] This tends to indicate that turgite is essentially a solid solution of ferric oxide (hematite) and ferric oxide monohydrate (goethite). All other evidence at hand is in favor of this assumption.

Fig. 5.

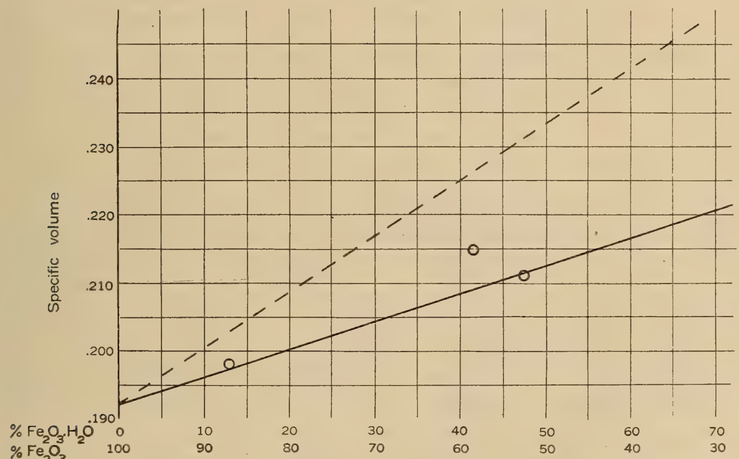


Fig. 5. Specific volumes of turgites. The solid line connects the specific volumes of goethite and hematite, while the broken one connects those of hematite and water.

Some Observations Concerning the Relative Stability of the Hydrated Ferric Oxides.

The questions that arise as a result of the present investigation concern the stability relation of the two forms of ferric oxide monohydrate, and the conditions of their formation, as well as of the solid solution. While

[44] The specific volume of No. 2 is somewhat higher and lies closer to the line connecting the specific volume of hematite and lepidocrocite. In view of the small number of turgite specimens at our disposal, the significance of this could not be ascertained, but it is evident that if, besides the water of solid solution some water in turgite is adsorbed, its specific volume would have a higher value. However, it is experimentally impossible at present to determine in this case the amount of adsorbed water.

no satisfactory answer can as yet be given, the discussion and recording of some observations in this connection may be useful in calling attention to the problems involved.

No thermal or optical indications of a transformation of either lepidocrocite or goethite could be observed on heating them between room temperature and the temperature at which they decompose. The transformation may take place at a different temperature or be very slow and it is not certain whether their relation is enantiotropic or monotropic. The microscopic study of some of our specimens (see p. 346) revealed that it is not uncommon to find lepidocrocite and goethite together, with either as the earlier mineral. It would seem that the conditions of their formation could not have been very different. However, as no crystals of goethite and lepidocrocite have so far been artificially prepared and their solubilities are not known, there is nothing to indicate their stability relation. It is probable that field observations will aid materially in the solution of this problem.

Not only are goethite and lepidocrocite found together, but turgite (the solid solution) may similarly appear with either of them. Pelikan[45] observed on some Brazilian specimens the formation of turgite on fibrous goethite[46] and from microscopic observations of their structure he concluded that the turgite could not have been derived by the dehydration of the goethite, but must have been deposited there directly.

Our observations (see description of specimens—lepidocrocite, Siegen, and R. C. 1489) lead us to the same conclusion, i. e., that turgite is not necessarily a dehydration product of goethite or lepidocrocite.

Red and yellow ferric oxides often occur in nature together, and the assumption is frequently advanced that the red ferric oxides are derived from the yellow ones. It has been supposed that in nature gradual dehydration of higher hydrates to some more stable ones or to anhydrous ferric oxide takes place under the influence of salt solutions or by atmospheric weathering.[47] This theory appeared plausible as long as a series of hydrates was supposed to exist, as it is obviously impossible for several

[45] Tsch. Mitth., **14**, 1.

[46] Pelikan describes it as limonite.

[47] Stremme, Zs. prakt. Geol. **18**, 18, 1910; Cornu, Zs. Chem. und Ind. d. Kolloide, **4**, 285, 1909.

hydrates to be truly stable under any given set of conditions. The evidence presented in this paper as to the existence of only ferric oxide monohydrate and a solid solution of this substance and ferric oxide, however, disposes of the assumed series of ferric oxide hydrates. The dehydration experiments further indicate that ferric oxide monohydrate is probably stable at any temperature which the earth's surface may normally reach and it is therefore unlikely that in nature the red ferric oxide is derived by the *direct* dehydration of the yellow. It is probable that both red and yellow substances may be formed at ordinary temperatures by somewhat different chemical reactions; both are relatively stable under the conditions usually met with near the earth's surface. No definite statement concerning their stability relation can be made at present and further studies are required for the solution of this problem.[48]

Synthetic and Natural Hydrated Ferric Oxides.

As was previously mentioned, statements concerning the formation of definite crystallized hydrates were reinvestigated by van Bemmelen[49] and proved by him to be erroneous. The supposed crystals prepared by himself were undoubtedly pseudomorphs after sodium-ferrite and it seems certain that up to the present no synthesis of definitely crystallized hydrated ferric oxide has been suc-

[48] As mentioned in the beginning of this paper, attempts were made to form crystallized hydrated ferric oxides. Various reactions were tried but only "amorphous" red and yellow substances were obtained; finally the system Fe_2O_3-SO_3-H_2O was systematically studied. A paper dealing with this system will soon be published. While this study did not yield all the information that was desired it may be of interest here to mention a few of the results obtained. Yellow hydrated ferric oxide, resembling in its optical and thermal behavior (see fig. 1, No. 24) the natural "amorphous" hydrated ferric oxide, was formed below approximately 120°, while only above that temperature were red hydrated ferric oxide, resembling turgite, and hematite formed. The temperature given may not be exact, as it was not possible on account of slow reaction to establish equilibrium from both sides; however, it seems certain that at lower temperatures only the yellow substance is stable under such conditions. Most of the hydrated ferric oxides thus formed contained considerable amounts of sulphate, which varied with the concentration of the solution and temperature and was proven to be adsorbed and not due to presence of ferric sulphates. The strong adsorptive power of the hydrated ferric oxides—(Biltz, Ber. 37, 3138, 1904 has shown that an adsorption phenomenon is responsible for its use, proposed by Bunsen, as an antidote for arsenic poisoning)—is probably one of the chief causes impeding the formation of crystallized products: the surfaces of the newly-formed nuclei becoming saturated due to adsorption. Another cause is the extremely small solubility of hydrated ferric oxide in pure water.

[49] Loc. cit.

cessful. The conditions of formation of hydrated ferric oxides are, therefore, not known and the numerous attempts to synthesize them produced apparently only substances of an indefinite composition, which gave rise to the idea of the existence of a large number of hydrated compounds. In regard to these synthetic products one fact, however, stands out more definitely, and that is that they were either red or yellow. Van Bemmelen[50] investigated the behavior of these hydrated ferric oxides and found their composition to vary considerably with the surrounding conditions. According to prevalent ideas he called the red and the yellow substances colloids and believed that as such they were not definite compounds and therefore could not essentially differ from one another. Our present knowledge, however, shows that colloids are not particular chemical substances or a distinct form of the substance, as was previously thought, but that any substance under certain conditions can be made to have properties characteristic of colloids; the term colloid, therefore, does not characterize the substance as such, but only indicates properties which are due to a certain condition of the substance. It is of interest now that van Bemmelen noticed a certain difference in the behavior of the red and yellow substances. He found that between 50° and 200° the latter held its water much more tenaciously than the former and that only above about 200° the two did become identical in their composition and behavior. Colloidal properties probably can not be responsible for this difference and in view of the marked difference in color it is more likely that the chemical nature of these two substances is different, although both of them may possess similar colloidal properties due to their physical condition. Fischer[51] tried to verify this assumption and found that on dehydration the yellow synthetic substance behaves similarly to the natural "limonites" and at about 200° changes its color and becomes red. We were able to confirm the observation that the yellow synthetic substance behaves like a hydrated compound; in fig. 1 (No. 24) the dehydration curve of a yellow hydrated ferric oxide (formed by the hydrolysis of a dilute solution of ferric sulphate) is given and its similarity with the monohydrates of ferric oxide is readily seen. The optical properties of such

[50] Loc. cit.
[51] Loc. cit.

preparations are similar to the natural "amorphous" hydrated ferric oxides, which were found to be from a chemical standpoint essentially a monohydrate of ferric oxide, and in all probability the two are identical. The synthetic yellow preparations present then the same possibilities in respect to their nature as those discussed in connection with the natural "amorphous" hydrated ferric oxides, *i. e.,* they ultimately may be found to be either goethite or lepidocrocite or isotropic ferric oxide monohydrate.

As to the synthetic red substance van Bemmelen[52] proved by careful dehydration experiments that it was not a hydrate of ferric oxide, and concluded that the water it held was adsorbed. The latter may be true but it is also possible that these red substances are partly a solid solution of ferric oxide and ferric oxide monohydrate, analogous to turgite.[53] Due to the extreme fineness of such preparations they undoubtedly adsorb a considerable amount of water; some of the water, however, may be accounted for by the solid solution mentioned. To determine whether water is held only in one or both the ways just indicated is very difficult, owing to the character of the material, and is certainly impossible by dehydration experiments alone. Both possibilities must therefore be considered.

Since only "amorphous" substances have been prepared artificially no strict comparison of these preparations with the natural crystallized hydrated ferric oxides can be made. However, as the result of the present investigation, a certain analogy in their chemical composition can readily be seen: in both cases ferric oxide monohydrate is probably the only definite compound and it is likely that in both cases solid solutions of this compound and ferric oxide exist.

Description of Specimens.

GOETHITE.

Goethite, Negaunee, Michigan. (N. M. 84970).—The ends of two prismatic crystals were measured goniomet-

[52] Zs. anorg. Chem., 20, 185, 1899.

[53] Recently H. W. Foote and B. Saxton (J. Amer. Chem. Soc., 38, 588, 1916; 39, 1103, 1917) attempted to determine the condition in which water exists in precipitated hydrated ferric oxide by observing volume changes on freezing such preparations. They came to the conclusion that it must be essentially a case of solid solutions.

rically. One, from excellent faces *e, d, m,* gave the ratios $a:b:c = 0\cdot928:1:0\cdot604$; the second, although giving good signal from faces *p, e, d, m, b,* gave less satisfactory axial ratios ($a:b:c = 0\cdot931:1:0\cdot605$) because two of the pyramid faces were rotated toward *a* 40′ from their true position over *m*. Near the base of each crystal was a compact group of small crystals in sub-parallel positions. Uniaxial at 610 to 615$\mu\mu$, at longer wave-lengths the optic plane is parallel to the elongation. $\alpha(\text{Na}) = 2\cdot260 \pm 0\cdot005$, $\beta(\text{Na}) = 2\cdot393 \pm 0\cdot005$, $\gamma(\text{Na}) = 2\cdot398 \pm 0\cdot005$. Absorption increases abruptly near 550$\mu\mu$ as short wave-lengths are approached.

Goethite, Cornwall, England.[54]—Coarse blades which have $\beta(\text{Na}) = 2\cdot39_4$ and $\gamma(\text{Na}) = 2\cdot40_0$. Uniaxial near 610$\mu\mu$. Dispersion of $\gamma(\text{Na}) - \gamma(\text{Li}) = 0\cdot60$.

Goethite, Florissant, Colorado.[54] (N. M. 84940). Uniaxial at 616 to 620$\mu\mu$.

Goethite, Pribram, Bohemia, variety Sammetblende.—Slender separate filaments like the nap of velvet. The filaments, although only a few μ in diameter, are clearly made up of small, nearly parallel, fibers or blades elongated $\perp$ α. Some filaments show the interference colors characteristic of goethite but interference figures (which were not very satisfactory) indicated the optic plane parallel to the elongation, and a slowly decreasing optic angle (toward blue). At 600$\mu\mu$ 2E = about 80°.

$\gamma(\text{Na}) = 2\cdot36_0$, $\beta(\text{Na}) = 2\cdot35_0$, $\alpha(\text{Na}) = 2\cdot23_5$. Dispersion $\alpha(\text{Na}) - \alpha(\text{Li}) = 0\cdot040$.

Goethite, labelled limonite, Diamond Hill, Rhode Island.[55] (N. M. 17879.) The specimen consists of radial-fibrous aggregates which break radially with glistening surfaces. A bladed to fibrous structure is revealed by the microscope, and interference colors like goethite appear in some grains. These grains are uniaxial at 575 to 590$\mu\mu$, and have 2E at 675$\mu\mu$ and at 546$\mu\mu$ 90° to 120°, or 2V = 35° to 40°. For these grains $\alpha = 2\cdot24$ and both β and $\gamma = 2\cdot37$; α is less absorbed. Dispersion $\gamma(\text{Na}) - \gamma(\text{Li}) = 0\cdot053$.

Goethite, Brazil.[55] (N. M. 80862.) Botryoidal and stalactitic masses break radially with semi-lustrous surfaces. Relatively few grains in a crushed sample resemble goethite. These are nearly uniaxial at 575$\mu\mu$, and have variable refractive indices: α, about 2·23, β

[54] Analyzed, see Table I.
[55] Analyzed (Table I).

about 2·32, γ about 2·35. Material which is more fibrous has α about 2·21 and β and γ about 2·31.

Goethite (labelled xanthosiderite), Neudorf, Germany.[55] (N. M. 84270.) Radial-fibrous, decidedly yellowish, interbanded with quartz. Microscopic fragments very cloudy with very minute inclusions or pores—which accounts for yellow color. γ near 2·37, β near 2·33, α near 2·27, all variable.

Goethite (labelled xanthosiderite), Ironwood, Michigan.[56] (Holden—K.)—Long fibers, yellow, translucent in microscopic grains, becomes slowly saturated with immersion liquids and thus becomes transparent. Its yellow color in mass is evidently due to invisible pores. γ varies around 2·33 and α around 2·25, as measured on material saturated with these immersion liquids.

Fibrous goethite.—A number of specimens marked "limonite" have the following characteristics in common: in the mass dark yellow-brown; breaking in radial splinters, which are transparent microscopically, and behave much like an optically positive mineral with prismatic cleavage. In some specimens lack of strict coincidence of the prismatic axis of small groups of fibers caused slight variation in the measured refractive indices. Other larger variations such as would result from structures, described on p. 320, or from lack of chemical homogeneity amounted usually to less than ± ·02. Table IX shows other optical properties of these specimens. The values given represent as nearly as could be determined the bulk of the material, taking account of observed variations. Absorption of light in the two principal directions was almost identical when determined in a liquid of intermediate refractive index; perceptible differences showed $\gamma > \alpha$.

TABLE IX.

Designation	γ	α	Remarks
*Chatfield, Conn., N.M. 17302	2·26	2·18	Very homogeneous
N.M. 13972_a	2·24	2·16	Variable indices
*Polevskoi, Urals. N.M. 40352	2·24	2·16	
*N.M. Specimen A.	2·23	2·14	
*Moselem, Pa., from E. T. Wherry	2·22	2·14	γ distinctly more absorbed
*N.M. 46746	2·17	2·09	
N.M. 14116	2·23	2·14	
N.M. 83867	2·21	2·13	
From a geode, E. T. Wherry	2·20	2·13	

* Analyzed, see Table I.

[56] The sample analyzed (Table I) labelled "goethite Mich." was similar optically.

Pseudomorph after pyrite, Louisa County, Virginia (from Prof. Holden).—Felted fibers of goethite having γ near 2·27, and α near 2·20. Small amounts of felted grains of turgite are scattered irregularly through the brown ore.

Fibrous goethite on and under lepidocrocite, Rossbach, Germany.—Small hemispherical radial-fibrous aggregates on lepidocrocite scales, $\gamma = 2{\cdot}26 - 2{\cdot}28$, $\alpha = 2{\cdot}18$—2·20. The scales grew upon fibrous goethite having γ and $\beta = 2{\cdot}32 - 2{\cdot}29$, $\alpha = 2{\cdot}18 - 2{\cdot}19$.

Fibrous goethite under lepidocrocite, Müsen, Germany.—Two structures are apparent: (1) the fibrous form cigar-shaped bundles; (2) these bundles are arranged in sub-parallel to radiating groups which do not extinguish well; γ about 2·28, $\alpha = 2{\cdot}16 - 2{\cdot}18$.

Fibrous goethite, R. C. 1489. Iron Mountain Mine, California. (From Prof. Graton.)—Fibrous, yellowish layers in the walls of a vug containing residual sulphides. This is remarkable because microscopic splinters have (1) what appears to be very different absorption for light in the two principal directions and the character of the absorption is the reverse of that in all other specimens observed, that is, is greatest across the fibers; (2) great porosity; (3) when pores are filled with liquid having n about 2·0, apparent homogeneity when seen in light vibrating parallel to the length of the fibers and non-homogeneity across the fibers. In the latter position the structure appears fibrous, with the diameter of the fibers about 1μ. All three characteristics would appear in structures somewhat coarser than those described under goethite above. The anomalous absorption would then be explained by the lateral diffusion of light at the comparatively large surfaces between differently oriented goethite fibers. The apparent refractive indices of this material are decidedly lower than for any other fibrous goethite examined; $\gamma = 2{\cdot}11$, α (which could not be determined accurately) is about 2·05.

LIMONITE.[57]

1206 Cananea, New Mexico.[58]—Transported ore in vug, outside hard. The earthy ore within and the hard crust

[57] See general description, p. 321. The first five of these specimens were collected by Prof. L. C. Graton, 1914, and the occurrences are given as described by him.

[58] Analyzed, Table III.

both made up of minute doubly refracting splinters with n about 2·08.

R. C. 701, Shasta County, California,[59] Analysis No. 20. —Gossan above ore body. Concentric but not readily separable layers of different n, double refraction about 0·03 in some parts, n about 2·09 (varies between 2·13 and 2·06).

R. C. 501, Mammoth Mine, Shasta County, California,[59] Analysis No. 21.—Gossan surrounding pyrite. Hardened clot-like masses with only traces of double refraction, $n = 2·00$ to 2·06. Cracks are coated with a thin film of *red material* showing no double refraction and having $n = 2·2$ to 2·3. Out of specimens from about 25 different occurrences of brown ores this is the only one having red material that did *not resemble turgite.*

1255, Holbrook Mine, Bisbee, Arizona,[59] from the 100-foot level.—Irregular ropy to platy open structure with glazed surfaces resembling the stalactitic limonite of Specimen D (see below). Layered structure conspicuous under the microscope, double refraction very marked (max. 0·04), $n = 1·99$ to 2·07. Alternating with the brown ore layers are interrupted layers of *turgite* amounting to 5 to 10% of the bulk of the material.

R. C. 683, Shasta County, California,[59] Analysis No. 23. —A botryoidal mass from a mine dump, separable layers having strong double refraction and n varying between about 2·01 and 2·06.

Oriskany Mines, Specimen D.[60]—Stalactitic limonite from Botetourt County, Virginia. A porous lace-work of small stem-like filaments, irregularly double refracting, contains spherules of turgite in interrupted layers, n mostly $<2·06$.

V 412, Wythe County, Virginia.[60]—Residual ore from weathering of Shenandoah limestone; contains several per cent of red spherulitic granules mostly less than 5μ in diameter, having refractive index 2·4 and strong double refraction like *turgite.*

LEPIDOCROCITE.

N. M. 81909, Easton, Pennsylvania.—Micaceous, orange red, on fibrous goethite;

$\gamma(\mathrm{Na}) = 2·51_5$; $\gamma(\mathrm{Li}) = 2·42_5$; $\beta(\mathrm{Na}) = 2·20$; $\alpha(\mathrm{Na}) = 1·93_5$.

[59] Analyzed, Table III.

[60] From a series of selected specimens presented to us by Professor R. J. Holden, Virginia Polytechnic Institute.

A second analyzed specimen from the same locality consisted of scales set edgewise and closely aggregated, on fibrous goethite.

Rossbach, Germany.—Scattered erect red scales attached on base to fibrous goethite, or in loose rosettes. The bounding edges correspond to forms $\{102\}$, $\{001\}$, $\{100\}$, but the outlines are usually considerably rounded. Fig. 1.

Müsen, Germany.—γ(Na) slightly $>2{\cdot}50$. Like Rossbach but $\{103\}$ is a prominent bounding form or edge. β(Na) = or $<2{\cdot}20$. Absorption for γ increases rapidly from 570 to 530$\mu\mu$ and beyond, and from 640 to beyond 750$\mu\mu$; for β absorption is nearly constant between 750 and 560$\mu\mu$ and this increases rapidly to 520$\mu\mu$ and beyond; for α no appreciable absorption except in blue and violet.

Siegen, Germany.—Compact aggregates of scales upon and under turgite. γ near 2·51.

N. M. 14118, near Lake Superior, Michigan.—Called goethite; closely aggregated erect scales in a layer on fibrous goethite. $\gamma(\text{Na}) = 2{\cdot}51_5$, $\alpha(\text{Na}) = 1{\cdot}941$, α(Li)—$1{\cdot}92_2$. Scales of such thickness that $\beta = 8k$ (Ridgway's colors) have $\gamma = 7n - 9n$; also $\beta = 15i$ and $\gamma = 14k$; also $\beta = 23h$ and $\gamma = 23h$ to i.

R. C. 1489, Iron Mountain Mine, California.—Bladed to fibrous lepidocrocite lining a vug containing residual sulphides, on fibrous goethite and turgite; $\alpha = 1{\cdot}92$.

TURGITE.[61]

Turgite, New York,[62] No. 18330.—$\alpha(\text{Na}) = 2{\cdot}58$, β(Li and $\gamma(\text{Li}) = 2{\cdot}55$; elongation of splinters negative, $\alpha(\text{Li}) = 2{\cdot}46$.

No. 65269.[62]—Refractive indices variable but about $\alpha(\text{Na}) = 2{\cdot}56$, β(Li) and γ(Li) about 2·52; elongation negative. $\alpha(\text{Li}) = 2{\cdot}43$.

Legal Tendre Hill, New Mexico. No. 48228.—Breaks irregularly and contains cavities (large and small); extinguishes very obliquely; refractive indices like No. 18330. Probably pseudomorphic after some fibrous mineral having oblique extinction.

Rockingham County, Virginia.[62] No. 17968.—$\alpha(\text{Na}) = 2{\cdot}46$, $\alpha(\text{Li}) = 2{\cdot}38$, elongation negative.

Germany,[62] "Hematite."—Fibrous, elongation *posi-*

[61] See p. 323.
[62] Analyzed, Table I.

tive, extinction parallel, contains many thin quartz veins; fibers cloudy and only translucent to feebly transparent; refractive indices variable, but the lowest is about 2·70 (Li). This is like a partly dehydrated fibrous goethite. (Are the quartz veins in shrinking cracks caused by dehydration?)

Cumberland, England.[63]—Like the specimen from Germany, but is covered with and contains many minute veinlets filled with specular hematite.

Recapitulation.

The work of the foregoing pages proves rather conclusively that no *series* of hydrates of ferric oxide exists among the natural minerals. The only existing hydrate is ferric oxide monohydrate. This substance occurs in nature in two polymorphic forms—goethite and lepidocrocite, and in an "amorphous" condition—limonite. The two crystallized forms are contrasted as follows:

Goethite.—Orthorhombic, $a:b:c = 0·91 : 1 : 0·602$; density (grams per cc.) $4·28 \pm 0·01$; $\alpha = 2·26$, $\beta = 2·394$, $\gamma = 2·400$; streak, dull orange-yellow; pleochroism faint.

When crystallized in dense aggregates of thin blades and fibers enclosing much adsorbed and capillary water it has commonly been called limonite; however, sufficient proof is now given to show that such crystallized material is really goethite.

Lepidocrocite.—Orthorhombic, $a:b:c = 0·43 : 1 : 0·64$; density (grams per cc.) $4·09 \pm 0·04$; $\alpha = 1·94$, $\beta = 2·20$, $\gamma = 2·51$; streak, dull orange; pleochroism very strong.

The name *limonite* is retained for material which appears to be essentially isotropic ferric oxide monohydrate with adsorbed and capillary water. However, this substance should not be considered a distinct form of ferric oxide monohydrate, as the real nature of such "amorphous" substances is still uncertain.

The fibrous mineral *turgite* is variable in composition and considerable evidence is given that it probably represents solid solutions of goethite with hematite together with enclosed and adsorbed water.

The genetic conditions of the hydrated ferric oxides, and the stability relation of the two monohydrates, are unknown.

[63] No. 1027 of R. B. Sosman and J. C. Hostetter in Trans. Am. Inst. Mining Engineers, 58, 427, 1917.

No definitely crystallized synthetic hydrated ferric oxide has up to the present been prepared. However, it seems certain that only two distinct types of "amorphous" hydrated ferric oxide exist: one yellow and the other reddish-brown. The yellow is apparently essentially ferric oxide monohydrate, while the reddish-brown substance may hold its water in either a dissolved or an adsorbed condition (or both). Thus the synthetic and the natural hydrated ferric oxides exhibit, chemically, great similarity.

Geophysical Laboratory, Carnegie Institution of Washington,
Washington, D. C., January, 1919.

ART. XXI.—*Brecciation in the Niagara Limestone at Rochester, New York;* by ALBERT W. GILES.

While engaged one day last spring in unpacking a collection of fossils made in the vicinity of Rochester, N. Y., the writer was surprised to note that a number of specimens of Niagara limestone, containing both minerals and fossils, exhibited excellent brecciation. Additional specimens collected during the past summer along the course of the Genessee River in the southern part of the city of Rochester show similar brecciation. A careful perusal of the geological literature touching on the Niagara limestone of western New York failed to yield any information regarding brecciation in this formation. This lack of information has led to a resurvey of the writer's field notes and a more careful examination of the specimens.

The Niagara limestone, more specifically named Lockport dolomite, is an old formation geologically and has had a long and checkered career in geological literature. Among early descriptions that by Prof. Hall is the most widely known and still remains the best (8).[1] He gives the following stratigraphic sequence:

5. Thin-bedded dark gray or brownish limestone. Few cavities. Highly bituminous. Sometimes contains nodules of hornstone.
4. Thick-bedded dark or bluish gray limestone with irregular cavities, and often siliceous accretions, or hornstone. Surface very ragged from weathering. Highly bituminous.
3. A lighter colored subcrystalline mass, very irregularly stratified, contorted and concretionary.
2. A bluish gray subcrystalline mass, mostly thin-bedded, and separated by seams of dark shale.
1. Gray or bluish gray siliceous limestone; hydraulic limestone, or beds of passage from the shale below.

The "gray or bluish gray siliceous limestone" at the base of the formation measures from 4 to 10 feet or more in thickness and has been regarded as representing a gradual gradation from the Rochester shale below. These transitional beds are best seen at the Goodman street quarries in the northern part of Rochester, and also

[1] Reference numbers in the text apply to the Bibliography at the end of this paper.

along the course of the new Barge canal just south of its junction with the Erie canal in Greece northwest of the city. They are firm, compact, free from cavities and exhibit no brecciation.[2]

The central portion of the formation, above the basal beds just noted, is well displayed in various places in and about the city. The Allen creek section east of Rochester has long been known, and along the course of the Genessee river exposures may be seen at the Court street bridge on the south side of the city, and again at the "rapids" one mile south of the bridge. In the present deepening of the river at the "rapids" to afford a harbor extending from the Barge canal at South Park, located beyond the southern limit of the city, to Court street great quantities of fresh rock have been excavated and thrown out onto the river banks on either side. A definite and comprehensive conception of the lithologic, mineralogic and faunistic characters of a considerable vertical section in the central part of the Lockport limestone may be obtained in a few hours study here. The finest section is found along the course of the Barge canal from Greece to its junction with the river at South Park. This section affords a complete sequence from the basal beds nearly to the upper limit of the formation.

This central portion of the limestone is full of cavities and exhibits brecciation on a large scale. The number of cavities and the degree of brecciation increase upward in the formation.

At the top of the formation the beds show a complete gradation into the Salina shales above. These uppermost layers, but a few feet in total thickness, are nearly everywhere thin-bedded, compact, being almost entirely free from cavities and exhibit little or no brecciation.

The restriction of the brecciation to the same portion of the formation to which the cavities are confined suggests a relationship between the two. This connection is reinforced by the fact that the rock most affected by brecciation is adjacent to the cavities, commonly being the walls of the cavities themselves, and especially the larger cavities. Inasmuch as the cavities are irregular in distribution through the strata the brecciation shows no defi-

[2] All or nearly all of the beds which are considered here as basal Lockport will probably be classified in the future as Gates limestone, a formation recently established by Chadwick lying above the Rochester shale and below the basal member of the Lockport, the Decew limestone.

nite arrangement but instead occurs in patches. Large areas of the rock free from cavities are likewise free from brecciation; this is true of the rock occurring between the cavities in the same stratum, and also in the strata superjacent and subjacent to the cavities.

The cavities have originated in four ways: (1) Preservation of the original openings in the growing reefs; (2) Jointing and fracturing of the rock during consolidation and subsequent earth movements; (3) Shrinkage of the rock in its transformation from a limestone to a dolo-

Fig. 1.

Fig. 1.—Niagara limestone breccia. The angular fragments of limestone are embedded in a matrix of calcite and dolomite (natural size).

mite; (4) Solution of the rock by circulating underground waters.

The agent involved in the last method of cavity formation may enlarge the cavities formed in the first three ways mentioned. However the cavities are small, rarely exceeding one foot in diameter, and commonly they measure but a few inches across. It is believed that the presence of these cavities has made possible the greater part of the brecciation of the rock.

The breccia is of the endolithic type, both crackle and mosaic patterns being represented. All of the fragments are angular and small, the largest having major dimensions of a few inches only, while many measure but an inch or even less in their longest directions. The brecciation has originated from a number of causes. Some of it is undoubtedly expansion breccia. The Lockport

FIG. 2.

FIG. 2.—Breccia fragments of Niagara limestone in selenite. Note the rhombs of dolomite in the extreme right at the top and the crystals of sphalerite just to the left of the center.

limestone carries a great deal of both gypsum and anhydrite, especially in the central and upper portions of the formation. In altering to gypsum anhydrite expands greatly, the increase in volume being 60·30 per cent according to Van Hise.[3] The force resulting from this expansion repeatedly fractured the containing limestone, the portions of the rock adjacent to the cavities being especially affected, for the stresses found easy relief by forcing the cavity walls inward.

[3] A Treatise on Metamorphism, U. S. Geol. Surv. Mon. 47, p. 357, 1904.

Again some of the breccia is to be classified as tectonic. Western New York has never experienced severe dynamic deformation. However, there are many evidences of minor and gentle movements, especially seen in the small anticlines and synclines with major dimensions of but a few feet, and in the small faults of both normal and thrust types with a vertical throw of a few inches. These gentle warpings and displacements have effectively brecciated the limestone which had been weakened by the numerous cavities present. Similar crush breccia originating in an analogous fashion is to be seen in the sheet breccias of the Joplin district (14). Owing to the limited time at the writer's disposal no safe conclusions have been drawn as to the precise relations of the areas of brecciation to the lines of deformation.

Founder, or solution, breccia is also represented although of relative unimportance in comparison with the prevalence of the preceding types. The walls of some of the larger cavities have collapsed, the fissures being healed by calcite, dolomite, barite, strontianite, gypsum and many other minerals occurring commonly in the Niagara limestone. In fact essentially all of the Niagara breccia is held together by these light-colored minerals. Such cavity collapse has been directly aided probably by the gentle stresses resulting from the slow settling of the heavy dolomite into the weak Rochester shale beneath,

Little has been said regarding brecciation in the Niagara limestone elsewhere. Possibly it is not a common characteristic of the formation. Chamberlin mentions a "brecciated or conglomeritic dolomite" of Racine age in his Wisconsin report (4), and Alden describes local brecciation in the same formation in the Milwaukee area (1). Some reference has been made also to brecciation in the Niagara limestone of Iowa (2).

It is hoped that these hasty and scanty observations will furnish the impetus for a more careful study of the Niagara brecciation not only at Rochester, but throughout western New York; a study that might well be undertaken in connection with the larger problem of the dolomitization of the Niagara formation.

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Art. XXII.—*Fossil Beetles from Vero, Florida;* by H. F. Wickham.

In the interesting locality at Vero, Florida, now noted for the finds of human remains in association with those of Pleistocene mammals, several rather good specimens of insect fragments were found. All of the Coleopterous relics, most of them elytra, have been turned over to me by Dr. Sellards, for study, and form the basis of the following notes.

A specific account of the locality, its geological history, stratification and fossils, will be found in an article by Dr. Sellards in the Eighth Annual Report of the Florida State Geological Survey, 1916, pp. 121-160. For the purpose of the present notes, it may be sufficient to say that the insects were found in both of the strata yielding human bones and implements, and in association with remains of the Columbian elephant, the American mastodon and other extinct mammals. The Coleoptera seem worth recording, partly because they throw some light on the probable climatic and ecological conditions at the time of their deposit, and partly because we may gather from them some ideas as to the relative rapidity of specific or subspecific change.

Two conclusions seem to be warranted after a study of the beetle fragments. The first is that there is nothing to indicate any particular difference in climatic conditions in Florida then and now, since the assemblage of genera is the same as one might expect to find in a stream valley there today. The nearest relatives of the species are still characteristic members of the Floridian fauna and many of them are apparently identical. Second, it seems evident that there has been some change in minor characters of sculpture, since it is not possible to match certain of the fossils exactly with modern forms. In view of the fact that other researches indicate that insect evolution has been extremely slow, so that many species, even as old as the Tertiaries, are rather difficult to discriminate from their modern allies, no more marked divergence would be anticipated.

Besides a few small fragments that could not be determined, the following species are contained in the collections:—

Family Carabidæ.

Diplochila laticollis Lec. Represented by a left elytron, complete except that the apex is slightly twisted and broken. In some lights the discal striæ are barely visibly punctate. There are no characters to differentiate this from a recent Iowa specimen. The species still occurs in Florida. Found in stratum 3.

Diplochila major Lec. Approximately the basal half of a right elytron is present. It shows no particular deviation from modern examples taken in Iowa, Indiana and Louisiana. Still occurs in Florida. Found in stratum 3.

Chlænius æstivus Say. A right elytron is before me, lacking a small part of the scutellar region and all of the tip. Part of the pubescence is still preserved near the side. Compared with recent specimens from Lake City, Florida, the fossil is darker, perhaps from discoloration, and the interstitial punctuation is a little more scabrous or mucronate. It is still a rather abundant Florida insect. Found in stratum 3.

Chlænius tricolor Dej. A left elytron, lacking the tip, seems to go here very well. An abundant insect in the eastern United States, including Florida. From stratum 3.

Chlænius sp. A pronotum, simply labelled Vero, Florida, is different in some respects from any modern Chlænius known to me. It may, however, belong to one of the southern species with which I am unacquainted.

Oodes amaroides Dej. An entire right elytron, labelled like the preceding, is apparently just like a modern specimen from Indiana. It still occurs in Florida.

Family Scarabæidæ.

Copris inemarginatus Blatch. Represented by somewhat more than the basal half of a left elytron and a smaller curled fragment, taken from stratum 2, north bank, 370 feet west of the bridge. Compared with a recent Iowa specimen of *C. anaglypticus* Say, the fossil has narrower and sharper striæ with deeper crenate punctures, giving the sculpture a rougher appearance. The interstrial ridges in the fossil are barely visibly punctulate (under a 9x lens) while in the Iowa example this punctuation is very distinct, though fine and sparse.

However, in this latter feature, the fossil is matched by an example from Gainesville, Florida, kindly loaned me by Professor Watson, which is probably an atypical specimen of the form called *inemarginatus* by Blatchley and I have classified the fragments accordingly.

Strategus antæus Fabr. From stratum 3 comes a left hind tibia which is shorter and relatively stouter than that of recent specimens from Florida and Massachusetts. The fossil is also darker, subopaque, the upper ridge more sinuate and the surface between this and the second ridge much more strongly and deeply punctate. Since a recent individual from Georgia approaches the fossil closely in ridge structure and punctuation, I do not like to propose a new name.

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Art. XXIII.—*Literature Relating to Human Remains and Artifacts at Vero, Florida;* by E. H. Sellards.

In the July, 1916, issue of this *Journal* the writer announced the discovery of human remains and artifacts in association with extinct vertebrates at Vero, Florida. Since that time there has accumulated a very considerable literature relating to the locality and to the discoveries. Among papers on this subject recently issued is a memoir by Dr. Aleš Hrdlicka which is included in Bulletin **66** of the United States Bureau of American Ethnology (pp. 23-65, 1918).

In this memoir Dr. Hrdlicka maintains the hypothesis previously proposed by him that the human remains and artifacts found at Vero represent burials by human agency. Aside from adhering to this hopelessly inadequate hypothesis, the paper is remarkable for what it omits rather than for what it contains. Papers by a number of geologists and anthropologists had been published previous to the final revision of this memoir, as is indicated by a statement found on page 65 of the paper, but to the contents of these publications there is no adequate reference. The hypothesis proposed by Dr. R. T. Chamberlin, which is in accord neither with that of Dr. Hrdlicka nor with that of the present writer, receives not so much as mention. The investigations of Dr. O. P. Hay, which support the Pleistocene age of the human remains, is only casually referred to. The observations of Dr. G. G. MacCurdy, which in no way support the burial hypothesis are not mentioned. It might have been supposed that the observations and conclusions of a specialist in paleobotany would have been of interest, since an important part of the evidence in this instance rests with the fossil plants. Nevertheless the fact that Professor E. W. Berry has stated that he has personally observed artifacts in place in these deposits lying beneath a late Pleistocene flora under conditions such that they could not possibly have been introduced by human agency is singularly passed over. In fact the brief reference to Berry's paper fails to indicate that in addition to a description of the fossil plants, he has placed on record observations relating to the place of the human relics in the deposits.

In the introductory paragraph of his "Critical Observations" Dr. Hrdlicka states that everything relating to human occupancy had been removed before anthropologists had an opportunity of visiting the locality. This is not in accordance with the facts, for, as everyone knows who has informed himself about the problem, the human artifacts have not all been removed, and anyone who is interested may yet see objects of human workmanship in place in this formation. Dr. Hrdlicka maintains that he has detected discrepancies in some of the writers' statements in regard to the measured thickness of parts of the section. Fortunately the problem does not rest on the writers' statements or observations alone, but on the observations of others as well. The student who is interested in the question of the age of the human remains found at this locality will do himself an injustice if he accepts this memoir by Dr. Hrdlicka as a fair presentation of the subject. Rather it will be necessary to consult the literature as a whole, and for the convenience of any who may be interested there are here included references to all the publications, so far as the writer is aware, that have appeared relating to the Vero deposits. The evidence both for and against the Pleistocene age of the human remains and artifacts has been fully stated in these papers. In the judgment of the writer it can not be successfully denied that at this locality there are found relics of human workmanship and human bones in association with and contemporaneous with a fauna and flora that elsewhere and heretofore have been considered Pleistocene.

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ART. XXIV.—*On the Relative Ages of certain Pleistocene Deposits;* by OLIVER P. HAY.

The writer accepts the conclusions of those glaciologists who hold that there occurred during the Pleistocene epoch four or five glacial stages, each of which was followed by a stage of mild climate. As a result of great extremes of climate and of alternate reduction and expansion of the habitable areas one might expect that, as the glacial epoch passed on, obvious changes in the faunas would show themselves through both extinctions and modifications. As to the development of new species during the part of the Pleistocene known to us, this might be hard to prove. As a matter of fact, it would now be hazardous to assert that any particular existing species had not been present, either here or in Asia, early in the Pleistocene. As to extinctions, these stand out clearly. I have a list of over 600 species of vertebrates which have been reported from our Pleistocene deposits; and of these about 60 per cent are extinct.

As is shown in and near the glacial region, many species, mostly conspicuous because of their size, as elephants, the American mastodon, the giant beaver, the existing beaver, and *Megalonyx jeffersonii,* lived on from the first interglacial stage to the post-Wisconsin. A considerable number of other species, as the long-horned bisons, at least one species of horse, the tapirs, sabertooth tigers, and mylodon, no longer appear after the Wisconsin stage, but did exist during the interval between the Illinoian and the Wisconsin. Other mammals, again, as *Elephas imperator,* the camels, and many species of horses, are not found after the second glacial epoch, the Kansan. Hence, in the glaciated region, we may for the present recognize three Pleistocene faunas, an early, a middle, and a late. Did these faunas have the same history in the nonglaciated region as in the glaciated; or did the early fauna continue on in the southern States virtually unchanged up to the end of the Pleistocene? There are those who take the view last mentioned. Some of these base their opinions on the geological structure of the Pleistocene part of the coastal plain; others on the fact that in certain localities the animal remains are associated with relics of man. It must be granted that either those who believe that the low-lying deposits along the Atlantic coast of the southern States belong to the late Pleistocene must surrender their position or it must be acknowledged that the animals found fossil in them existed up to near the end of the Pleistocene or later.

It seems improbable that the early Pleistocene vertebrate fauna remained practically unchanged up to the end of the epoch. Time itself is a powerful factor in bringing about extinctions among living beings. All species are continually under stress; and it is to be expected that normally first one and then another will succumb; so that in the course of a long period there will result a more or less gradual change in the fauna, even though there are no great changes in the environment. During the course of the Pleistocene there were, especially in the north, several alternations of climate from one extreme to another; and it is hardly probable that these changes did not affect the vertebrates of the southern States. Furthermore, the northern species were at each glacial stage forced southward, so that these regions tended to become overpopulated. Also, if there is anything of importance in the idea that northern animals are more hardy, these would have had an advantage over those not accustomed to the colder climate. It is the species of the southern States which especially might be expected to have gradually died out during the progress of the Pleistocene. There are those[1] who assert that the fauna in question belongs to the late Pleistocene or even to the Recent. If such an assemblage of vertebrates as is found in the low-lying formations of Florida, Georgia, and South Carolina, existed there after the end of the last glacial epoch and then suffered the extinction of more than two-thirds of the species, some adequate cause ought to be sought for such a disaster. That the Indians with their feeble weapons effected the destruction is not to be believed. They were making no impression on the game animals of the country when the whites arrived. Nobody has found the bones of elephants, horses, or ground-sloths in the shell heaps of Florida.[2]

If such animals as *Elephas imperator,* the camels, the tapirs, horses, the great cats, the saber-tooth tigers, the mylodons, and *Bison latifrons,* had lived around the Gulf

[1] MacCurdy, Jour. Geol., vol. 25, p. 62; R. T. Chamberlin, vol. cit. p. 662.
[2] Nelson, Science, vol. 46, p. 394.

and along the south Atlantic coast after the passing away of the last glacial stage, there appears to be no good reason for supposing that they would not have moved northward and reoccupied their ancestral hunting grounds. All of these had once lived in the regions of Iowa, Nebraska, Kansas, and most of them as far east as New Jersey. Many species, large, medium-sized and minute, did return to the newly opened fields. *Equus complicatus* had more than once been driven from the glaciated region; but each time it returned; and its remains have been found in deposits overlying Illinoian drift. Is there any reason to be suggested why, after the Wisconsin glacial stage, this horse and *Bison latifrons* preferred to remain and perish on the sandy plains of Florida when they might have reoccupied their old ranges, which furnished as fine grazing lands as have existed? It cannot be said that the climate in the northern States was unfavorable, for we cannot doubt that, as the glacier began to withdraw, the climate grew milder; and there are evidences in both the animal and the vegetable kingdoms that the climate was for some time warmer than it is to-day. The writer has elsewhere noted the former existence of peccaries along the south shore of Lake Ontario and in Michigan; also the presence of *Megalonyx* as far north as Minneapolis. In 1915 Dr. H. L. Shimer[3] printed a list of mollusks which had been found in post-glacial deposits at Boston. Of about 60 species, approximately one-half no longer live north of Cape Cod, or only rarely in sheltered areas. He says that the record is of primary interest because of the evidence it furnishes as to a warmer period after the retirement of the glacier.

In the same volume of this Journal, on pages 17, 18, Barrell quotes a letter written by Fernald regarding certain plants which had been found on Prince Edward Island, the Magdalen Islands, and in Newfoundland, but whose relationships are with plants found in the pine-barrens of New Jersey. "Thirty-five per cent of the plants of Newfoundland are southwestern types, and 7·7 per cent of these are plants characteristic of the coastal plain of New Jersey and the South" (Barrell, p. 16). The reader may consult with regard to this matter also J. W. Dawson's Canadian Ice Age, pages 140 to 144.

[3] This Journal (4), vol. 40, pp. 437-442.

That the Pleistocene camels, horses, and bisons were better adapted to the sort of climate that was furnished during interglacial stages in the northern States than they were to that of Florida is shown by the fact that it is in the north where the greatest number of species of each is found. Four or five species of camels appear to have inhabited Nebraska and Iowa, whereas rare traces are found of one in the Pleistocene of Florida. About nine species of horses are credited to the northern States, to three in Florida. Some seven species of bisons have been described as inhabiting the northern States during the Pleistocene, while only *B. latifrons* is known to have occurred in Florida; although one, possibly more, smaller species probably existed there.

It must be taken into account also that the camels, horses, bisons, tapirs, saber-tooth tigers, and edentates, if they existed during the Wisconsin glacial epoch, were certainly not all crowded down into Florida. There was, east of the Mississippi, a wide stretch of territory between Florida and the glacier which the hardier species might with safety and comfort have occupied. Finally, there were the great plains of Texas down to the Gulf where the mammals which existed during the Wisconsin might have betaken themselves and whence they might have made their way over the northern lands after the passing of that epoch. Two species of bison, *Bison occidentalis* and *B. alleni,* were apparently abundant west of Mississippi river during the early Pleistocene, but are not known after the Wisconsin stage. Both of these species ranged into Alaska and Yukon. Why then, if they existed during any part of the Wisconsin stage, should they have perished between the Wisconsin moraine and the Gulf of Mexico?

For all those who hold that the animals referred to existed in Florida during and until after the Wisconsin stage, it may be recalled that at Charleston, S. C., a Pleistocene fauna of at least 40 species has been collected, of which 70 per cent are extinct. Among these are such warm climate forms as two species of capybaras, two species of tapirs, a megathere, an alligator, and a huge land-tortoise. If these were living there during the last glacial stage they had as companions the North Atlantic walrus and a moose identical with, or closely related to, the existing species.

Of those who insist that the great roll of extinct species which perished in Florida met their doom during the prevalence of the Wisconsin ice sheet and not at its end, it may be asked why this epoch was more fatal than the three or four preceding glacial stages, during some of which the ice reached still farther south. I think that there are no evidences to show that during this stage the climate was more rigorous than during earlier glacial stages; and it is probable too, that it was a stage of shorter duration.

To the writer it appears, therefore, that the assignment of the formation which contains the extinct fauna referred to and which constitutes the lowest plain in Florida, Georgia, and South Carolina, to the last glacial epoch is made impossible by the character of the fossils contained in it.

Some of our geological friends argue that the lowest formation in the southern States, which they synchronize with the Talbot, is young because it shows little erosion and dissection. Time, however, is not the only factor in the production of erosion and dissection. One would not expect much diversification of the surface of Dismal Swamp to occur in a million years. In his description of the Sardis plain, in southern Mississippi, belonging to the Citronelle (Pliocene) formation, Matson[4] says that there are some interstream plains from five to more than ten miles in width which have inadequate drainage. W. M. Davis,[5] in speaking of an area which has reached the stage of a peneplain, says that "if no accident enters to disturb the relation of mass and base-level, the area will remain indefinitely with insignificant change, maintaining, like the Sybil, an immortal old age." Contrariwise, the formation which, in the southern States, has been regarded as equivalent to the Cape May and Talbot might continue to maintain an immortal infancy.

In North Carolina the Pleistocene formations have been studied and mapped by Dr. L. W. Stevenson.[6] Five terrace plains are recognized, as follows, beginning with the oldest and most elevated: Coharie, Sunderland, Wicomico, Chowan, and Pamlico. The last two together are regarded as being equivalent to the Talbot of Mary-

[4] U. S. Geol. Surv., Prof. paper, 98 L, p. 182.
[5] Jour. Geol., vol. 2, p. 546.
[6] N. C. Geol. Surv., vol. 2, pp. 266-290, pl. XIII, 1912.

land. It may here be noted that from Charleston, S. C., to New York City, the Pleistocene deposits do not furnish a great number of species of vertebrates. In North Carolina mastodons, in twelve localities, have been found, and these within the areas of all of Stevenson's formations, except the Coharie. *Elephas columbi* and *E. primigenius* have been discovered within the Pamlico; but, as these elephants and the mastodoms lived from the first interglacial stage to near the Recent, their presence furnishes no certain basis for determining the age of any of the terraces. However, horse remains have been secured at four localities, Elizabethtown, apparently in Sunderland or Wicomico; at Greenville, in the Wicomico area; at New Bern, in the Pamlico area; and at Plymouth, near which are found Chowan and Pamlico. At New Bern it is pretty certain that the fossil-bearing stratum does not belong to the Pamlico, but to the underlying Chowan, or something still older. Stevenson (op. cit. p. 288) grants the possibility of this. The present writer believes that the horse remains are as old as those found at Vero and Charleston.

Writers who are interested in maintaining the geological youthfulness of the lowest plain, or terrace, along the coast, and who do not feel required to hold that the animals lived late in the Pleistocene, may insist that the remains of the latter are really buried in older deposits which are overlain by the Chowan and Pamlico and their equivalents. Now, at Brunswick, Georgia, eleven species of mammals have been collected, all of which are extinct. There are present *Elephas columbi,* the common mastodon, a tapir, three species of horses, mylodon, and the great megatherium. Lyell observed that the skeleton of the last-named animal was so near the surface that it was penetrated by the roots of a pine. The fossil vertebrates found at Vero and at Charleston occupy equally superficial beds; and this fact makes it impossible to refer the animals to an earlier deposit which is overlain by a later one.

In Virginia the same terrace plains are recognized by Clark and Miller as in Maryland. No equivalent of the Pamlico is mentioned by them. Few vertebrate fossils are known from the coastal plain of this State, especially no horses.

For many of our geologists Maryland and the District of Columbia furnish a standard for the number and names of terraces, Sunderland, Wicomico. and Talbot. Here, as in North Carolina, *Elephas columbi* and *E. primigenius* and mastodon occur, but they do not help us in deciding the age of the formations. In Charles county, near Patuxent river, Cope found two extinct vertebrates, *Grison macrodon* and supposed *Tagassu lenis.* The latter occurs at Vero, Florida, and Charleston, South Carolina; also in Wythe county, Virginia, with many extinct species; but possibly also in post-Wisconsin at Galena, Illinois. At Marshall Hall, 15 miles below Washington, *Equus leidyi* was discovered many years ago, in supposed Talbot deposits. Long ago horse remains were found near Georgetown, now a part of Washington, during the construction of the Chesapeake and Potomac canal. Near Mitchellville, Prince George's county, teeth of an extinct horse have been discovered in Tertiary materials evidently reworked during the Pleistocene. A horse, probably *Equus leidyi,* has been met with at Chesapeake beach. In the eastern peninsula some vertebrates not characteristic of any special formation have been discovered at Oxford Neck, and in Queen Anne's county, both localities not far from Chesapeake bay. No Pleistocene vertebrates are known to have been met with in the eastern half of this peninsula or in the State of Delaware.

In New Jersey three formations are recognized alike by the State Survey and by the Maryland geologists; but the local deposits are often differently identified by the two schools. If a line be drawn from Salem, Salem county, near Delaware river, to Long Branch, on the Atlantic, it will mark pretty accurately the outcrop of the Cretaceous. Nearly all of New Jersey southeast of this line, comprising nearly one-half of the State, is occupied by the Cohansey sands, overlain to a considerable extent by deposits belonging to the Cape May formation. Now it is a fact, the significance of which is not understood, that nowhere in this area of Cohansey sands have any Pleistocene vertebrate fossils been found, while close alone the line indicated and north of it they are not uncommon. At nine or ten different localities along the Cretaceous outcrop mastodons have been met with. These do not help us much on the question of the age of the deposits containing them, and there are few other species which give us help. Horse remains, however, were found long ago in the Navesink Hills and again at Swedesboro; but too little is known about the condition under which they were discovered. Fortunately the conditions are better understood at Fish House, just above Camden. The clays at this place had long been regarded as belonging to the Cretaceous; but in 1869[7] Cope announced that he had found at the bottom of the clays a skull of a horse, and he referred the deposit to the Pliocene. In 1897[8] Woolman described other horse remains, teeth, from the same clays; and he referred the beds to the Pensauken formation. Salisbury and Knapp[9] recorded their final opinion that these beds belong to the Pensauken. On page 78 of the volume just cited these geologists suggest that this formation was, in part at least, older than the Kansan drift.

Immediately below the horse-bearing layer are found many shells which have been referred to the genera *Unio* and Anodonta. Twelve species were described during the time that the beds were regarded as Cretaceous; but a close relationship with existing species was recognized. They are quite certainly to be identified with species now existing in rivers of North America; but at present only one-half or fewer of them live in that region. The others are now found in the St. Lawrence drainage system or still further away. One is confined to the Ohio, Cumberland, and Tennessee rivers. Another occupies the Mississippi and Gulf drainage regions; while one of the species of *Anodonta* is found only in the upper Missouri river region. We have then these reasons for believing that the clays at Fish House are of early Pleistocene age: (1) Competent geologists have referred them to Pensauken. (2) They contain remains of *Equus,* no native species of which is known to have lived during or after the Wisconsin glacial stage. (3) The clays enclose many species of Unionidae, the majority of which now live only in far distant regions.

There are those who believe that the Fish House clays belong to the Cape May formation, which was laid down, as Salisbury and Knapp inform us, during Wisconsin times. These people ought to explain what has caused

[7] Trans. Amer. Phil. Soc., vol. 14, p. 249, fig. 55.
[8] N. J. Surv. Rep. for 1896, p. 201.
[9] Geol. Surv. N. J., vol. 8, p. 104, 1912.

the wide dispersion of the Unionidæ since that relatively late time. Furthermore, if those horses, belonging apparently to *Equus leidyi* and *E. complicatus,* lived at Fish House during the prevalence of the last ice sheet, both of these species must have occupied a widely extended region west and south of the Wisconsin moraine. To this same late time would naturally be referred the horses found at Navesink and Swedesboro, N. J., those found along the Potomac at Washington; and those found at the various localities in the Carolinas. In such case what need is there to suppose that Florida furnished them and their contemporaries a last asylum? Why, too, after the close of the Wisconsin stage should these horses have migrated to Florida and not to the grazing lands which stretched from Hudson river to the Great Plains?

If the numerous species found at Vero, at Charleston, and Brunswick, and the horses found farther north are to be assigned to the latest stages of the Pleistocene there appears to the writer no good reason why the same disposition should not be made of the numerous species of mammals, the great majority of which are extinct, which have been gathered in the Port Kennedy cave, above Philadelphia. It seems to the writer that this assembly of species is satisfactorily connected up with those of South Carolina and Florida; and according to the writer's views, they all belong to about the time of the first interglacial stage.

This conclusion means, of course, that the formations known as the Sunderland, the Wicomico, and much that goes under the name of Talbot, and their geologic equivalents of whatever names, were laid down during the time of the first interglacial and perhaps of the Kansan stages.

Salisbury and Knapp refer the Cape May to the Wisconsin epoch, and the writer knows of no reason for questioning this conclusion; also, as they say, the southern part of the State may at the time of its deposition have been submerged to the extent of from 30 to 50 feet. At very shallow depths at Long Branch and Manasquan inlet, have been found remains of mastodons; but these could hardly have lived there during the submergence. Fairchild[10] is probably correct in representing this part of the coast of New Jersey as being submerged while the glacial front was occupying northern New Jersey and

[10] Bull. Geol. Soc. Amer., vol. 28, pl. XI.

southern New York and New England. Not until the region north of Manasquan river had slowly emerged from the sea could mastodons have lived there; and this was probably not before the glacial sheet had retreated some considerable distance up the Hudson, That is, these mastodons belong probably to the Champlain stage of the Pleistocene.

In the peninsula lying east of Chesapeake bay is found typical Talbot. None of the few vertebrate fossils found along the eastern shore of Chesapeake bay in supposed Talbot give us any clue as to the part of the Pleistocene to which it appertains. It probably corresponds to the Cape May. The central part of the peninsula is occupied by an older formation. Sanford[11] states that in Virginia the Talbot is 30 miles wide at the south. If Stevenson's map of the superficial formations of North Carolina be consulted it will be found that this corresponds almost exactly with the width of the Pamlico formation at the line between the two states. That seems to mean that the Talbot merges into the Pamlico alone. On the latitude of Cape Lookout this formation narrows abruptly and continues on down the coast as an inconsiderable strip. The writer knows no reason why it may not be referred to the Wisconsin stage of the Pleistocene. In Carteret county, a little north of Beaufort, there was dredged up a tooth of *Elephas primigenius,* the most southern point known for this cold climate species. It seems to be most natural to refer it to the last glacial stage.

According to this view, the Cape May of New Jersey, as recognized by Salisbury and Knapp, the Talbot of Maryland (or at least most of it), and the Pamlico of North Carolina are of late Pleistocene time. All of those deposits, which furnish remains of horses, the Navesink Hills, Fish House, Swedesboro, Chesapeake Beach, Marshall Hall, Washington, Plymouth, New Bern, Charleston, and Vero, belong to a much older Pleistocene time, approximately the first interglacial.

Prominent geologists, especially those of the Maryland Geological Survey and of some of the States farther south, have recognized the various formations and terraces above-mentioned as the product of as many periods of submergence in the sea. At the foot of each terrace

[11] Virginia Geol. Surv., vol. 5, p. 25, 1913.

these geologists find, or believe they find, remains of old sea-beaches. The writer's views regarding the existence of the three faunas referred to above do not require him to contest the actuality, only the ages, of the supposed marine terraces. He must, however, call attention to the fact that the two oldest terraces, the Sunderland and the Wicomico, are confessedly devoid of all remains of marine animals, of mollusks as well as of bony creatures. On the other hand, there are found in them, all along the coastal plain, bones and teeth of such land animals as elephants, mastodons, and horses. At some localities, close to the seashore and near the surface, collections have been made of considerable numbers of species of land vertebrates. That is, in these formations the very things that the theory of submergence requires are wanting, and the very things that would not be expected are present. It is vain to insist that in all that stretch of coast, from the mouth of Mississippi river to Staten island, in such abundant deposits of clays, sands, and gravels, the conditions have been so uniformly unfavorable that no beds of oysters or of other mollusks could be formed and preserved. The conditions have not precluded the preservation of the bones of numerous land animals.

If Maryland, during the Wisconsin stage, was depressed as much as 45 feet, the maximum thickness of the Talbot, one might suppose that the depression was connected in some way with that within the glaciated region. Fairchild has determined, however, that the submergence diminished from about 800 feet in northern New York to nothing near the mouth of Manasquan river, New Jersey.

While not denying that there may have occurred change of level along the coast and occasional limited submergence, especially in the case of the latest formation, the writer believes that the terraces have been laid down mostly by some kind of river action. Salisbury[12] has shown how the terraces of New Jersey might in some such way have been produced.

The low-lying formations around the Gulf coast of Texas, the Lissie, and the Beaumont of Deussen's report (Water-supply paper No. 335), have been supposed

[12] Geol. Surv. N. J., vol. 8, pp. 2-10, figs. 1-6.
See also Chamberlin and Salisbury's Geology, vol. 3, page 452.

likewise to have been laid down rather late in the Pleistocene and in the sea; but here, as along the Atlantic coast, there is a lack of marine fossils and an abundance of land animals. All along that coast, down to salt-water or close to it, are found remains of mastodons, *Elephas columbi, E. imperator, Equus complicatus*, and a camel. To say that these animals lived here at a later period than they did in Kansas and Nebraska is pure assumption. Unless the further assumption is indulged in that these and numerous other species and genera perished in Texas during the prevalence of the Wisconsin glacial conditions, there appears to be no reason why they should not have migrated northward as these glacial conditions relaxed; especially since it is hardly to be conceived that all these animals were confined to a narrow strip immediately along the Gulf.

As will be noted, the writer assigns the Sunderland and Wicomico and their equivalents to the early part of the Pleistocene, but not to the earliest. What was going on in our country during the probably long first glacial epoch is not known. At some time, either in the late Pliocene or early Pleistocene, the whole continent appears to have had a much greater elevation than it has at present. During that time the courses of the great streams appear to have been excavated to enormous depths and sometimes to great widths, so that our country became furrowed by vast canyons. It is well known that many of our great rivers are flowing at levels far above former channels. It appears possible that at some later period of diminishing altitude, during perhaps the first interglacial stage, these old channels and canyons became filled up completely, or nearly so. While they were being filled, the bones and the teeth of animals of the time might have been buried in the deposits. Still later, these old deposits, soils, sands, gravel and stones, might have been partially removed by quickened currents, but partly retained as terraces. It seems possible to account thus for the presence of the same kinds of extinct animals in the upper and the lower terraces and in the present banks of some Texas rivers. In the upper and the lower terraces are found well-preserved remains of camels. In apparently the higher lands at Fort Worth and at Waco have been collected fine teeth of mastodons of the genus *Gomphotherium*, not long ago supposed to have lived only in the Miocene and the Pliocene; and Dr. Mark Francis finds that Brazos river is now washing out from its flood-plain or from deposits underlying it, jaws and teeth of mastodons of the same genus.

At the same time that such channels were being re-excavated the materials might have been dumped at the lower and flatter reaches and have built up a terrace-like plain.

In this connection it may be allowed to discuss briefly the geological age of the Alachua clays in Florida and the Idaho formation in Idaho and Oregon. The Alachua clays have furnished a considerable vertebrate fauna, and have been assigned to the Pliocene apparently by nearly all who have written about them.[13] This conclusion has doubtless been forced by the occurrence in those clays of rhinoceroses belonging to the genera *Teleoceras* and *Aphelops,* camels of the genus *Procamelus,* and species of *Hipparion,* all of which genera were represented in the Tertiary by numerous species; but which are not known, with the exception of *Hipparion,* in deposits acknowledged generally to belong to the Pleistocene. However, the Pleistocene fauna with which the Alachuan species have been compared is that which is found in the so-called Equus beds of the plains. This is itself to be regarded as equivalent to the fauna of the Aftonian beds, intercalated between the first and the second drifts. This stage was, therefore, preceded by another, the Nebraskan, about whose vertebrate animals we know nothing whatever. This stage probably occupied a long period of time. Indeed, Chamberlin and Salisbury[14] suggest that it (the "sub-Aftonian") may have been as long as all the rest of the Pleistocene. Inasmuch as a considerable number of genera of mammals did continue on into the Aftonian Pleistocene from the Pliocene and even from the Miocene, it is not unreasonable to expect that still other Tertiary genera will be met with in deposits that were laid down during Nebraskan times, if such should be discovered. Now among the genera which continue on into undisputed Pliocene deposits are those found in the Alachua clays, *Teleoceras,*

[13] Dall, U. S. Geol. Surv., Bull. 84, p. 127; Matson and Sanford, Water-supply paper 319, p. 142; Sellards, 8th Ann. Rep. Fla. Geol. Surv., p. 93; Merriam, J. C., Bull. Dept. Geol. Univ. Calif., vol. 10, p. 439.

[14] Geology, vol. 3, pp. 383, 414, 420.

Aphelops, Procamelus, and *Hipparion. Hipparion* reaches also into the Aftonian stage; and remains of a camel found at Ocala, Forida, have been identified as those of *Procamelus.* It must certainly be admitted that the other genera might have attained the Nebraskan. Considering the strong, peculiarly Pleistocene element found in the Alachuan fauna, the writer is inclined to believe that the beds belong to the earliest Pleistocene rather than to the Pliocene. There do not appear to be in the collections made in them any considerable chances for admixture of fossils of different ages. Whether or not Sellard's Dunnellon belongs with the Alachua clays may be regarded as questionable.

In southwestern Idaho there is a deposit which has been called by Cope the Idaho beds. Merriam has discussed the age of these clays in his paper cited above (p. 431). They have been regarded as belonging to the Pliocene or even the Miocene. From these beds Cope described twenty-two species of fresh-water fishes. Merriam presents a list of the mammals that have been found in the same beds. Among them are species of *Equus,* a rhinoceros belonging either to *Aphelops* or to *Teleoceras,* and a species of *Procamelus.* That is, here is a fauna quite like that of the Alachua clays. Leidy's *Mastodon mirificus* (*Stegomastodon mirificus*) occurs there likewise. Merriam regards this as a Pliocene species, but it has been found in the Aftonian of Iowa; and Leidy's type quite certainly belonged to the Pleistocene.

Dr. W. D. Matthew (Bull. Amer. Mus. Nat. Hist., Vol. XVI, p. 321) has referred to a small collection of mammals which had been made somewhere in the Oregon desert. The deposits had been considered by Cope as belonging to the Pliocene, doubtless because it had contained *Hipparion, Teleoceras,* and camels of the genus *Camelops,* or possibly of *Procamelus.* It contained likewise bones of *Elephas* and *Equus.* In short, we have here the same unusual assemblage of genera that are met with in Florida and in Idaho. Merriam and Buwalda[15] have discussed the Ringold formation, found along the Columbia river, in Franklin county, Washington. A vertebrate fauna, not determinable specifically, but consisting of about eight forms, was found. This included a species of

[15] Bull. Dept. Geol. Univ. Calif., vol. 10, pp. 255-264.

Megalonyx, an equid (*Equus* or *Pliohippus*), one or two camelids (*Pliauchenia?*), a deer, a leporid, a *Testudo,* and fish remains. While these authors were inclined to place the Ringold in the Pleistocene, they had doubts on the subject. It has been supposed that at the Oregon, the Idaho, and the Florida localities, there has occurred a mingling of remains belonging, some to the Pleistocene, others to the Tertiary; but the occurrence of this combination through accidental admixture in so many different places is improbable. To the writer the most probable explanation is that the three deposits belong to the first stage, the Nebraskan, of the Pleistocene.

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Art. XXV.—*Some Fossil Parasitic Hymenoptera*; by T. D. A. Cockerell.

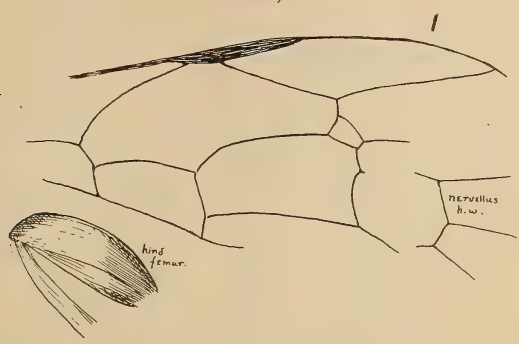
The Hymenoptera described below all come from the Miocene shales of Florissant, Colorado. It is an interesting fact that as far back as the Miocene, at least, the American Ichneumonoid Hymenoptera were abundant and varied, just as they are to-day. There has apparently been little if any progressive evolution in the group within the last million years, although there has been a shuffling of characters, and presumably all the species of the Florissant epoch have become extinct or modified into recognizably different insects. Perhaps a correct picture of the larger aspects of insect evolution is this: When a new and successful mode of life (*e. g.* the parasitism of the Ichneumonoids) develops, evolution proceeds rapidly until practically all the opportunities afforded are exhausted, whereupon the group enters upon a relatively static period, with little or no evolutionary advance. The parasitism of the Ichneumons is presumably much older than that of certain other groups, such as the parasitic bees. Probably the principal developments took place during the latter part of the Mesozoic, a period from which we have very few insect fossils.

Mesopimpla (n. gen.) *sequoiarum* n. sp.

Length 12mm. of which 6 is abdomen; anterior wing 8mm.; width of head slightly over 2mm., of thorax nearly 3; hind femur about 3mm. long and slightly over 1mm. wide. Black, including the femora, but the tibiae and tarsi appear to have been paler, perhaps ferruginous. Antennæ long and slender, the joints rather short. Mesothorax with close minute and weak punctures; metathorax elongate, with at least two parallel longitudinal carinæ, not far apart, in the manner of *Theronia* and related genera. Hind femora extremely stout; legs only moderately long. Wings hyaline, with dark nervures, the essential features of the venation shown in the figures.

Fossil Stump Hill, Florissant; obtained by purchase at Florissant by Professor Wickham. Resembles *Xanthopimpla* in the general form and robust legs, and also in the form of the second recurrent nervure; but differs in the nervellus of the hind wings, which is as in *Glypta* and related genera. The venation of the anterior wings is very like that of *Lissonota;* and the abdomen, as in this and allied genera, appears to be smooth and without

Figs. 1, 2.



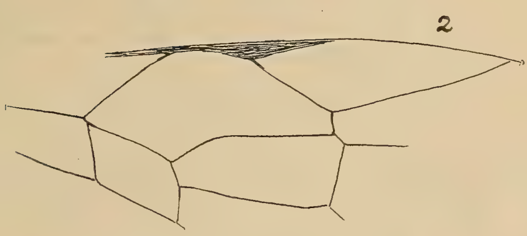


Fig. 1. *Mesopimpla sequoiarum.*
Fig. 2. *Anomalon miocenicum.*

impressed lines. The notauli seem to be complete, though rather weak. Mr. S. A. Rohwer, to whom I sent a brief account of the principal characters, thinks the insect must fall in the *Theronia* group. It seems in fact to combine the characters of different genera, and on the characters just cited, may be regarded as typical of a new genus. Under the microscope the surface of the abdomen appears roughened or irregular, but shows no distinct punctures.

Anomalon miocenicum n. sp.

Length 9·5mm. (not counting terebra), of which 5·2mm. is abdomen; terebra stout, 2·5mm. long, about 2mm. projecting beyond abdomen; wings reddish hyaline, anterior wing 5·2mm. long; antennæ slender, moderately long.

Flagellar joints longitudinally striated; head sub-circular, narrow, not transverse; eyes apparently not hairy; head and thorax black; legs ferruginous, hind femora black or fuscous; abdomen ferruginous, the first two seg-

FIG. 3.

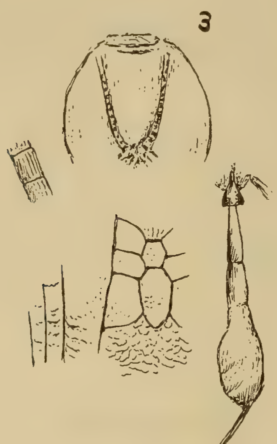


FIG. 3. *Anomalon miocenicum.*

ments black or fuscous; stigma and nervures ferruginous. Hind femora somewhat swollen, about 1·5 times as broad as middle ones.

Florissant (*H. F. Wickham*).

Theronia wickhami n. sp.

Length 8mm. (not counting terebra); terebra exserted 1·6mm.; head and thorax dark brown or black; antennæ slender, fuscous; abdomen and legs pale ferruginous, the abdomen slightly dusky at base; wings clear hyaline, stigma and nervures very pale; anterior wing about 5mm. long; abdomen fusiform, narrow basally, the dorsal carinæ on first segment confined to its basal half.

Florissant (*H. F. Wickham*).

Tryphon explanatum n. sp.

Length 7·3mm., anterior wing about 5mm.; head and thorax black; abdomen ferruginous, the petiole darker, and the apex also more or less infuscated; hind legs black or fuscous, the others apparently paler; wings perfectly hyaline, stigma and nervures fuscous. Metathorax areolated; hind femora about 2mm. long, rather stout.

Station 14, Florissant (*S. A. Rohwer*). Type in Museum of University of Colorado.

FIGS. 4, 5, 6.

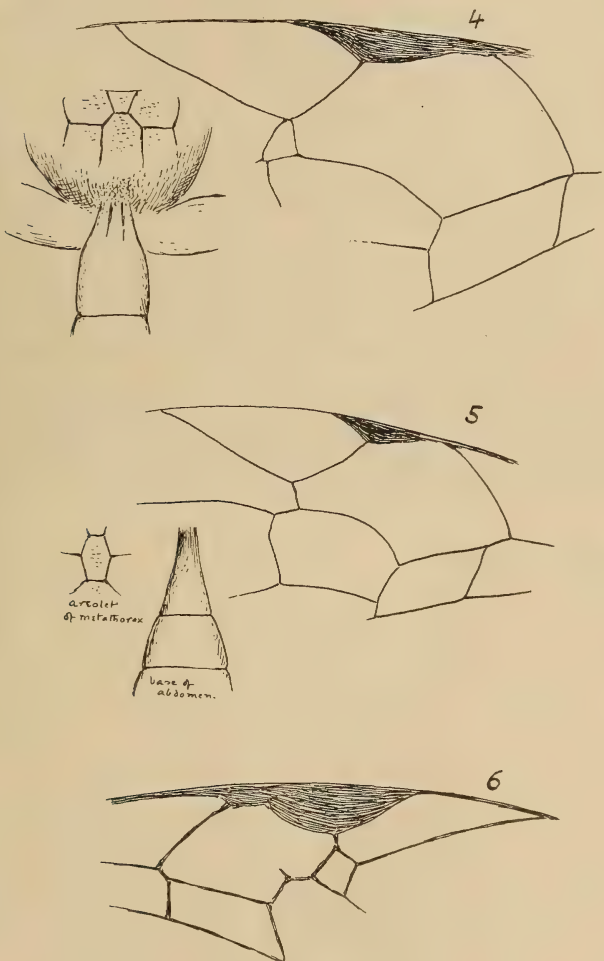


FIG. 4. *Theronia wickhami.*
FIG. 5. *Tryphon explanatum.*
FIG. 6. *Bracon florissanticola.*

Bracon florissanticola n. sp.

Length 5·6mm., of which about 2·7mm. is abdomen; anterior wing about 4mm. Head and thorax black, antennæ dark; abdomen pale ferruginous; legs ferruginous, hind femora very stout; wings perfectly clear, stigma and nervures ferruginous. Grooves on mesothorax finely beaded. The shape of the head cannot be ascertained, as only the upper side is presented, but this, with the scape, resembles that of *B. vulgaris* (Cresson). The flagellum also shows the same delicate longitudinal fluting of the joints, but the joints are distinctly longer, the middle joints at least 1·5 as long as wide.

Florissant (H. F. Wickham). This differs from the modern *Bracon* (*Cremnops* Foerster) in the hyaline wings, and as the elongate form of the head cannot be demonstrated, it is possibly a member of the tribe Microdini (Bassinæ of Viereck), where it might fall near *Crassomicrodus* Ashmead, being separated by the quadrangular areolet. Among the described Florissant fossils, it is nearest to the larger *Agathis saxatilis* Brues, which is perhaps not a true *Agathis*. From this, it will readily be known by the confluent first cubital and first discoidal cells, and the pale veins and light red abdomen. The Florissant fossils described under *Bracon* by Brues (Bull. Mus. Comp. Zool., 54) will stand as *Microbracon cockerelli, M. abstractus* and *M. resurrectus.*

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SCIENTIFIC INTELLIGENCE.

I. Chemistry and Physics.

1. *Note on the Preparation of Glycerine by Fermentation.*—Karl Schweizer has explained his experiments which led to a greatly increased yield of glycerine during the fermentation of sugar by yeast, and states that during the recent war certain of the belligerent countries have prepared their glycerine industrially by this method. As early as 1857 Pasteur found that glycerine was formed during alcoholic fermentation, and he obtained a yield of 3·60 to 3·64 parts for 100 parts of sugar fermented. Later it was found by Laborde that the quantity of glycerine formed varies with different races of yeast, and obtained as much as 7·75 g. from 100 g. of sugar. It has been found also that the amount of glycerine formed is greater in a medium rich in nutritive matters, and less in cases where the conditions are less favorable for the growth of the yeast plant. It was evident that the amounts of ethyl alcohol and glycerine were not proportional.

It was supposd by T. Erlich that glycerine could be formed from certain acid amines, as is the case with amyl and other higher alcohols, and thus its formation was attributed to the fatty matter that is found in little droplets in the yeast cells, but it was demonstrated later that the quantity of this fat was too small to explain the formation.

Oppenheim proved that glycerine can be formed by the reduction of glycerine aldehyde and of dioxyacetone, substances that are formed during alcoholic fermentation, and various hypotheses were made in regard to the intermediate products of the transformation of sugar into alcohol. It appeared plausible to the author that the use of reducing agents in the fermenting liquid might increase the yield of glycerine, and accordingly experiments were made, both in his laboratory and upon a technical scale. The greatest difficulty was to find a race of yeast that would withstand the conditions, but this was found in a commercial pressed yeast made from molasses. Powdered zinc in dilute sulphuric acid solutions did not give satisfactory results, and attempts with acid solutions were abandoned. The reduction in solutions as nearly neutral as possible by means of sodium sulphite in the presence of powdered chalk was studied and finally led to success, after the proper concentration of the sugar solution, the amounts of sulphite and nutrients had been determined.

After dissolving 40 g. of sugar, 2 g. of ammonium biphosphate and 1 g. of dipotassium phosphate in 400 cc. of water, then adding 10 g. of pressed yeast, the beginning of the fermentation was awaited, and then sodium sulphite to the amount of 30 g. was added. After 24 hours the fermentation was finished, 800 cc. of carbon dioxide had been given off, the liquid had a strong odor of vanillin, and 100 g. of sugar had produced 21·3 g. of glycerine as an average of several experiments.—*Helvetica Chimica Acta*, **2**, 167. H. L. W.

2. *The Determination of Nitrous Acid and Nitrites.*—J. S. Laird and T. C. Simpson, of the University of Michigan, have found that the methods given in the literature for these determinations are not satisfactory, and they suggest a modification of Raschig's method, which they have found to give excellent results. An excess of standard permanganate solution is placed in a flask and acidified with 10-20 cc. of 1:4 sulphuric acid. The nitrite solution is run in slowly with constant shaking. In this way there is no danger of loss of nitrite due to decomposition upon acidifying. Excess of ferrous sulphate, hydrogen peroxide or sodium oxalate, in the form of a standardized solution, is then added, and the clear solution is then titrated with the permanganate solution. It was found that this method is not interfered with by moderate amounts of chlorides or small amounts of bromides.

In the course of their investigation the authors found that silver nitrite, which has been highly recommended for the purpose, is not a satisfactory material for use as a standard in nitrate determinations. They prefer to use a sodium nitrite solution standardized either by the volumetric method given above, or gravimetrically by the reduction of silver bromate to bromide according to the method of Busvold.—*Jour. Amer. Chem. Soc.*, **41**, 524. H. L. W.

3. *The Natural Organic Colouring Matters;* by Arthur George Perkin and Arthur Ernest Everest. 8vo, pp. 655. London, 1918 (Longmans, Green & Co., New York. Price $9 net). —This book is one of the exceedingly important "Monographs on Industrial Chemistry" which are in course of publication under the editorship of Sir Edward Thorpe. It gives a comprehensive discussion of the present knowledge of natural organic coloring matters, particularly from a chemical point of view, but with many statements concerning their properties as dyes.

The authors state that prior to the year 1880, excepting in the cases of madder and indigo, very little was known of the chemical structure of these coloring matters, and, in fact, it is only during the last 30 years that a large amount of information in regard to them has been obtained. In looking through this volume one is much impressed with the vast amount of knowledge that has been gained in this recent period by observing the hundreds of complex structural formulas that are presented as representing these chemical compounds. The great industry and success of the organic chemists who have labored in this field is well shown by the fact that the discussion of the coloring matters of unknown constitution is confined in this large book to a chapter of only 42 pages.

The book is well arranged, with an interesting introduction and chapters which classify the natural dyestuffs according to the chemical groups to which they belong. There are copious references to the chemical literature, and it should be extremely useful to all chemists who are interested in the constitution of dyestuffs. H. L. W.

4. *Chemistry in Old Philadelphia;* by Edgar F. Smith. 8vo, pp. 106. Philadelphia, 1919 (Printed by the J. B. Lippincott Company).—Within the past four or five years we have been indebted to Dr. Smith for two sumptuous volumes, important contributions to the history of American Chemistry, entitled "Chemistry in America" and "The Life of Robert Hare." We now welcome this additional contribution, material for which has been found, as the author says, "in ancient volumes, musty documents and seared and forgotten letters."

The earliest chemist mentioned is Dr. deNormandie, of whom nothing is known except that he published an account of the examination of a spring water, and actually used a balance in this connection as early as 1768. The following year, 1769, was the date of the appointment of the celebrated Dr. Benjamin Rush at the University of Pennsylvania, the first professor of Chemistry in America and a signer of the Declaration of Independence. Very interesting information is given in regard to Woodhouse, under whom Benjamin Silliman studied chemistry, concerning Seybert, who described many mineral analyses in the early volumes of this Journal, while additional facts are given concerning the famous Joseph Priestley's life in America. Only a summary of the work of Robert Hare is given, since this has been treated elaborately in the author's "Life." Incidents in connection with many other early Philadelphia chemists are given, and the book is an exceedingly interesting and readable one.

H. L. W.

5. *Forms Assumed by Drops and Vortices.*—In the usual methods of producing vortices the various stages of the phenomenon succeed one another with great rapidity, so that either unusually acute observation, or instantaneous illumination and photography, is required to isolate any particular one. A very ingenious method for producing permanent three-dimensional records of vortical forms has been devised and thoroughly tested by Emil Hatschek. The fundamental idea was to produce drops or vortices of a suitably colored gelatin sol in one of the numerous solutions which promote the setting of gelatin sols or cause hardening of gelatin gels. Apart from the possibility of arresting the vortex at any given stage by the proper choice of solution and concentrations, this procedure gave results which

are not obtainable even transitorily with liquids alone, namely, shrinkage or imbibition, and consequent modifications of the smooth surfaces of revolution presented by the primary vortex.

The gelatin sol was allowed to drop into the coagulating solution through the air, the distance from the orifice of the dropper to the free surface of the solution having various values up to about 15 mm. In the first series of experiments the gelatin sols were usually made by dissolving 14 grams of gelatin in 100 cc. of water. The best results were obtained with aqueous solutions of aluminium sulphate. The density and temperature of the fixing bath had to be regulated and controlled with the greatest care. The density range was from 1·026 to 1·035 grams per cc. for gelatin sols varying from 10 to 14 per cent. The temperature influenced the results more through the viscosity and setting velocity than through the density. The second best salt was found to be ferrous sulphate.

When the density and temperature of the solution were practically the same as those of the gelatin sol, and when the orifice (of diameter 4 mm.) was close to the free surface of the bath, the familiar forms of the "hanging drop" were obtained in great perfection. These configurations, however, differ from the analogous forms assumed by liquid drops in one significant particular. That is, the outline of the top surface, which rests in the free surface of the solution, is not circular, but crenate or stellate, owing to shrinkage, and the crenated cross-section extends down the neck of the drop, so that a number of meridional corrugations or ribs are formed.

This feature can be greatly accentuated either by slightly reducing the density of the solution or by running in the sol more rapidly, so that the weight of the drop increases quickly before the sol has had time to set completely. In this way, the length of the neck can be increased very considerably, while at the same time shrinkage becomes more pronounced; the cross-section is star- or cross-shaped, while, in extreme cases, the drop may hang at the end of a long and delicate flat band. Shrinkage at different distances from the center is likewise not uniform, so that the ribs of a single band become crinkled, showing in some instances a very striking resemblance to the "undulating membrane" found on many organisms.

If single drops of the same gelatin sol, at temperatures between 25° and 30°, are allowed to fall into a solution of aluminium sulphate having a density of 1·030 to 1·032 at 18° to 18·5°, a small portion of the drop adheres to the surface of the bath and the rest develops a vortex which attains its final shape and comes to rest at 5 to 12 mm. below the surface. The general contour is now that of the vortex "mushroom."

To show conclusively that the formation of ribs was due to shrinkage, the author tried gum arabic sol, thus avoiding the presence of a salt. This sol has no dehydrating or lyotrope effect whatever on gelatin sol, and the setting of the latter is therefore pure gelation, due to fall in temperature. Extremely beautiful "medusa" forms were obtained, showing no trace whatever of ribs. In many cases the bell became so thin that although the rim was deeply colored (with Congo red), its central portion showed no color at all, and the specimen could be mistaken for an open vortex ring were it not for the fact that the stem could be seen issuing from, and attached to, the center of the bell.

The original paper contains an account of many more interesting and suggestive experiments, but lack of space necessitates referring the reader to the source for further details. Suffice it to say that, by using potassium ferrocyanide or tannin, semi-permeable membranes were formed around the figures and many patterns of the lower organisms were artificially produced. In particular, it was found possible to make models of the human red blood corpuscle, magnified from 700 to 800 diameters.—*Proc. Roy. Soc.*, **95** A, 303, 1919. H. S. U.

6. *Electrical Resolution and Broadening of Helium Lines.*—This investigation has been recently undertaken by Thomas R. Merton, who has improved the technique of the method which he so successfully employed in the study of the Balmer series of hydrogen. The basic idea consisted in mounting a neutral-tinted glass wedge in front of the slit of a prism spectrograph, thus causing the spectral lines to be brightest at the ends corresponding to the thinnest portion of the wedge, and to gradually fade away in the direction of the thicker region of the wedge. A vacuum tube of the conventional Plücker form, containing very pure helium, at a pressure of about 1 mm., was set at a distance of about 30·5 cm. from the slit, and the image of the capillary was brought to a focus at the plane of contact of the slit and wedge. The time of exposure was about six hours, the vacuum tube being excited by means of a fairly heavy discharge from an induction coil which was capable of giving a 25 cm. spark in air.

The results obtained are in complete accord with Stark's hypothesis that the broadening of the lines is largely, if not entirely, due (under the present experimental conditions) to the influence on a radiating atom of the intense electric fields of neighboring particles. The principal conclusions are summarized as follows:

1. The broadening of helium lines by condensed spark discharges is in close agreement with the electric resolution of the lines.

2. The "isolated components" in the electric resolution, which have been recorded by Brunetti and by Takamine and Yoshida, have been found in the broadened lines.

3. An explanation is offered of the relative degree of broadening of lines of the "arc" and "spark" type, on the supposition

that the latter act as a kind of safety valve to the former when the intensity of excitation becomes very great.

4. It is suggested that the "isolated components" are not a direct product of the electrical resolution, but are in reality an extension of the helium spectrum. Two of these lines may perhaps be represented as lines of combination series.—*Proc. Roy. Soc.*, **95** A, 30, 1918. H. S. U.

7. *From Nebula to Nebula. Fourth Edition;* by GEORGE HENRY LEPPER. Pp. 401. Pittsburgh, 1919 (The Author).—"The object of this work is twofold: (1) to present a re-valuation of the time-honored doctrines upon which modern theoretical astronomy is based, and (2) having shown wherein they are defective, to propose a new and far more comprehensive system revealing the entire visible universe in the philosophic aspect of a single organic unit co-ordinated throughout, as *a priori* it *must* be, by a single dynamical force."

The author explains practically all celestial phenomena by the conception of the "stellar resultant," which seems to mean the resultant force acting on any mass due to the gravitational attraction of all the stars and other masses in the universe. The line along which the solar system, or any component member of this system, is supposed to be constrained to move by virtue of the stellar resultant is called the "prime resultant." The severe adverse criticisms of Newton and astronomers in general are, for the most part, absolutely unfair as they are based on false premises and glaring misconceptions. On page seven the attraction of the earth on the moon is expressed in horse-power, and confusion starts as a consequence of complete ignorance concerning vector subtraction, the true nature of centripetal acceleration, the action of constraints, etc. On page fifteen we find: "*It is not the law of the inverse square* that our astronomers employ in their computations, but that of the inverse 2·0000001574 power!" Again (p. 96): "In a word, Newtonians while *ostensibly* representing the circulating body as traveling on the strength of its *inertia*, *actually* treat it as *self-motored,* i. e., as *persistent,* while I frankly face the truth and cite the Prime Resultant as the centrifugal agent." With regard to the principle of the degradation of energy the author expresses his sentiments in the following words: "College professors who have grown gray in the teaching of this vicious and altogether erroneous doctrine have doubtless become hardened to its monstrosity, for they seem to proclaim it in and out of season with every mark of proud paternity!" The volume does not contain an index but it closes with blank pages headed "Notations." H. S. U.

8. *Elements of Astronomy, Revised Edition;* by CHARLES A. YOUNG. Pp. x, 464 + 42, figures 159, maps 4. Boston, 1919 (Ginn and Co.).—This excellent text first appeared in the year 1889, and it was thoroughly revised by its author in 1897.

Accordingly it does not seem necessary to give, at the present time, a detailed account of the scope and salient features of this deservedly popular book. The preface to the latest edition, which is signed by Anne Sewell Young, consists of the following single, explanatory sentence: "While the greater part of the text remains as it was written by its author, such changes have been made in this issue as are necessary to bring it down to date." H. S. U.

II. Geology.

1. *Notes on the Geology of the Glass Mountains;* by J. A. Udden. *Geologic Exploration of the Southeastern Front Range of Trans-Pecos, Texas;* by C. L. Baker and W. F. Bowman. University of Texas Bulletin **1753**, 1917. Pp. 177, 12 pls., 1 map.—The southeastern Front Range of Trans-Pecos, Texas, recently explored and mapped by Baker and Bowman, is a region of exceptional interest. It includes the greatest-known development of Permo-Carboniferous strata, and "every mode of mountain making is there represented." The mountain-making movements of the Western Cordillera are superposed upon Paleozoic folds of the age and character of the Appalachians. Deposition in Upper Cambrian time was followed by emergence and erosion and the deposition of Ordovician sediments, which are unconformably overlain by Devonian(?) cherts or novaculite. An erosion surface separates these cherts from middle Pennsylvania beds, which before the close of Upper Pennsylvanian time were folded into a mountain range. After a long period of erosion this range was submerged and over it deposited the great thicknesses of Permo-Carboniferous beds. Re-emergence was accompanied by gentle folding and followed by subaerial erosion during the Triassic and Jurassic periods. Later events were: the advance of the Comanchean sea, Eocene vulcanism, Tertiary erosion, and formation of the present mountain ranges near the close of Tertiary time.

Glass Mountains described by Udden are a part of the Front Range made of 9,640 feet of folded Permo-Carboniferous sediments which "rose for some time above the surrounding country in the Comanchean sea." (For a discussion of the important paleontologic discoveries at Glass Mountains, see this Journal, vol. **47**, pp. 305-307, 1919.) H. E. G.

2. *Geological Observations in Fiji;* by Wilbur Garland Foye. Proc. American Academy of Arts and Sciences (Shaler Memorial Series), vol. **54**, no. 1, 1918. Pp. 145, 40 figs., 1 map.—Six months' study of the geology of Fiji by Professor Foye supplements work of Darwin, Dana, Gardiner, Agassiz, Andrews, Woolnough, Guppy, and Davis. The geologic history of the group of islands is summarized as follows: "Batholitic intru-

sion, erosion, volcanism, brief erosion, subsidence, uplift, erosion, volcanism, subsidence, uplift, erosion, volcanism, submergence.'' The dates of all these events remain to be determined. The conclusions reached regarding the origin of barrier reefs and atolls is that they develop on antecedent platforms and could have existed in pre-glacial as well as in post-glacial time; that progressive subsidence is not a general cause. No evidence of Pleistocene wave-cut platforms was discovered. Although the object of Dr. Foye's expedition, made possible by a Sheldon Traveling Fellowship, was a study of the geology of coral reefs, the largest amount of new material relates to structure and petrography. Four periods of volcanism are indicated—the first rhyolitic, the second and third andestic, and the fourth basaltic. H. E. G.

3. *The Metamorphic Rocks of Adelie Land;* by F. L. Stillwell. Australasian Antarctic Expedition 1911-1914, Series A, vol. **3**, part 1, section 1, 1918. Pp. 230, 14 text figs., 35 pls. (including 125 figs.)—A large collection of metamorphic rocks from Cape Denison, Cape Gray Promontory, Aurora Peak, and other localities in Adelie Land have been subjected to petrographic and chemical study. The rocks include phyllite, garnet gneiss, garnet-cordierite gneiss and cyanite-biotite gneiss, developed from sediments, and a variety of basic and acid metamorphosed gneisses, equivalents of dolorite, aplite, and granite. The amphibolite series is well represented. On the basis of the collections in hand Dr. Stillwell discusses several interesting problems in metamorphic geology to which he makes helpful contributions. He supports the hypothesis of diffusion to account for amphibolites, calls attention to the limitations of chemical criteria, and clarifies some points in the problem of migration of material during metamorphism. The charnockite series, the kodurite series and the ''infra plutonic zone'' hypothesis are somewhat fully discussed. The value of Dr. Stillwell's presentation is much increased by the inclusion of 48 excellent microphotographs, 30 reproductions of rock specimens, and 47 outdoor views. H. E. G.

4. *The Factors Influencing Gold Deposition in the Bendigo Goldfield,* Part II; by F. L. Stillwell. Advisory Council of Science and Industry, Bulletin **8**, 1918 (Melbourne, Australia). Pp. 47, 14 pls.—To meet the demands for increased production and to secure co-operation of organizations and individuals concerned with Australian resources, the Commonwealth Advisory Council of Science and Industry was organized. The results of the investigations have appeared in nine bulletins dealing with problems of stock raising, agriculture, and mineral products. A special committee under the chairmanship of Professor Skeats has in hand a study of the mode of occurrence of gold in quartz with the object of cheapening the cost of deep prospecting. As part of the program the Bendigo gold field, formerly one of the

world's greatest producers, has been re-examined by Dr. Stillwell (Bulletins 4 and 8). Evidence has been obtained to show that the reefs are younger than the faults and that replacement plays a larger part than hitherto assumed. Confirmation is given to Taber's theory and experiments (this Journal, Vol. **41**, 1916)—that veins may grow in porous rock in the absence of pre-existent fissures and then increase in width by pushing apart the enclosing walls. H. E. G.

5. *The Geolgoical Results of an Expedition to South Australian Border, and Some Comparisons between Central and Western Australian Geology Suggested Thereby;* by H. W. B. TALBOT and E. deC. CLARKE. Jour. and Proc. Royal Society of Western Australia, vol. **3**, 1918. Pp. 1-29, 12 figs., 3 pls.—The unusually favorable season of 1916 permitted a geologic traverse by means of camels across the level desert region stretching from Laverton, West Australia, to the eastern boundary of that State. Observations of geographical features and of manner of erosion were made and an interesting new formation, the Wilkinson Range Series, was studied. The base of this series is a bed of flattened, striated boulders with a thickness over wide areas of about 15 feet and included between sediments of shallow water origin. The authors ascribe this bed to debris from icebergs, which implies that in late Mesozoic (Tertiary?) time bergs extended to 26 degrees south latitude. Sediments of Ordovician age in the Townsend Range bear such close resemblance to formations in West Australia classed as Devonian as to cast doubt on previous correlation. Unfortunately the leader of the party, Mr. Talbot, and an assistant, Mr. Johnson, were wounded in a night attack made by the native blacks, and the expedition was forced to return before their program was completed.

H. E. G.

6. *The Geology of South Australia;* by WALTER HOWCHIN. Pp. xvi, 543; 330 figs. Adelaide, 1918 (Education Department). —Australian teachers and students will doubtless welcome Howchin's Geology. It present the Australian viewpoint, and relieves schools from the necessity of using English and American texts which are unsuitable for Australian needs. The first part of Mr. Howchin's text (pp. 1-326) is a treatise on the facts, principles, and methods of structural, dynamical, and physiographic geology after the manner of American books. The distinguishing feature is the use made of Australian researches and illustrations. The second part of the book (pp. 327-515) deals with the geology of South Australia with references to the geologic features of other states of the Commonwealth. The treatment is chronological with chapters on each system. Most space is naturally given to those groups of rocks most fully developed in South Australia—Cambrian, Permian, Cretaceous, and three divisions of the Tertiary. Interesting features to

students unfamiliar with Australian geology are the descriptions of the Permo-Carboniferous tillites and glacial deposits of earlier age placed by Howchin in the Cambrian. In the preparation of the book the work of the South Australian Survey and of individual investigators is utilized; but the major part of the text is the result of field and class-room work carried on for 30 years by the distinguished author. H. E. G.

7. *Eighth Biennial Report of the Commissioners of the Geological and Natural History Survey of Connecticut, 1917-1918;* by Herbert E. Gregory, Superintendent. Bulletin **28,** 21 pp., 1919.—During the period of the war the Connecticut Survey has devoted its energies chiefly to military mapping, study of water supplies, and similar investigations in co-operation with the Federal Government. To save appropriations only one report—Arthrostraca of Connecticut, by B. W. Kunkel—has been sent to press. The work planned for the biennium 1919-1920 includes a study of the ecology of the State, an investigation of contamination of waters along the shore of Long Island Sound, mapping of areas of metamorphic rock, and preparation of educational bulletins.

Obituary.

William Watson, professor of physics in the Imperial College of Science and Technology in London and the author of a well-known text-book of physics, died on March 3 at the age of fifty years. Previous to the war he had carried on important researches in magnetism, in color-vision and other fields. In 1915 he was made director of the Central Laboratory, B. E. F., which had as its object the study of the methods for combating gas attacks in the war; his early death is ascribed to the effects of the hazardous work in which he was employed.

Ludwig Sylow, the eminent Norwegian mathematician, died in September last at the age of eighty-five years.

Dr. Wallace Clement Ware Sabine, of the Department of Physics in Harvard University from 1895, professor since 1905 and dean of the Graduate School of Applied Science, died recently in his fifty-first year. His death was indirectly the result of his self-sacrificing labors in connection with the recent war, both in France and in this country.

Dr. Herbert Huntington Smith, the naturalist, Curator of the Museum of the University of Alabama, died suddenly on March 22 at the age of sixty-eight years.

Dr. George Ferdinand Becker, for forty years a member of the staff of the United States Geological Survey, died on April 20 at the age of seventy-two years. A notice is deferred to a later number.

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[FOURTH SERIES.]

Art. XXVI.—*Classification of the Cycadophyta**; by G. R. Wieland.

Extension of the knowledge of cycads, cycad-like plants, and their remoter relatives, has now gone on for just 90 years. When Buckland in 1828 came to give closer attention to the "crow's nests" of the Isle of Portland, he happily emphasized the cycad-like character of these petrified stems in the generic name *Cycadeoidea;* while the great contemporary botanist Robert Brown suggested the family name Cycadeoideæ. Brown evidently regarded the abundant ramentum, and free lateral budding, as the main characters indicating the new family. He doubtless recognized that the fructification must vary; but as Buckland very soon sought to give even more emphasis to a cycad relationship by inadmissibly using *Cycadites* for *Cycadeoidea,* it is evident that only the simpler outer characters were the ones held mainly in mind.

The first evidence to deeply affect the classification was forty years in appearing. In 1870 came the two notable papers of Williamson and Carruthers. Williamson associated the *Zamites* fronds, "pyriform axes," and the "collars" or "disks" of the Yorkshire coast; while Carruthers described the Isle of Wight trunk *Cycadeoidea* (Bennettites) *gibsoniana* with its unique ovulate

* To give all of the references bearing on this classification would require undue space. The reader should refer to the chronologic list of literature on the Williamsonian Tribe, this Journal, vol. 32, p. 465, Dec., 1911. See also the bibliography in my American Fossil Cycads, Carnegie Institution of Washington Publication 34, vol. II, 1916. The dates here freely given will facilitate such reference in most instances. The two volumes on the American Fossil Cycads now constitute an extensive catalogue to which there is constant occasion to refer. Accordingly it is wished to use an abbreviated reference form, thus, Am. Fos. Cy., Vol. I, Vol. II.

cones. In these he saw the type of a new family—the "Bennettiteæ," in which were included the Isle of Portland specimens as well as the historic Dresden trunk "Raumeria" [*Cycadeoidea reichenbachiana*]. The latter had only twelve years earlier received the attention of Goeppert, unfortunately without significant result. Carruthers' observations should be recalled:

"Were Buckland's name [*Cycadeoidea*] unobjectionable it ought to be retained, because of its priority by a month or two . . . The remarkable stems of this genus [*Cycadeoidea* or *Mantellia*] have been fully investigated in the important memoir of Buckland . . . The fossils differ from *Bennettites* in their form, as well as in the more distinctly rhomboidal petioles and the elongated secondary axis. They agree in the nature of the tissues and the method in which they are built up in the stem. The petioles are clothed with a dense ramentum, and they have numerous axillary branches which bore small, simple, linear-lanceolate leaves. The branches, when full-grown, are broken off at the point where they leave the bases of the petioles. Sometimes they are undeveloped, and still exist as unexpanded leaf-buds, terminating the shortened branch. These buds are composed of leaves, protected by a very dense and very abundant ramentum. The branches precisely agree with those in *Bennettites,* and have been, I have no doubt, like them, the supports of the organs of reproduction; only the fruits, having been borne at the ends of elongated and consequently unprotected branches, have been broken off. Some stems have no lateral buds. These may have been male plants; and their staminal flowers were perhaps cones, produced at the termination of the main axis."

On the question of the position of his Bennettitean group Carruthers makes an incisive statement, the most interesting in his memoir:

"In comparing the structure of this plant with the inflorescence of the recent Cycadeæ, the points of difference are more obvious than those in which they agree. The most important correspondence is to be found in the structure of the seed and its envelopes. The fossil is truly gymnospermous, the pollen having access to the embryo-sac through the tubular openings in the covering of the seed and not through a style developed from an investing carpellary organ. The most remarkable difference is to be found in the compound fruit of the fossil. In the recent members of the order, the fruit, whether borne on slightly modified leaves, as in *Cycas,* or on the peltate or imbricated scales of a cone, as in the other genera, is always produced on foliar organs. In the fossil, on the other hand, it is borne at the end of the axis. In this respect, however, it agrees with *Taxus,* except that it possesses innumerable seeds; it must be considered to hold the same relation to the other *Cycadeæ* that *Taxus,* with its succulent, cup-shaped pericarp, does to the cone-bearing *Coniferæ.*''

So rested the central problem in the classification for the next twenty years. Saporta (1875) had made as little direct progress with the material he held in hand as had Goeppert (1853), but was led to certain interesting suggestions as to the forerunners of the angiosperms. So, too, Nathorst's earlier work on the Rhætic forms but vaguely foreshadowed the brilliant results that later followed. Solms, however, after restudying the cone of ''Bennettites gibsonianus'' came to a very direct conclusion (1887):

''It is possible that the seed-stalks may prove to be carpophylls of a peculiar kind; in that case we should be obliged to separate the Bennettiteæ altogether from the Cycadeæ, and to regard them as an intermediate group between Gymnosperms and Angiosperms. We should then have a typical case of that which Saporta and Marion call proangiospermy, though we could not perhaps assume a direct derivation of Angiosperms from this plant, and though it may have belonged to a line of development which never reached our era.''

Then Potonié in Engler and Prantl's Natürlichen Pflanzenfamilien (1897) separated all the fossil trunks from the cycads as the Bennettitales. This separation, be it noted, was not based on renewed study, or new materials. It was, however, at once adopted by Ward (1899), though he had at first included the petrified trunks in the Cycadaceæ, as had been done in practice for fifty years. But Ward (as he remarked to me) was much impressed with the fact that the foliage, the flowers, and so much of the structure remained unknown; while Zeiller and Scott (1900) adhered to the earlier Cycadean grouping. In this I followed a year later. The determination of the Cycad-like foliage of *C. ingens* (1899) had completed the vegetative parallel; and (1901) it was urged that the staminate frond, despite campanulate emplacement, afforded an analogue to the carpellary leaf of *Cycas.* These features were also held significant by Zeiller. Their discovery was in fact easily the most signal since Carruthers sectioned *Cycadeoidea gibsoniana;* though

Nathorst's elaboration of *Wielandiella* with its Nilssonioid foliage, small freely bifurcate stems, and reduced flowers, soon followed. The supplementary discoveries affecting the cycad classification most profoundly were thus made in rapid succession. The American studies proved the floral type to be one theoretically plastic; and Nathorst's determinations showed (with some further study) the presence of far greater variety in foliage as well as small reduced stems and flowers. It had become evident that much if not most of the cycadeous vegetation of the Mesozoic had more affinity to *Cycadeoidea* and *Wielandiella* than to modern forms. In fact fossil types positively referable to the latter are few, and cannot be cited beyond the Jurassic, although theoretically the ancestry must go back to the Paleozoic as a discrete line.

It was at this point (1902) that Nathorst proposed as a term of convenience the Cycadophyta to include all plants with cycadeous foliage existing and extinct. That many relatives with types of foliage not distinctly cycadeous must formerly have existed was at the same time emphasized. The usableness of the term Cycadophyta was presently recognized, and in 1907 Bessey, a keen systematist, suggested the following extension: CYCADOPHYTA.—I, Cycadofilices, Lyginopterideæ, Medulloseæ, Cladoxyleæ, Protopityæ, Araucarioxyleæ; II, Cordaitineæ; III, Bennettitineæ; IV, Cycadineæ, V, Ginkgoineæ. The logic of Bessey's suggestion is firmly grounded on both the paleontologic record and well-known structural features. It properly emphasizes the lapse of time through which the cycadeous foliar structures have apparently dominated the vegetation of the globe—from the Devonian to the Cretaceous. The question is thus raised as to whether the dicotyl blade is equally longevous. And just as there is the proximate question of mid-Mesozoic transition from Cycadophytes to dicotyl foliage, so there is the ulterior question as to mid-Devonian transition from the *Bornia-Pseudobornia* foliage to more bladed types like Archæopteris, theoretically leading into the earliest Cycadophyta.

Now, having recalled the larger outlines of the Cycadophyta, and the more crucial discoveries leading up to recognition of this gymnospermous leaf-type as a forest constituent, let attention be turned to the appended provisional classification based on the general structure, known or inferred. Obviously such a classification essays first the orderly presentation of facts; but yet it can only be usable as discovery progresses, if it has both flexibility and impermanence. Nor are the uncertain boundaries an objection. Indeed one chief function is to present inferences from the known facts.

CYCADOPHYTA	Cycadales (Cycads)	Cycadaceæ	Zamiæ	(A)	Zamia, Microcycas, Ceratozamia, Dioön.
				(B)	Encephalartos, Stangeria, Macrozamia, Bowenia
			Cycadeæ		Cycas
		(incertæ sedis)	Pseudocycadeæ		Pseudocycas, Cycadites, Stangerites
			Podozamiteæ		Podozamites, Plagiozamites, Sphenozamites
	Hemicycadales (Cycadeoids)	Pericycadeoidaceæ (Pericycadeoids)	Cycadeoideæ (The Petrified series)		Cycadeoidea, Fittonia, etc. Amphibennettites, etc.
			Williamsoniæ (The Williamsonian tribe)		Williamsonia, Bucklandia, Zamites, Ptilophyllum, Otozamites, Pterophyllum, Glossozamites, Dictyozamites, Cycadolepis
			Microfloræ		Wielandiella, Williamsoniella
		Apocycadeoidaceæ (Apocycadeoids)	Holophytæ		Anomozamites, Nilssonia, Tæniopteris, Ctenis, Pseudoctenis, Ptilozamites, Macrotæniopteris

Primitive and Hypothetic Groups:

Cycadofilicales, Medulloseæ or Paracycadales, Proangiosperms, Hemiangiosperms.

(Wieland, 1918 Revision)

In this new classification, then, it is primarily aimed to give due homogeneity to the grouping of the Mesozoic Cycadophyta. This cannot be done if the term Bennettitales, as first used and defined, is retained. While it would take us far afield to discuss at full length the questions of mere priority relating to the use of Bennettitales, there are simple and good reasons for letting this name fall into disuse. As already noted the boundaries are greatly extended; there are now without much question several groups ranking as high as the Cycadales within the Cycadophyta; while the Bennettitales as used, neither expressed such relationship nor gave sufficient recognition to the vegetative equivalence between the silicified stems, at first the only ones included, and the existing cycads. It was this latter fact that largely influenced the retention of the fossil cycads in the Cycadales in both Volumes I and II of my American Fossil Cycads. Approach from the paleontologic side led to the same comparisons with cycads that had obtained for seventy years; although it was freely admitted at all points that the discussions of relationship must be inherently tentative.

The vegetative characters of the Cycadeoids bear such a general resemblance to, and present so many points of agreement with those of the cycads, that an ancient contact is indicated. The facts were summed up in the American Fossil Cycads, Vol. I, page 226 *et seq.;* and the additions to our knowledge of the anatomy since made confirm rather than disprove a degree of vegetative affinity. It is difficult to admit that such a complete similarity is in entirety the end result of homoplasy. All recognize, however, that the reproductive organs must indicate an exceedingly ancient separation—perhaps even mid to early Paleozoic. Scott says:

> "It is a striking fact that in their reproductive organs, that is to say, in the very characters on which systematists are accustomed to rely, the Bennettiteæ differ *toto coelo* from the Cycadaceæ. The organisation of the flower is so different from that of the cones of any recent Cycad that it is difficult to determine with any certainty the homologies of the parts in the two groups. It is, of course, possible that future palaeontological discoveries may reveal the existence of types of fructification intermediate between those of Cycadales and Bennettitales; at present, however, it seems as if their development had followed different lines from a very early stage."

If anything this overdraws the reproductive divergence. A cycadeoid with short more peltate micro-sporophylls organized into cones, would nearly close the gap between *Cycas* and the cycadeoids; while it can be held certain that the Cycadophyte types presented in the early Mesozoic many vegetative similarities which were later obscured.

All in all, therefore, the extinct group of cycadeoids to which *Cycadeoidea* has afforded the structural key, are half-cycads,—in the most exacting sense of the word, HEMICYCADALES. That this is a cosmopolitan and a homogeneous group of varied stem and floral structure is now known. It is also a feature of the group that so far as can be detected the large stemmed forms are nearest the cycads. They are therefore the true Pericycadeoids.

Of these PERICYCADEOIDACEÆ, two family groups appear to view. The first is Bucklands Cycadeoideæ (1828), in the synonymy of which is included a plethoric series of generic names. These were in part reviewed by Ward (1900) when he sought to establish his *Cycadella.* The material has afforded the most exacting and complex of all redintegrations of ancient plants. The broader outlines of the second family, the Williamsoniæ (Carruthers, 1870), are only less well attested. Doubt as to the character of the genera attributed here, can occasion no great inconvenience. It would, for instance, be rash to believe that all the Pterophyllums can belong to any one family.

In the second greater order of the hemicycads, so far as the first necessities of a preliminary classification are concerned, the characters are fairly enough established to indicate a steady departure from the pericycadeoid forms. These are, therefore, the apocycadeoids or APOCYCADEOIDACEÆ, also with two families. The first, or MICROFLORÆ, includes the typically small-flowered *Wielandiella* and *Williamsoniella.* The small freely bifurcate stems bear their small bladed leaves in close set whorls, or more diffusely, and may have pertained to larger forest trees of semi-magnoliaceous habitus; but unfortunately the stem structure remains inferential. The second hemicycad family is a hypothetical one of mainly large-leafed imprints, numerous and cosmopolitan, presumably allied here. It can be given an arbitrary name, the HOLOPHYTÆ, or the all-leaf-family, with both fruit and stem inferential. The genera included are, *Anomozamites, Nilssonia, Taeni-*

opteris and *Macrotaeniopteris* (not necessarily all forms), *Ctenis, Pseudoctenis, Ptilozamites.*

Reasons for this grouping are, however, neither lacking nor solely inferred. Thomas and Bancroft (1913) have shown that *Nilssonia, Tæniopteris,* and *Ptilozamites* have characteristic stomata suggesting the existence of a provisional great group—the Nilssoniales. The facts they adduced, position of the genera in time, certain leaf features, and the probability of departure in the fructification from *Wielandiella,* led me to use this classification (1916). But reasons for such a wide separation are less evident. The fact that *Tæniopteris vittata* leaves of the Yorkshire coast, which are hardly distinguishable from some of the smaller *Nilssonia* foliage, pertain to small fruits not remote from *Wielandiella,* is important (Thomas, 1915). This new type, *Williamsoniella,* thus falls into the better defined Microfloræ, and at the same time suggests that Tæniopterids in general, and doubtless Macrotæniopterids, are truly cycadeoid. It accordingly seems preferable to drop the term Nilssoniales[1] and so leave the several genera in question as the terminal family of the apocycadeoids, or HOLOPHYTÆ.

This family group appears to have its most striking development in the Rhætic, and attention has elsewhere been called to the fact that while many macrophyllous forms occur in the Trias of Virginia and North Carolina, microphyllous forms are a feature in the Rhætic of Argentina. There too the *Ptilozamites* types are seen.

Evidently there was an ancient line which led toward the Cycadales, Hemicycadales, and Ginkgoales—the Paracycadales it might be called. As members of a group, leading toward the Ginkgoales, yet in all probability but slightly removed (if at all), from the Holophytæ, there

[1] Thomas, H. Hamshaw. On *Williamsoniella,* a New Fruit Type of Bennettitean Flower. Phil. Trans. Roy. Soc., vol. 207, p. 113.

[In giving my classification of the Cycadales (Amer. Fos. Cy., vol. II, p. 26), I was unaware of this important paper. While on the other hand my inclusion of a great group Dioönitales was a *lapsus calami,* due to having after a time overlooked the later notes of Nathorst on *Dioönites spectabilis.* These leaves are, as recalled, associated with what at first suggested a decompounded spore or *antherangium;* found on later study by bettered methods to belong to a lax seed cone of the *Beania* type. The so-called *Beania* is rather difficult to place anywhere, though more cycadeous than cycadeoid. Seward (Fossil Botany, p. 502) notes the resemblance of this two seeded megasporophyll type to abnormally paired *Ginkgo* seeds; and I called attention to a certain sporophyll resemblance between *Zamiostrobus* or *Stenorrachus* of Nathorst and *Cycadeoidea* (Am. Fos. Cy., vol. I, p. 232).]

may be enumerated, *Zamiopsis* (Fontaine)[2], *Ctenopsis, Thinnfeldia,* and *Dicroïdium.*[3] The furcate Cycadophytan leaf type is so striking in the Rhætic that evolution of Ginkgoid leaves from more fern-like forms seems to go on before one's eyes.

That Bessey was justified in including within the Cycadophytes a great *Ginkgo* series is as certain as anything in paleobotany. But such a group or equivalent family is not added here because discovery within it may any day lead to a more felicitous nomenclature than is now possible to propose. These Ginkgoid forms, with the Araucarineæ, represent the older boundary lines.

More terminal is the approximation of the Holophytæ to the dicotyls. These forms must be regarded as a relatively generalized line. A certain degree of specialization in the ovulate cone need not mislead us. That would be less evident in the few seeded forms which must certainly have occurred. The disk is entirely plastic. The leaves present variety and are not highly xerophyllous; the stems may be small, and were capable of variation in branching. There is excellent reason for believing that large, normally forest-making tree types are included.

Hardly one of these facts is true of the Cycadaceæ, and the suspicion is always strong that far back in time the spinose or highly xerophyllous and *Podozamites*-like fronds belong either to the Pericycadeoids or the Cycads. There need be little hesitation in making of such forms an arbitrary group and placing it terminally to the Cycadaceæ, next to the Pericycadeoids as done herein. Inclusion of *Stangerites* (McClellan) is theoretic; but this leaf type could as readily go with carpels as with cones [Zamiæ]. *Stangerites* has scarcely had the attention it merits. Also, this doubtful boundary has on its remoter side the Holophytæ.

The generalized plastic Apocycadeoids therefore lie near to the theoretic persisting type. The Pericycadeoids were the Proangiosperms of Saporta, but these Apocycadeoids come near to or into actual contact with the theoretic ancestors of the angiosperms, the Hemiangiosperms of Arber and Parkin (1907).

[2] Fontaine, W. M., The Older Mesozoic Flora of Virginia, Monographs of the U. S. Geol. Surv., vol. 6, Washington, 1883, pp. 144, pl. LIV.

[3] Anteys, Ernst. Die Gattungen *Thinnfeldia* Ett. und *Dicroidium* Goth. Kungl. Svenska, Vet. Ak- Hand., 51, No. 6, 1914, pp. 69, pls. 5.

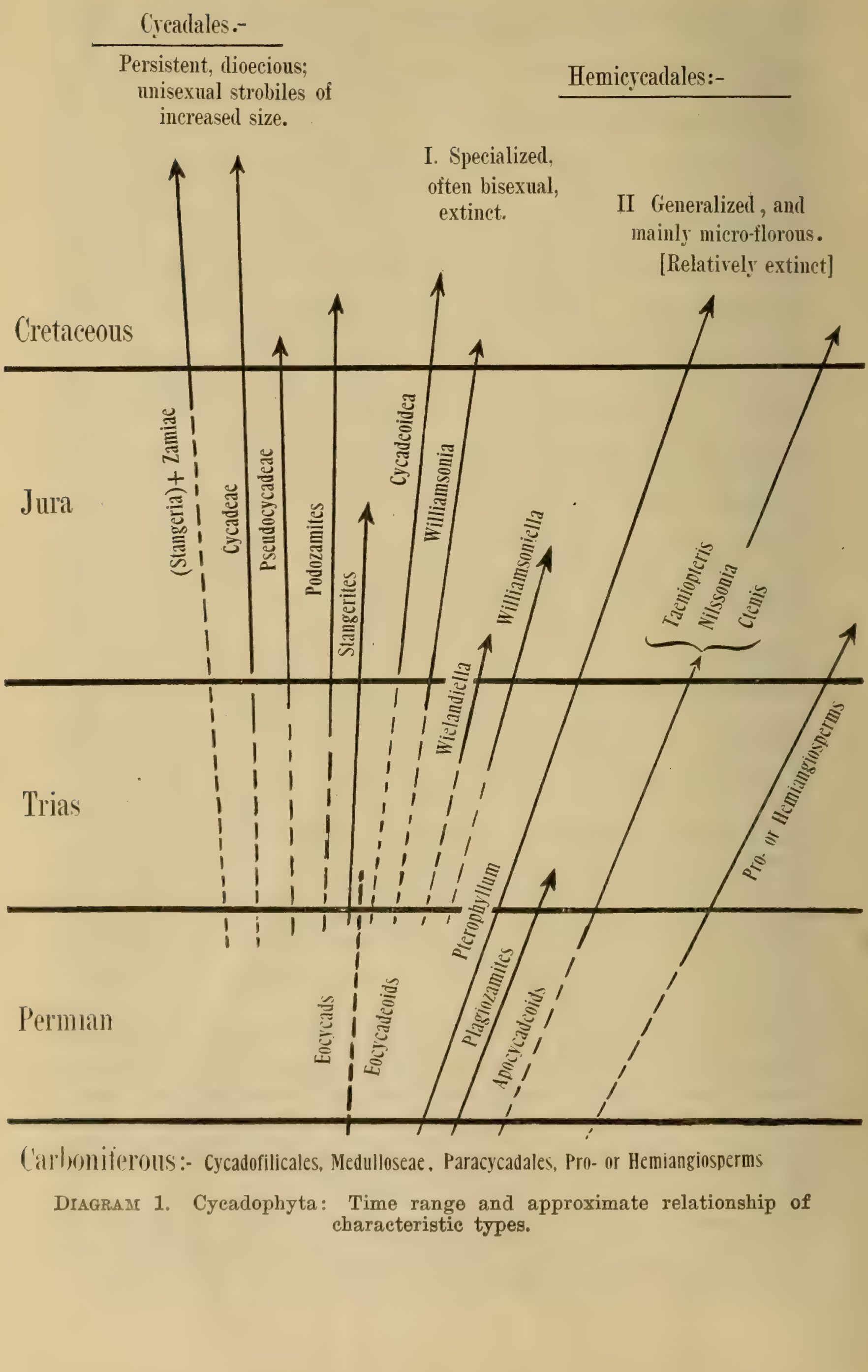

DIAGRAM 1. Cycadophyta: Time range and approximate relationship of characteristic types.

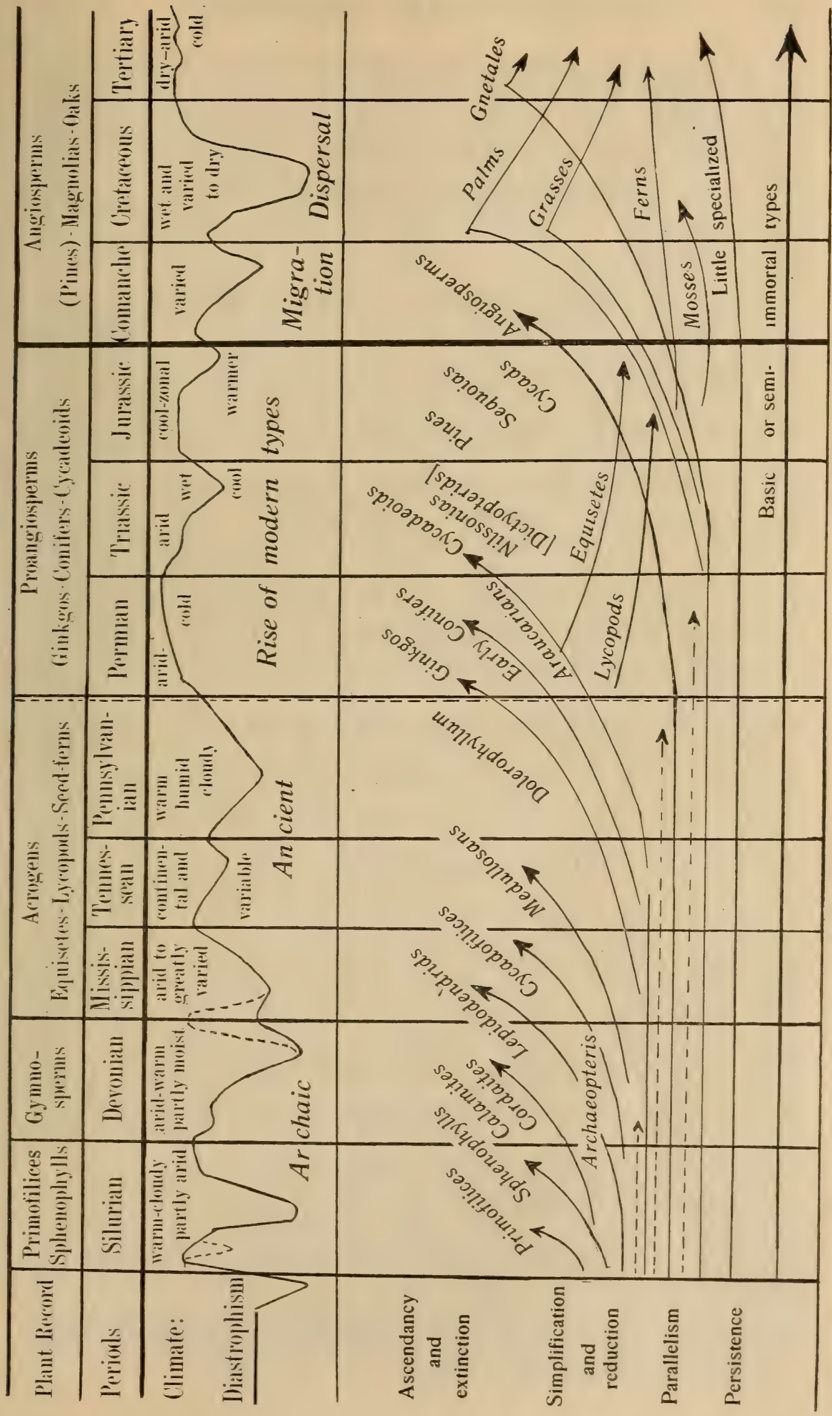

Diagram 2. Appearance of Dominant and Specialized Land Plants.

Completer accounts of the genera composing the several families just outlined, with notes on the abundance and relative range of important forms would find a place here. But such extended treatment may fairly be left over for incorporation in studies of floræ. The two diagrams appended will, however, throw some further light on the main facts on which the Cycadophyte classification must rest.

In the first diagram the approximate time-range and relationships of the better known or the more characteristic Cycads and Hemicycads are given. To the left are the two great persistent diœcious lines with strobili of increased size [reaching a weight of 100 pounds]. It is unlikely that large strobili have uniformly characterized the cycads. Earlier views have implied this; but neither the record nor theoretic considerations can be here invoked. The reduction and consolidation of sporophylls into cones is ancient; and nearly all through the Permian and the Trias, sporophylls are small and cones lax. The marvelous conservation of the cast *Lepidostrobus browni,* a compact sizable cone, shows that larger sclerous cones are preserved as fossils, fortuitously. In North America just one good *Araucaria* cone has been recovered.[4]

The two Cycadalean arrowheads fix the present in the diagram then, as the era of specialized great cones, seen in conifers also; while the succeeding arrows show the relative persistence, known and inferred, of the lines more and more Hemiangiospermous. In a sense these are also the more and more generalized groups; though it is doubtless consistent to regard small bisexual flowers as denoting specialization. The point is that these were near the lines destined to persist; and such, while making fundamental changes early, must from period to period hold to some structural mean, passing which always ends in extinction. There is then found in these groups, combined with varying degrees of specialization, a profound underlying relationship to the forms leading on to the dominant races of today.

Taking the Zamiæ, it is curious to find so fern-like a frond as *Stangeria,* and one so aberrant as *Bowenia.* These forms are more ancient than the record indicates, as also the strobilar crown of *Cycas.* There is no reason

[4] This is the *Araucaria hespera* (Wieland, 1908), now being more carefully studied in the course of a joint investigation by Dr. Neil E. Stevens and myself, taking up the aplosporophyllous gymnosperms.

for uniting these two Cycadalean lines anywhere in post-Paleozoic time; and what is true of them is true of all the main Cycadophytan types. Thus *Pseudocycas* suggests relationship to the Cycadeæ, just as does *Podozamites* to the Zamiæ; though both are clearly old. So too the borderline frond type *Stangerites*.

Coming to the Pericycadeoid division of the hemicycads, the macroflorous Cycadeoideas persist nearly as long as the cycads—being last found in the Upson shale of Texas, high up in the Upper Cretaceous, and not known earlier than the Jura. Taking the record as it stands, the Microfloræ are an older line than the Cycadeoideæ, but generalized in the sense that so far as appears, they tend less to extreme types. *Pterophyllum,* with an exceedingly long history, must be hemicycadeoid. The Permian-Carboniferous *Plagiozamites*[5] is an old cosmopolitan form (*incertæ sedis*) of short range. *Tæniopteris, Nilssonia, Ctenis,* are hemicycads of longer range, unless the slightly net-veined *Ctenis* be excepted. The very fact of extinction implies that these genera reached a degree of specialization; but it is improbable that they bore heavy cones. Entirely too little consideration has been given the possibility that many of these leaf types may be those of forest-making trees, flowered like the magnolias. Much less has it been noted that with only a slight innervation,—invasion of a marginal veinule, in any bladed type with well separated pinnate venation netted types could easily arise. Recall once more that leaf-hiatus between *Tumboa* and *Gnetum gnemon.*

In the Permian the several Cycadophyte lines are more uncertain, but shown as discrete. Using these terms in a purely adjective sense, there must be the Eocycad, Eocycadeoid, and the Apocycadeoid groups. Finally the pro- or hemiangiosperm arrow has the position laid down, except that the head representing the actual appearance of the angiosperms might be placed at the close of the Jura.

Not to add theory to theory; but rather to give a simple form of expression to basic conceptions sometimes overlooked, a second diagram has been arranged to show the Cycadophyta in their larger relationships. As plotted, the object is first to accentuate the very earliest appear-

[5] See the paper by Harvey Bassler; A Cycadophyte from the North American Coal Measures, this Journal, vol. 42, pp. 21-26, July, 1916.

ance of typical forest trees, groups or phyla; and where there is comparative evidence for earlier origin than the fossil record shows, the fact is in a general way indicated. But such a scheme is always provisional. The upturned lines are used because, as well known, the study of invertebrates, vertebrates and plants shows that when new types first appear, the evolution of species is rapid, and the later decline slow.

Secondly, the terminal gymnosperm lines show an inherent relationship so far back in time that it is not always consistent to speak of these more specialized termini as absolutely extinct. They are only relatively so. The record proves rather that the forward movement was always widespread, with the extinct forms always structurally near the persisting mean. Specialization rises little beyond oddity of outer feature. Of this the Ginkgos are a notable instance.

Those who work much with the recent types, or those relatively recent, like the mammalia, may be led to regard evolution as one vast series of adaptations and specializations, and thus become ardent culturists of paleontologic trees. Such must ever express the facts too superficially; the main or greater course of change is far better defined as one of modification, reduction, and the avoidance of specialization.

The exceedingly long plant series permits a glimpse of the average course of upward change, and the great rôle of reductions. Its study, so often severely histologic, also brings into closer view the climatic factors. But the study is only just begun. Hence the introduction of the brief climate characterizations in diagram 2, is only meant to emphasize the fact that there is continuity in the changes going on from age to age. Geologists may even object to these terms,—in that case because the compilation is faulty. [The continental area curve is from Schuchert.][6] Similarly, terms correspondent to the Siluro-Devonic, Carboniferous, Permo-Triassic, and

[6] In bringing climate into the time scheme, the main uncertain factors are cloudiness and atmospheric composition, both unmeasurable. Climate and diastrophism are, however, inseparable factors, whether in dealing with successive floræ precise inferences can at once be gained or not. Certain periods have been cold and arid, others wetter in both time and space. A continent-wide soil change is thus also ever going far to control forest limits and types. With the appearance of bipolar ice caps a kind of culmination is reached. These are the greater factors which led during transition time for instance to the specialized stem of an oak, one of the highest plant products yet seen.

recent, long continental emergences are required. Here, *Archaic, Ancient, Transition,* and *Recent,* may serve to indicate the four great land plant worlds of the past, following the Eopaleozoic aquatics.

The view here emphasized is not new, but goes back to Saporta (1881), and has been only recently again brought forward by Clements in his Plant Succession (p. 288). It will be observed however that the terms suggested are used in the physical as well as phytologic sense, and that both the divisions and events are set back much further in time. This is held absolutely justifiable from both the plant and diastrophic records.

In lieu of a *résumé,* let the fact be emphasized that the various "paleobotanic trees" and gymnosperm classifications still include features irreconcilably divergent. One of the most suggestive "trees" is that of Lignier (1903), written out as follows:

I. LYCOPODINALES (Lycopodineæ).
II. PROTOPTERIDEANS (*Filicinales,* Filices)
III. *B* CYCADALES (Cycadaceæ)
SALISBURIALES (*Salisburiaceæ* 1. Euconifers) 2. Taxineas)
A BENNETTITALES
CORDAITALES (*Gnetales,* Angiosperms)

Now Lignier's "tree," viewed in the light of his later critical studies of the Gnetaleans, gives a degree of expression to that extreme homoplasy which becomes with every succeeding year of investigation, more and more evident, especially in the four great gymnosperm lines. But it has the lack inherent to all such schemes. They always somewhere detach or separate important groups, here the cycads and cycadeoids. Plotted on a cylinder (better a hemisphere), this difficulty is partly met.

It is worth while to give and to examine diagram 3, the sectors being movable (and also to be taken in the spherical sense). This diagram, while showing the Cycadophyte-Coniferophyte division, is not given as a formal classification, but as a first step in reaching one. It is believed to be a better form than any other for bringing out certain inconsistencies in the classification—taken from the paleobotanic viewpoint. Ampliation is much simplified; at the center are the early Lycopods and "seed-bearing quasi-ferns." Dicotyledony is not bracketed; most spermatophytes have been dicotyledonous far back in time, as they are today. But I follow R. B. Thomson in regarding *aplospory* and *diplospory* fundamental. Also, Van Tieghem's view that the *Ginkgo* sporophyll is simple (diplosporous), I am forced to adopt, as earlier inclined (Am. Fos. Cy., vol. I, p. 232). For this and other reasons, as well as inferences from fossil types like *Beania* and *Dicroïdium, Ginkgo* is put hard by the Cyca-

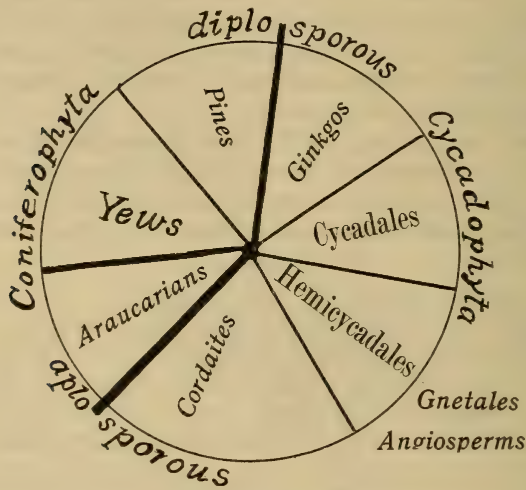

Diagram 3. The gymnosperm phylum.

dales. Placing the Abietineans next to the Ginkgoales, however, partly accords with Lignier's scheme, above; though some botanists would certainly bring the yews nearer the Cordaites. The Araucarians are perhaps the most difficult of all the gymnosperms to place; theory has run the entire gamut from separate derivation through a lycopod stock, to Mesozoic origin from the Abietineæ. The latter view is absurd.

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Art. XXVII.—*The Chert of the Wreford and Foraker Limestones along the State Line of Kansas and Oklahoma;* by W. H. Twenhofel.

Introduction.

Chert is abundantly distributed throughout the Pennsylvanian and lower Permian strata of Kansas and Oklahoma, and its presence scarcely ever fails to attract the observer's attention, even though he is not a geologist. In some sections it so thoroughly litters the fields as to make them unfit for cultivation. There are other sections where it is extremely abundant; but not sufficiently so to prohibit cultivation. Over these areas the chert has been gathered into heaps in the hollows or along the borders of the parts cultivated. It is used as road material in many of the counties in which it occurs, and its use for this purpose is certain to be more extensive in the future.

It is quite probable that some chert is present in practically every important limestone member of the Pennsylvanian and Permian systems of Kansas and adjacent states and it is extremely common or abundant in many members; the Winterset, Oread, Foraker and Wreford limestones containing it in large quantities. In this paper only those cherts are considered which occur in the Foraker and Wreford members.

For the opportunity of studying these cherts in the field the writer is indebted to Mr. B. E. LaDow of Fredonia, Kansas. The suggestions and criticisms of the writer's colleagues, Professors Winchell and Mead, have greatly aided in the preparation of the article.

The Foraker Limestone Member.

The Foraker limestone forms the summit of an important escarpment in southeastern Cowley County, Kansas, and western Osage County, Oklahoma. Its correlative in the Kansas River section has not been determined.

The thickness of the limestone averages about seventy-five feet. There is some variation in the thickness, which in places rises to one hundred feet, but whether there is a systematic increase or decrease in any direction has not been determined.

The greater part of the member consists of limestone, but thin beds of shale and shale partings are present. Much of the limestone is not very resistant and these portions are commonly covered with soil, or weathered products from overlying strata. Exposures of the strong thick beds, in particular their upper portions, are of abundant occurrence.

The Foraker limestone is extremely fossiliferous, but the number of common species is few. Some beds are literally jammed with *Fusulina,* others have them in a few individuals. An interesting feature connected with the occurrence of *Fusulina* is that in some beds the shells are enclosed in a coating of calcium carbonate. This, however, is not peculiar to this horizon. The incrustation is believed to be of algal origin. Other fossils which are not uncommon are *Aulopora* (?) *anna, Composita subtilita,* species of *Productus,* species of bryozoa, and fragments of crinoids.

Some beds of the member contain numerous chert nodules, the exact horizons of which in many instances are not readily determinable. On fresh surfaces the chert nodules are not particularly conspicuous, but little difficulty is experienced in finding them. Weathering of the limestones brings the chert into relief and ultimately concentrates it on the surface. The chert is abundantly fossiliferous at all localities where it was examined,—some four or five hundred. Nodules in which fossils are not present apparently are extremely rare. The nodules do not appear to attain a great size—five to six inches being about the average—and they are of irregular shapes. The chert is quite porous, the cavities in large part appearing to be molds of small fragments of fossils.

The Wreford Limestone Member.

The Wreford limestone is known to extend from northern Kansas into central Oklahoma. Throughout the Flint Hills of Kansas (The Wreford limestone member in considerable part yielded the flint after which the hills are named) the thickness varies from thirty-five to fifty-five feet.[1] Near the Kansas-Oklahoma line it is much thinner. Its base is pretty sharply deliminated from the underlying shales, the change from shale to limestone being quite abrupt. The upper limit of the formation does not appear to be quite so sharply defined.

Of the descending sections which follow, the first was measured about one mile east of the little village of Otto, Cowley County, Kansas. The second section was measured about eight miles nearly due north of the first. The two sections serve to show the persistence of the individual units of the member and also their variations.

11. Slabby gray limestone weathering into rounded dome-shaped surfaces. Not well exposed at the base. Upper layer one foot thick ....3 feet.

10. Gray limestone with yellow and gray chert in lenticular masses parallel to the bedding planes. Not well exposed at the base ....4 feet.

9. Compact gray limestone, coarser grained than that of zone 8. This zone contains an abundance of chert concretions of which many attain diameters exceeding two feet. The concretions have odd and peculiar shapes. Many of them have their longest axes parallel to the bedding planes. Others have them vertical or inclined to these planes. Locally, the concretions are connected with those adjacent, and places have been observed where the chert composes nearly the whole of the zone. The chert thoroughly litters the ground over the outcrop of the zone which, as a general feature, occurs on the rim of a well-defined rock terrace. Both chert and limestone are fossiliferous, the fossils for the most part being fragments of shells .....3 feet.

8. Compact, fine-grained, yellowish gray limestone, containing a great deal of pale blue and yellow chert which is thoroughly and intimately intergrown with the limestone. The chert composes about fifty per cent of the rock, but the ratio varies somewhat with locality. On weathered surfaces it stands out in irregular relief. Both chert and limestone contain many fragments of fossils ....2 feet, 8 inches.

[1] Prosser, C. S.: Jour. Geol. vol. **10**, p. 713, 1902.

7. Limestone having a rotten appearance, yellow when weathered, light colored on fresh fracture. Contains considerable argillaceous material and, if much weathered, has the appearance of shale. Fragments of fossils are present. . 2 feet.

6. Compact gray limestone containing numerous silicified (chert) fossils, the greatest number being those of *Composita subtilita.* The beds are six inches to one foot thick and are separated by partings of thin limy shale. In some exposures this zone has a chalky appearance . . . . 3 feet, 10 inches.

5. Light yellow shale with thin, compact, bluish-gray limestone. About one-third is shale. Numerous *Productus nebraskensis,* together with other fossils, are present. The fossils are not silicified. Base of the Wreford limestone . . 1 foot, 8 inches.

4. Light yellow shale with thin gray limestones . . 6 inches.

3. Light brown and yellow shale with thin (½ inch) lenticular limestones . . . . 8 inches.

2. Light blue shale in lower six inches, upper foot composed of yellow shale . . . . 1 foot, 6 inches.

1. Red gritty shale . . . . 4 feet.

The second section was measured about a mile northeast of the town of Dexter. It is as follows:

10. Gray limestone weathering into rounded blocks of about eight inches in diameter. Base not exposed . . . . 4 feet.

9. Gray limestone which on exposure occurs as large slabs on the slope. Contains many round vertical holes which vary between three and six inches in diameter. Chert occurs in this zone but its relation to the limestone has not been determined . . . . 1 foot, 5 inches.

8. Gray limestone, not honeycombed. Separates into slabs with diameters of from three to four feet . . . . . 1 foot, 6 inches.

7. Gray limestone (one bed) in which are many vertical circular holes of about one inch in diameter, giving it a honeycomb appearance. Fresh exposures show that these, in all probability, were originally worm burrows which were about as deep as the rock is thick, since passing nearly vertically through the fresh rock are tube-like structures of three-eighths to one-half inch in diameter which are composed of material—chiefly mud and fragments of fossils—which is less resistant than the surrounding limestone. In some exposures this zone is united to the overlying, the two zones in such exposures making a single bed . . . . . 2 feet, 3 inches.

6. Gray limestone in two- to six-inch beds . . 2 feet, 3 inches.

5. Gray limestone with little chert in the upper portion, but with an abundance of large brown-surfaced chert nodules in the lower half. Some of the nodules are as great as three and a half feet in their greatest horizontal diameters. The vertical diameters do not exceed a foot . . . . 2 feet, 4 inches.

4. One bed of intimately intergrown yellowish-gray limestone and pale blue chert ....2 feet, 2 inches.

3. Thin white limestone with an abundance of silicified (chert) *Composita subtilita* and, more rarely, *Derbya,* fenestelloid bryozoa and other fossils ....2 feet, 4 inches.

2. White, somewhat chalky limestone. Contains silicified (chert) echinoderm spines (*Archæocidaris*) and bryozoa ..... 6 inches.

1. Thin, compact, gray limestone with poorly defined bedding planes ....1 foot, 3 inches.

Relation of the Cherts to the Limestones.

The sections show that the chert occurs in four more or less distinct relations.

In the Foraker limestone it is present as isolated nodules, of which the average is about five or six inches in diameter. These nodules commonly, but not always, have their longest axes parallel to the bedding planes and in places the chert and limestone are quite intimately intergrown.

The first zone of the Wreford which contains chert has it only in the fossils. The main body of the zone consists of limestone.

The second zone which carries chert has it intergrown with the limestone in an exceedingly intricate and labyrinthine way, so that in any one mass of rock the chert is essentially one piece, which is also true of the limestone. On weathered surfaces the division between the chert and the limestone is extremely sharply defined and no difficulty exists in stating where the chert begins and the limestone ends. Freshly fractured surfaces, however, show that there is a zone of about one-half inch in width between the chert and the limestone, in which there is a minute intergrowth of calcite and silica.

The third chert of the Wreford occurs in large irregularly shaped nodules of marked concentric structure, the nodules in considerable, and probably greater, part being elongated parallel to the bedding. There are many nodules of a spherical shape in which no longest axis exists, and there are numerous others which have their longest axes transverse to the bedding. The nodules are not sharply delimited from the enclosing limestone.

A fourth chert zone is known to occur in the Wreford, and there may be others. This has the chert in lenticular masses and also like that of the third zone of chert. These may represent two zones and, as they have not been well enough seen to place them in the section with sufficient definiteness, they will not be further considered.

Description of the Cherts.

The chert of the Foraker limestone is quite porous, most of the pores appearing to have resulted from the removal of an organic fragment. The color is either some shade of gray, a pale gray blue, or a mottled gray and blue. Yellowish-gray shades are not uncommon. The abundant fossils are commonly of a different color from the surrounding material. In most instances they are lighter than the matrix; in some instances they are darker.

Little concentric arrangement of material is shown in these cherts, but the peripheral portions of each nodule have a more porous texture and lighter color than the interior portions. The interiors also have a conchoidal fracture, which is not true of the peripheral portions. These differences are probably due to leaching of the exterior portions of the nodules.

Fossils, chiefly *Fusulina,* are abundantly scattered throughout the chert, their cross-sections making from ten to fifteen per cent of the areas of the thin sections and fracture surfaces. The distribution is quite uniform. While there are patches where they are not abundant, these relatively barren portions are not confined to any particular parts of the nodules, so that as many fossils are in the bottom portions of a nodule as in the top. There is no arrangement of the fossils into bands, and the fusiform shells of *Fusulina* are oriented so that the axes of symmetry are parallel neither to a line, plane, or curved surface, the shells being oriented in every possible direction. The fossils are also composed of chert.

The preservation of the *Fusulina* is extremely excellent, being generally better in the cherts than the enclosing limestone, and some of the most delicate details of structure are shown. The concentric walls of the shells are perpendicularly perforated by small threads of limonite. These thread-like structures are considered to be fillings of the original pseudopedial openings of the test. They are wanting in the radial portions. The material composing the main body of both types of wall is of a pale yellow color which between crossed nicols breaks up into a mosaic of fine grains of chalcedony and quartz. The material filling the cavities of the shells has a radiate or dove-tailed structure, and consists of colorless chalcedony or of small units of quartz and chalcedony of irregular shapes in irregular arrangement. The material surrounding the shells is an aggregate of tiny units of limonite, quartz and chalcedony. No amorphous silica was observed. Small crystals of calcite are commonly present.

The lowest chert zone of the Wreford, that in which the fossils alone are composed of silica, has the chert only as a replacement of the original matter of the shells. Many of the fossils have the silica in rosette arrangement, while in others it duplicates to a greater or less extent the original structures of the shells. The chert is commonly of a gray color. The interiors of the shells are filled with intergrown calcite and glassy quartz which in many instances are discolored by iron oxide. Shells in which the interiors are composed of chert are quite rare.

The zone in which the silicified fossils occur was seen in fully five hundred exposures over an area of about one hundred square miles, so the silicification in this zone is quite general. Many of the exposures are in deep stream-cuttings and were fresh, and one is in the bottom of a recently dug well, the shells coming from about twelve feet below the surface of the ground, so that it is quite certain that the fossils in this zone are silicified beneath the surface. No exposure was found where the shells are composed of lime carbonate.

In the second chert zone of the Wreford, the chert, except for peripheral portions, is of gray-blue, yellowish-gray, dark gray, and mottled gray and blue color. The peripheral portions are more granulated than the interiors and do not have the conchoidal fracture which is characteristic of the latter. The outer portions are also minutely porous and the colors are shades of yellow and brown. Except for this peripheral portion the chert shows no concentric banding. There is, however, a rude banding parallel to the bedding of the limestones. The inner portions are composed of dense, compact chert which in some specimens is minutely porous. Fossils are present in both the limestone and the chert. They are commonly fragments and young shells. *Fusulina* is extremely rare. The fossils have the appearance of being most abundant in the outer granular portions of the chert, but in reality such is not the case. Many of those in the limestone are composed of chert. The preservation in the chert is as good as in the limestone.

The chert masses, in general, are elongated parallel to the bedding but they also cut across the bedding and go from slightly lower to slightly higher levels. In addition, fingers of chert go out in every possible direction, so that each unit—if a unit may be said to be present—is united to chert above, below, and laterally.

The groundmass of the chert of this zone consists of exceedingly minute grains of chalcedony, quartz, and limonite, limonite and limonite staining being quite abundant. Amorphous silica does not appear to be present. In the groundmass are many minute fragments of fossils of which the most conspicuous are of needle-like shape. As these are not parallel in arrangement, it results that a thin section shows them with different outlines. Those whose axes are parallel to the surface of the thin section have needle-like outlines; those whose axes are perpendicular appear as circles; while those transverse give ellipses. The needle-like structures are of light color in thin section and each of them appears to have had a central axial canal or filament, which is indicated by a thread-like portion of different color, a pale yellow being most common. These needle structures appear to be almost wholly composed of chalcedony, very little, if any, quartz being present, and are believed to be monaxial sponge spicules. They are about one-tenth of a millimeter in diameter and one millimeter long. Bryozoa have also been recognized among the minute fragments of other fossils which are present. A cylindrical rod-like structure is present in one section which may have come from one of the calcareous algæ. This is peculiar in that it appears to have the remains of a small coiled organism in its interior. If *Fusulina* be present in this chert, it is extremely rare.

The chert of the third zone of the Wreford (see fig. 1) is in the form of large and small nodules of variable and peculiar shapes. Maximum diameters equal and perhaps exceed four feet. The surfaces are extremely irregular by reason of dome-shaped protuberances which appear to have developed as secondary centers of secretion. Tangential sections across these protuberances indicate that at these places there is a bulging outward of the concentric bands. The interior in every specimen studied is of banded concentric structure, the structural bands being commonly wider on the top of a nodule than on the bottom side, and laterally generally wider than on top. The bands are not always the same widths on horizontally opposite sides; one nodule which was studied having sixteen bands on one side extending through three and one-half inches of radius. On the other side these merge and

Fig. 1.

Fig. 1. The specimen on the right is from the second chert zone of the Wreford limestone. The irregular mass crossing the center is limestone, the rest is chert. Two small nodules of chert are shown in the limestone. The specimen on the left is from the third chert of the Wreford. The dark blocks are chert, one with its longest diameter parallel to the bedding, the other with its longest diameter transverse thereto. Each specimen is adjusted so that the bedding planes are in horizontal position. These two chert zones are known to extend over more than a hundred square miles and are not more than 5 feet from each other vertically. Except that each is composed of silica, they have no other common feature. The dimensions are shown by the 6-inch rule.

extend through only five-eighths of an inch of radius. In any radial section the bands are not the same width, varying in one specimen from three-fourths to one-fourth of an inch. The exteriors of exposed nodules are of a brown color due to oxidation. The color of the weathered interiors is a striped blue and gray, the shades varying, depending on degree of exposure. Interiors of freshly broken specimens do not have the banding so plainly shown and are commonly of dark gray-blue color. Weathered nodules are porous, the gray areas more than the blue, and on much exposure to the weather the gray portions become yellow or some shade of brown. Little distinction can be made between the peripheral portions and the interior. No parts of these nodules have a distinct conchoidal fracture.

Fossils are scattered throughout the chert and occur on the surface, many being represented by cavities. A form quite common in some nodules is a fenestelloid bryozoan. The fossils in the chert are as good as, and apparently a little better than, those in the limestone. The chert on weathered surfaces is sharply separated from the limestone, but fresh fractures across both chert and limestone show that each is intergrown with the other. Nodules were observed with masses of limestone almost completely surrounded by chert, so that it is quite probable that nodules exist in which masses of limestone are completely enclosed. Quite fresh chert contains a great deal of calcite—at least twenty-five per cent—scattered throughout, and the solution of this is believed to be largely responsible for the cavities in weathered nodules, these in places making from twenty-five to fifty per cent of the surface of a thin section, the lighter colored bands of the chert appearing to be largely due to their presence; since, except for the cavities, there is little microscopic difference between the lighter and darker bands.

The groundmass consists of an aggregate of microscopic grains of quartz, chalcedony, calcite and limonite. The last occurs both as stains and little particles, and in places is so abundant as to render the thin sections nearly opaque. It is present both in weathered and unweathered chert. A little siderite also appears to be present, but the quantity is not great. Sections from unweathered chert contain much calcite. Some of the cavities are lined with minute crystals of quartz and chalcedony, making them microscopic geodes. No amorphous silica was observed.

Source of the Silica.

Respecting the source of the silica from which cherts are formed, there are three general theories, namely: (1) the silica is directly derived from the shells and supporting structures of organisms, such as spicules of sponges and shells of radiolarians and diatoms, these organisms largely obtaining it from silica dissolved in the waters of the ocean in which they live, or from silicates held in suspension; (2) the silica is precipitated directly from the sea water through chemical processes; (3) the silica is deposited with the sediments as a mechanical precipitate of finely divided silica or silicates carried in suspension in the sea water, and is subsequently segregated to form nodules.

That organic silica in great abundance is deposited with sediments hardly needs statement. The immense deposits of diatom and radiolarian ooze show the extent to which silica now accumulates and nearly all bottom deposits appear to contain siliceous tests in greater or less abundance.

That silica is carried by the rivers to the sea in great abundance is now well known. River water that does not have some silica in solution is extremely rare and great quantities of silica are annually delivered to the ocean. Of the solid matter in solution in average river water, 11·67 per cent consists of silica,[2] and the rivers of the world annually deliver to the sea dissolved silica to the extent of a little more than 223 million tons.[3] As there is very little silica solution in the ocean water,[4] it follows that essentially all of this is precipitated, and that, too, before going very far from the shore. Some of it is taken out by organisms, but it seems quite certain that considerable quantities are chemically precipitated. Tarr has demonstrated[5] that this precipitation is accomplished in ordinary sea water by the salts which are in solution therein. The silica probably reaches the bottom as extremely tiny particles and is mingled in that form with the sediments.

The abrasion brought about by wind and the corrasive work of water and ice certainly produce a great deal of finely divided silica. Much of this reaches the sea and is deposited with other sediments. Possibly this may be dissolved and segregated to form chert.

It is certain, therefore, that there is no dearth of silica brought to the sea, and that some of this silica ultimately becomes segregated to form the chert nodules is equally

[2] Clarke, F. W., Data of Geochemistry, U. S. Geol. Survey, Bull. 616, 116, 1916.

[3] Clarke, ibid., 115.

[4] Clarke, ibid., 123-125.

[5] Tarr, W. A., this Journal, 44, 409-445, 1917.

certain. Respecting the time and method of segregation there is considerable diversity of opinion.

Time and Method of Origin of the Chert Nodules.

Views relating to the time and method of origin of chert nodules fall into two general classes, namely: (1) the cherts develop subsequent to the solidification of the strata in which they are imbedded through replacement of certain parts or through the filling of cavities; and (2) the cherts develop prior to, or contemporaneous with, the solidification of the containing strata, either as original precipitates or as segregations in the unconsolidated sediments.

Of those who hold that the chert develops subsequent to the solidification of the containing strata, one group maintains that the chert forms in the zone of cementation through replacement of the carbonates or through filling of cavities, the silica being derived from that held in solution in ground water. Another group maintains that chert develops as a consequence of weathering and that it is far more abundant in exposed strata, or strata which at one time have been exposed, than in strata which have not been subjected to weathering agencies; it being rare or wanting in the latter.

Likewise there are two groups of those who consider that chert is formed prior to, or contemporaneous with, the solidification of the containing strata. According to one group the cherts are deposited contemporaneously with the associated materials; according to the other the nodules develop by segregation of silica in the sediments before the latter become consolidated and cemented, or while this is being accomplished.

It is quite possible, and even probable, that chert has been formed in each of the ways postulated. Furthermore, it is but fair to state that it is certain that the students who hold to the several theories which have been outlined do not insist that chert originates in any one particular way. Each of these theories will now be examined with particular reference to the cherts which are considered in this paper.

Theory that the chert is a consequence of weathering.—This view appears to have been developed by Dr. E. O. Ulrich,[6] who considered that the chert in the Potosi group

[6] Bain, H. F. and Ulrich, E. O., U. S. Geol. Survey, Bull. 267, 27, 1905.

of southeastern Missouri developed "largely as the result of segregation of siliceous matter under conditions of slow subaerial decomposition of the limestone." The present writer believes that some chert has been developed in this way, observations made at fossil localities suggesting that in some cases the replacement of fossils by silica is consequent to weathering.

It is quite certain, however, that none of the chert which is considered in this article developed in this fashion. As has already been stated; the chert has been observed under essentially every condition of exposure, and in fresh rock it is just as abundant and, except for oxidation, of the same character as in that in which it has been exposed to weathering agents. The test would come more particularly in the case of the first chert zone of the Wreford limestone, that in which the chert occurs in fossils (chiefly *Composita subtilita*). This zone was seen in hundreds of places under all conditions, and invariably the shells are composed of silica, while the material filling the hollow interiors is composed of calcite and quartz. Had the silicification been a consequence of weathering, it would seem that somewhere the specimens of *Composita* should have been composed of calcium carbonate, especially as places were observed where the immediately underlying bed has its fossils in that form.

It may be argued that the exposure antedated the present and that the cherts lie along disconformities or old erosion surfaces. This view can not be sustained.

Theory that the chert developed through filling of cavities, or replacement of solid rock.—That some chert occurs as fillings of cavities and fissures rests on many observations, so there is no doubt that it is of quite common occurrence,[7] but that the chert under consideration did not develop through filling of cavities is quite evident from the distribution of fossils therein. In no instance were these found to be confined to the lower portions of the nodules; but, so far as observed, and fully a thousand nodules were examined in the field, they are uniformly distributed throughout. Furthermore, none of the cherts shows any relations to fractures and not a single fracture was observed which had been filled by chert.

That chert may develop as a replacement of solid limestone through replacement of the carbonate by silica held

[7] Van Tuyl, F. M., this Journal, 44, 450, 1918.

in solution in water has been demonstrated,[8] and it is quite probable that a great deal of chert develops in this way. When solid limestone or dolomite is thus replaced by silica, the original structures of the replaced rock should be duplicated, or be less perfect, in the resulting chert. Original structures would include bedding, lamination, fossils, etc. It is impossible that they could be better and it is more than likely that they should have lost something in the process of replacement. As a substance of which fossils may be composed, silica is about but hardly quite so good as calcite. If the fossils held in the cherts are of better preservation than those in the limestone, it should be considered positive evidence that the chert is not a replacement of solidified limestone. Cherts which are replacements of solid limestone should have bedding and lamination planes continued from the limestone into the chert and, if these structures end abruptly at the chert, the latter could hardly be considered of this origin. The conclusion would be stronger if the cherts were fossiliferous, as it does not appear possible that in the same chert fossils could be retained and bedding planes eliminated. Replacements of this kind should be related to fractures and should also give the same character of chert in vertical distribution in beds which are essentially similar—quite similar limestones within less than five feet of each other vertically should have similar cherts—, while in horizontal distribution the chert should be considerably localized.

The cherts of the Foraker limestone appear to be confined to certain beds of this member and in these there seems to be general horizontal distribution. The Fusulinas of these cherts are exquisitely preserved and, in general, they are of better preservation than are those of the enclosing limestone; in collecting, few of the latter were considered of much value. Not only is the detail of the interior much better shown in the silicified fossils, but also the character of the surface. Few traces of bedding are shown in the specimens which have been studied. On a basis of these characteristics it is considered that these cherts are not replacements of solid limestone.

The siliceous fossils in the lower chert zone of the Wreford are without doubt replacements of solid material. That point is settled, but whether this replacement occurred before or after the solidification of the sedi-

[8] Church, A. H., Journ. Chem. Soc., 15, 107, 1862.

ments from which the limestone was formed remains to be decided. It is difficult to understand how a replacement of shells could have been so general in horizontal distribution, and so slight in vertical distribution, as the bed immediately below contains its fossils still almost wholly in carbonate form. The fact that the shells were replaced while the surrounding limestone was not affected might be explained on the ground that the shells were composed of a less stable form of calcium carbonate than that of the surrounding limestone. It would seem, however, that in the recrystallization of the sediments to form the limestone the shells would also have assumed the stable form of lime carbonate. An additional source of difficulty is how to account for the entrance of water to the shells, as the enclosing limestone is quite fine-grained, without being affected in any apparent degree and without any nodules forming. These difficulties have led to the rejection of the theory that the chert fossils are replacements subsequent to solidification of the limestone.

The cherts of the second zone of the Wreford and those of the third are totally different in appearance and structure. In fact, they are about as different as any two cherts could very well be. The distribution of each of these cherts is horizontally uniform over an area of at least one hundred square miles, with the probability that the horizontal distribution far exceeds this figure. In the upper zone there is no trace of the bedding of the limestone in the chert, while fossils are preserved therein. The second zone shows faint traces of bedding, but fossils are as a rule better preserved in the chert than in the limestone. No chert of the character of that of the third zone is found in the second zone and the reciprocal is also true.

These facts strongly militate against the view that these cherts developed through replacement of limestone; in fact, they prove the contrary. It is therefore concluded that the cherts being considered did not develop subsequent to the solidification of the containing strata. The alternative is that they are antecedent in origin to solidification or contemporaneous therewith.

Theory that the chert nodules originated from direct precipitation of silica from sea water.—This theory, first enunciated by Prestwich,[9] has lately been independently

[9] Prestwich, J., Geology, Chemical, Physical, and Stratigraphical, vol. 2, 320-324. Oxford, 1887.

elaborated by Tarr,[10] who came to the conclusion that the Burlington chert nodules resulted from direct precipitation of silica and that these nodules were subsequently buried in the sediments. "The silica," he says, "is believed to have been derived from the land by chemical weathering and transported to the sea by the streams as colloidal silica," where "it is believed to have been precipitated by the alkali salts in the sea water after it had undergone considerable dispersion and a certain amount of concentration—; the silica thus precipitated on the sea bottom would tend to assume more or less globular or elliptical forms. Upon burial these forms would become compressed into their elliptical or lenticular shapes by weight of the accumulating sediments. Fossils falling into this soft colloidal mass would be perfectly preserved" (p. 428). It is argued that the "gel-mass" was for a while carried about by currents, until its mass had become sufficiently great to cause it to sink to the bottom. "If the waters were shallow, currents and waves might have shifted and rolled the masses of gel about, thus tending to form larger aggregates. This rolling aided in producing the banding of the chert, but only the relatively small masses were rolled about. Circular bands are found only in the smaller aggregates, those not exceeding eight to ten inches in diameter." "If the currents were unable to move the masses, the latter would have grown through mass action, the larger aggregates attracting the smaller ones. As growth proceeded, the banding and mottling of the chert was developed, due to carbonaceous materials that are believed to have been included in the chert as it grew" (p. 437). "When several nodules were formed close together they united to form a larger mass which shows a lobed circular outline from the flattening of the several spherical aggregates" (p. 439).

Certain other characteristics of cherts which might have developed in this manner may be suggested. If the postulated masses of "gel" were rolled around by waves and currents so as to develop the banding through the inclusion of carbonaceous matter, there would also be included the shells of small organisms which lay upon the sea bottom, and as a consequence there ought to be some sort of banded arrangement in the distribution of the fossils, and their longer axes should be parallel to the tan-

[10] Tarr, op. cit.

gents of the globular masses. If the globules developed without rolling, the shells of organisms would be largely those of pelagic habitat, and it would seem that this should have led to the arrangement of the long axes of the shells parallel to the upper surfaces of the "gel-masses." If "gel-masses" of the characteristics postulated were formed and rolled about by wave and current, it would appear that not uncommonly some, and quite likely many, would ultimately have reached places of deposition of clastic sediments. This would occur quite commonly in such a series of sediments as compose the Pennsylvanian and Permian strata of Kansas, Oklahoma, Missouri, etc., in which lateral gradation from one to the other type of sediment is extremely common and occurs within short distances. This, apparently, has not occurred.

If the circular banding of cherts developed through rolling about, with banded chert nodules of large size there should be an abundance of evidence of wave activity. If the banding developed in this way, the bands of the top and bottom should be of about the same width and number and the bands of the horizontally opposite sides should also be of about the same width and number, for it does not appear reasonable to suppose that the included material which developed the banding would have accumulated in the process of rolling to a much greater extent on one side than on the other, while the silica which was being added apparently would have been distributed quite uniformly along every radius. The greater width of the bands laterally, as compared to their widths in the vertical direction, might have developed as a consequence of their flattening through their own weight or the weight of the overlying sediments, because of silica moving from the top to the sides.

The evidence, as the present writer sees it, does not favor the view that the cherts which are considered in this article were formed in the manner which has just been outlined.

The *Fusulinas* of the Foraker cherts are uniformly distributed and show no concentration in any way whatever. The greater number of modern species of Foraminifera[11] are bottom-dwellers—only about twenty-five species being pelagic—and the chances are that large forms like

[11] Cushman, J. A., Bull. 71, U. S. Nat. Museum, 8, 1916.

Fusulina had a similar habitat. If this were true, they could hardly have dropped into the coagulating masses of silica, and, if these were rolled around on the sea bottom, some sort of banded arrangement in their distribution in the nodules ought to have developed. As these cherts are little banded, the implication would be that they had not been rolled about; such being the case, the *Fusulinas* must have dropped into, or crawled upon, the "gel-masses." If they lived on the bottom the former was not possible. If the Fusulinas were indeed pelagic in habitat and fell upon the coagulated chert, or were bottom-dwellers and crawled upon it, it would seem that the long axes of the tests would be tangent to the upper surface or sides of the "gel." Such, however, is not the case, as the axes of these shells are oriented in every possible direction.

For the basal chert of the Wreford—that in which the chert occurs only as a replacement of the shells of organisms—the explanation of original precipitation has no application. These are obviously replacements.

The second chert of the Wreford, in which there is the intricate intergrowth of limestone and chert, is also difficult to explain on the theory of original precipitation. These cherts do not have an elliptical globular shape, and to the writer it does not appear possible that the intricate intermingling of the limestone and the chert could have developed through the confluence of any number of coagulated globular or elliptical masses of silica, since the chert has ramifications in every direction which are confluent with neighboring masses laterally and vertically and has all sorts of projections and embayments. Furthermore, the sponge spicules which are present in this chert offer difficulty. It is possible that they might have floated to the masses and adhered to them and subsequently been covered by more silica. Three thin sections made from the associated limestone where it occurs in the same block from which a thin section of the chert was made, and within one and six inches of the place where the fragment for the thin section of chert was derived, do not show a single thing which can be positively identified as a sponge spicule, although other fossils are present. It may be that sponge spicules were once present in the limestone and have been dissolved, otherwise there must have been some selective action of the objects to which they may have floated. If they were dissolved and precipitated about other sponge spicules, those in the chert, for instance, a method of origin considered in the succeeding topic is approximated.

The third chert zone of the Wreford, that in which the large banded nodules occur, is also difficult to explain on the theory of original deposition. According to this theory, the nodules should be flattened parallel to the bedding, and this is true for many and perhaps most of them; but there are many others which are globular and not flattened at all. Others are of irregular shapes and still others have their longest axes perpendicular to the bedding. In places the chert composes the entire zone. Many of the nodules have diameters of three feet or more, and these, like the small ones, have concentric structure. If these were once "gel-masses" of silica which were rolled around so as to give them concentric structure, it implies rather strong currents for which the associated material gives no evidence whatever. If they were not rolled around, the greater additions of silica should have been from above and laterally and, if this could have been deposited in banded form, the banding which is present in these nodules would have been realized. At the lateral peripheries, the bands are two to three times as wide as on top. This might have been brought about by the flattening through their own weight or the overburden; but, as will be shown subsequently, the banding may be explained equally as well in another way. The somewhat botryoidal aspect of the exterior shows the development of many centers of accretion; but these, too, have a concentric structure which appears to be no more than an outpushing of the interior bands. These could not have been developed through any process of rolling or by the cohering of one "gel-mass" to another.

The observed facts relating to the cherts under consideration do not favor an origin through direct precipitation from silica in solution in the sea water, the precipitation and formation of the nodules taking place in accordance with the theory outlined in this topic. That processes of the nature considered may have assisted in the formation is quite possible. Furthermore, the writer considers it extremely improbable that large "gel-masses" could have developed in the manner postulated, and more probable that the silica is precipitated in extremely small particles and that these are buried with other sediments. No such "gel-masses" appear to have been reported from ocean waters or ocean sediments.

Theory of partial replacement of unconsolidated lime sediments either before or during the process of consolidation

This theory in its broadest statement maintains that the silica replaced unconsolidated sediments either before or during the process of consolidation, the silica being derived from organic and other silica mingled with the sediments, either in solid form or in solution. The silica in solution in the sea water is not excluded from aiding in the formation of the chert. The term replacement is used not only to include actual substitution of the lime sediments, but also replacement of the space held by them through their being pushed out of the way. Organic substances and organic silica are believed to have quite commonly served as nuclei for the nodules.

As conditions on the sea bottom change from time to time, and as each bed represents a somewhat different condition from that obtaining during the formation of a previous or subsequent bed, it readily follows that the chert of each bed may be quite different from that of any other bed. Each separate band probably represents a separate period of accretion under slightly different conditions, and if the bands show a rhythmic character, such as exists in the third chert zone of the Wreford, it points to a recurrence of similar conditions which may well have been seasonal. If the recent suggestion of Barrell,[12] that geologic time should be expanded in large multiples and that each bed represents a much longer time than has previously been supposed, approximate a correct estimate of geologic time and the duration of sedimentary processes, there would be given time for as many periods of accretion as one could well wish. At any rate, not more than one hundred years would be required for the development of a Wreford nodule of the largest size on the assumption that each band is an annual accretion, and a much shorter time would be required if the bands represent seasonal accretions. Since the sediments were still soft while the nodules were growing, there would be

[12] Barrell, J., Bull. Geol. Soc. America, 28, 884, 1917.

no good reason for the preservation of structures which were not yet in solid form, and these might, or might not, appear in the cherts. Fossils would quite certainly be preserved and the preservation could be better than, as good as, or worse than, that of those in the associated materials.

The process of the growth of a nodule is thought to have been something as follows. As silica in solution was carried through the sediments by diffusion, it is believed to have been precipitated about centers, such as small pieces of silica, fragments or organic matter, and, slightly extending previous conceptions, perhaps a very small "gel-mass" of the type postulated by Tarr. The dominating factor in the process of nodule growth was the attraction exercised on the dissolved silica by the growing nodule. As silica was taken from solution, it destroyed the equilibrium of the solute, resulting in more silica being diffused toward the nodule. A relatively sharp boundary was maintained between the limestone and the chert by the pressure which the growing nodule exercised on the associated lime sediments and which favored their going into solution.[13] That this boundary is gradative so far as the two substances are concerned is shown by the cherts which have been described in this article. In the development of the nodule any organic substances could become incorporated and these could be oriented in any direction. Masses of lime sediments, crystals of calcite, and all sorts of material could and should be present. As the movement of silica through the sediments would be greatest laterally because of bedding and lamination planes, and least from below because of greater pressure and hence less permeability in that direction, the greater width of the bands laterally and their least width below is readily explained. The different widths of bands on opposite sides would arise from differences in the quantity of silica supplied from different directions, while the different widths of the bands in radial section could be referred to differences in the quantity of silica supplied from period to period.

The chert of the Foraker limestone is believed to have developed as outlined. The theory harmonizes with the facts as they relate to this chert and fully explains the distribution and preservation of *Fusulina*.

[13] Faber, S., this Journal, 41, 555, 1916.

It hardly needs to be stated that the fossils in the basal chert layer of the Wreford are replacements, and the theory that this replacement preceded, or was contemporaneous with, the solidification, encounters none of the objections urged against the others. This theory also quite readily explains the labyrinthine intergrowth of limestone and chert in the second chert zone of the Wreford, as well as the fact that the chert contains an abundance of spicules, though there are few in the limestone. That this chert is not concentrically banded may be referred to a continuity of uniform conditions. The obscure horizontal banding is an inheritance of banding in the unconsolidated lime sediments.

The facts relating to the third chert of the Wreford also harmonize with the theory. All the characteristics are readily explained, and the globular and irregular nodules offer no difficulty; neither do those whose long axes are perpendicular or transverse to the bedding. The abundant calcite in this chert is thus easily accounted for.

It may well be, however, that original precipitation and also other processes played some part in the development of these nodules. Nature forms the same things in different ways and rare indeed is the occurrence of a geological result which was produced through the operation of a single factor. History, beginning with the founders of geology, notably Werner, has recorded the errors of those who have thus assumed.

One other theory deserves consideration, and this concerns the method of origin of the concentric structure of the nodules of the third chert zone of the Wreford limestone. While studying these nodules in the field and in the laboratory, the suggestion recurred again and again: Might not these structures be of organic origin? They are not markedly different in general outward appearance, irregularities of the surface, and microscopic internal structure from Cryptozoa. Moreover, algæ are known to have existed in large numbers in some parts of the world during the Carboniferous.[14] Search for microscopic structures of a type approximating those possessed by algæ has, however, been absolutely barren of results. If ever present, they have been totally

[14] Garwood, E. J., Geol. Mag., Dec. V, **10**, 497-498, 1913; Dec. VI, **1**, 265-271, 1914.

destroyed. If these nodules are of algal origin, they were probably calcareous in the beginning and were subsequently changed to chert by replacement.

Résumé of Facts and Conclusions

1. The cherts of the Foraker and Wreford limestones in the outcrops in the vicinity of the state line of Kansas and Oklahoma are quite varied in character and the different varieties are confined to distinct zones of wide horizontal distribution.

2. The observed facts do not harmonize with theories postulating an origin for these cherts consequential to weathering, or one of replacement, or of cavity-filling in solid rocks. It is not disputed, however, that chert develops in such ways.

3. It is possible that these cherts developed through direct precipitation of silica in solution in the sea water, but it is not believed that the facts support such an origin. That some silica may have been added to the nodules from silica in solution in the sea water is considered quite possible.

4. The chert is believed in major part to have resulted from replacement of unconsolidated limestone, the silica being derived from silica in solution which was mingled with the sediments, from silica in solution in the sea water, and from solution of organic or other silica, or silicates deposited in some form with the sediments.

5. The suggestion is made that the banded nodules occurring in one of the zones may have had an algal origin, but no microscopic structures similar to those occurring in algæ have been found.

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ART. XXVIII.—*A New Synthesis of Phosgenite;* by
W. A. HAMOR and H. E. GILL.

Phosgenite, the chlorcarbonate of lead, $PbCO_3.PbCl_2$, which occurs in Scotland, Sardinia, and Upper Silesia, has heretofore been synthesized by two procedures. C. Friedel and E. Sarasin[1] heated lead chloride, lead carbonate, and water together in a sealed tube to 180° C., and effected the synthesis; and another preparation was that of A. de Schulten,[2] who allowed a filtered solution of lead chloride to stand in a large flask while a current of carbon dioxide passed slowly through the space above.

A third, and very logical method, occurred to us as worthy of trial. This consisted in heating lead hydroxide and phosgene under pressure in a sealed tube, to effect the linkage of the lead hydroxide with phosgene, accompanied by the liberation of two molecules of water. With this object in view, a series of experiments were carried out using anhydrous lead hydroxide and phosgene,[3] the phosgene being in excess. The experiments were repeated many times, varying both the temperature (95°, 120°, 150°, 175°, 200°, and 250° C.) and the period of heating (1 to 4 hrs.).

The best results were observed at a temperature of 175° C., falling off entirely at 250° C. At the intermediate temperatures slight yields were obtained, but the crystal formation was very ununiform. The resulting material in each experiment was freed from phosgene and any lead hydroxide that remained and was then submitted to a thorough examination. The crystals obtained at 175° C. were quite small, but well-formed, faintly yellow in color, and soluble in dilute nitric acid. These crystals gave positive chemical tests, responding to tests for chloride and carbonate radicals, and fusing to a globule of lead covered with a white coating of lead chloride when heated upon charcoal: the crystals were unquestionably identified, both chemically and crystallographically, as phosgenite.

Mellon Institute of Industrial Research,
Pittsburgh, Pa., April 24, 1919.

[1] Bull. Soc. Min., 4, 175, 1881.
[2] *Idem,* 20, 194, 1897.
[3] The phosgene used was obtained from the Edgewood Arsenal, Baltimore, Md.

ART. XXIX.—*A Neglected Factor in the Rounding of Sand Grains;** by E. M. KINDLE.

Since rounding, or subspherical shape, in sand grains has come to be regarded as one of the criteria of dune sand deposits, the desirability of knowing all of the factors which contribute to the rounding of sand grains has become increasingly important. It is generally assumed that the higher degree of rounding which characterizes dune sands as compared with sea sands is the result of wind action.

The theory of the greater potency of wind action in rounding sand grains was clearly stated by Mackie in the following passage: "This leads us to investigate why wind should be a more potent agent in the rounding process than water. In air the particles roll with their full weight. In water they lose weight, by the weight an equal volume of water, so that in water they roll with only a fraction of their weight. This is one reason why much larger particles are moved by water than by wind. It should be remembered however that in the rounding of the larger particles or pebbles it is only the exceptional force of the current that is concerned whereas in the case of wind, a relatively large proportion of the work of rounding is probably done by comparatively low velocities."[1]

Sowerby pointed out the rapidly decreasing power of water to produce wear on the surface of a sand grain with reduction of diameter. "Perhaps, then we may conclude that a grain 1/10 of an inch in diameter would be worn as much or more in drifting a mile as a grain 1/1000 of an inch in being drifted 100 miles."[2]

Daubrée[3] argued that a minimum size is reached in the reduction of sand grains by water below which no reduction can occur since quartz grains less than 0·1 mm. will float in water very slightly agitated. Because of the cushion of water which keeps extremely small particles from contact with each other he concluded that "any finer grained sand would doubtless be angular." In the

* Published with the permission of the Director of the Geological Survey of Canada.

[1] Mackie, Wm.: Laws that Govern Rounding of Particles of Sand, Edinburgh Geol. Society, vol. 7, pp. 309-310, 1893-98.

[2] Sowerby, Anniversary Address, Quart. Jour. Geol. Soc., p. 59, 1880.

[3] Études synthetiques de Géologie experimentale, p. 256, 1879.

operation of the agency to be described it will be seen that the limitation on rounding imposed according to Daubrée by small size largely disappears.

None of the numerous geological papers dealing with this subject, which are known to the writer, consider any factors other than wind and water in discussing the rounding of sand grains.[4] A third factor which the writer believes to be of some importance is the agency of certain invertebrates in triturating sand grains within their digestive tracts. Certain echinoderms, notably the sea-urchins, feed upon sandy sediments and the diatoms, sea-weed and other organic materials which may be associated with sea sand. Various naturalists have noted the peculiar feeding habits of echinoderms which leads them to eat sand. Scott[5] has given the following account of his observations on the feeding habit of sea-urchins in the Bay of Fundy:

"When the urchins came from localities remote from seaweed the excrements were the small globular masses such as are observed in the alimentary tract. In tide pools where sea-urchins are abundant, the bottom is frequently covered with a layer of the castings of these animals . . . In only a few cases was sea-weed observed in the intestines of the urchins which had been dredged in the deeper waters of the bay. In their case, as in the case of urchins living on rocks devoid of sea-weed, the digestive tract contained chiefly the globular masses of surface sand. . . . It feeds partly on diatoms and other small algae, &c., which it cuts from the rocks with the sharp points of its teeth but it is also fond of dead fishes which are soon devoured, bones and all, by it in the Bay of Fundy." "The sea-urchin has thus two principal foods which we may call sea-weed and surface sand."

Prof. Verrill[6] found sea-urchins to be very efficient agents in reducing to small fragments the great variety of sea shells found in the Bermudas. He states that "the shells on the average constitute about 80 to 90 per cent of the whole mass (of sand), limestone detrites perhaps 5 per cent. The shells are mostly recently dead. Their generally broken condition (fig. 9) is due to the fact that

[4] A paper on the rounding of grains of sand by solution by J. J. Galloway is contained in the April number of this Journal, 47, pp. 270-280—Editors.

[5] Scott, Dr. F. H.: Food of the Sea-Urchin. Contr. Can. Biology 1901, Suppl. to 32nd Ann. Rept. V, pp. 50, 51, 52.

[6] Verrill, A. E.: Notes on Geology of the Bermudas, this Journal, 9, p. 330, 1900.

they have mostly been swallowed and passed through the intestines of the large sea-urchins (*Toxopneustes*) and two species of large holothurians (*Stichopus*) which are very abundant everywhere on these sandy bottoms and whose large intestines are always found filled with the sand. Many of the abundant smaller fishes also feed largely on the shells, are in fact continually at work killing and breaking up the shells, large and small. Such mollusks are however very prolific and mature rapidly so that they are able to keep up their customary numbers.''

Henderson[7] gives the following observations on the feeding habits of sea-urchins and holothurians in Cuban waters:

''Owing to the shifting nature of the sands the flats seemed to be very bare of life excepting for the many white-spined sea-urchins, some large stars, and a few holothurians. All of these creatures, especially the latter, were busily at work triturating the coarse organic matter it contains subjecting it to a grinding process. The amount of coarse sand thus quickly reduced to finer particles is far greater than one would at first suppose. No doubt the feeding habits of these echinoderms constitute an important factor in the breaking down process of reef from massive rock to fine mud.''

Various other naturalists, among them Sharpey[8] and Butler,[9] have noted the sand-eating habits of sea-urchins.

Sea-urchins occur in abundance wherever conditions are favorable to their existence. On the shores of Grand Manan island in the Bay of Fundy Dr. Wm. Simpson found ''such numbers of sea-urchins that it is impossible to make a step without crushing one or more of them.''[10] Verrill reports sea-urchins as ''very abundant in the Bay of Fundy from low water to 109 fathoms.''[11] Scott reports sea-urchins so abundant at some localities in the Bay of Fundy that ''they are massed in heaps, often obscuring the bottom.''[12]

[7] Henderson, J. B.: The Cruise of the Tomas Barrera, pp. 131-132, 1916.

[8] Sharpey, W.: Echinodermata, Todd's Cyclopaedia of Anatomy and Physiology, vol. 2, p. 39, London, 1838.

[9] Butler, F. H.: Echinodermata. Encyclopaedia Britannica, ninth edition, vol. 7, p. 631, Edinburgh, 1877.

[10] Stimpson, W.: Proceedings of the Boston Soc. Nat. Hist., vol. 4, p. 96, 1854.

[11] Verrill, A. E.: Rept. upon Invertebrate Animals of Vineyard Sound and the adjacent waters with an Account of the Physical Characters of the Region, Rept. Comm. Fish and Fisheries, Washington, 1874.

[12] Scott, F. H.: Food of the Sea-Urchin, Contr. Can. Biol., p. 53, 1901.

The sea-urchin is one of the few invertebrates which appear to thrive best on a sandy bottom. The effect on the sand of being passed through the echinoderm stomach and subjected to the rubbing and grinding which it must there undergo must be of considerable importance in reducing both the size of the grains and their angularity. Under the influence of muscular compression there would appear to be scarcely any limit to the small size to which the muscular attrition could reduce the sand particles, as there is in the case of their reduction in water.

Darwin estimated that earthworms on each acre of land suitable for their habitat passed through their bodies annually a weight of more than ten tons of earth.[13] It appears not improbable that echinoderms and holothurians on sea bottom areas which afford a suitable habitat may subject an equally large volume of sand to trituration in their stomachs. In any event it must be granted that a very large volume of sand is annually passed through the bodies of these voracious creatures and that they play an important rôle in the rounding of sand grains.

Recognition of the agency of echinoderms in rounding sand grains seems to lead to the conclusion that more rounding of sand grains occurs on the sea bottom than has hitherto been suspected. It can hardly be claimed however that the work of echinoderms, important as it may be, rivals that of the wind in rounding grains of sand. It should also be noted that the wind probably exercises a selective process in removing sand from the sea shore to the dunes, taking more of the rounded than of the angular grains because "a round sand grain will probably run before the wind better than a flat one."[14]

[13] Darwin, Chas.: The formation of vegetable mould through the action of worms, p. 236, 1904, ed. (1st ed.) 1881.

[14] Richardson, Hugh: Sea Sand.—Ann. Rept. Yorkshire Philosophical Soc. for 1902 (1903) pp. 57, 58.

Art. XXX.—*Notes on a specimen of Stylemys nebracensis Leidy;* by E. C. Case.

The University of Michigan expedition to the Big Bad Lands of South Dakota, in 1917, recovered the shell of a large specimen of *Stylemys nebracensis* in such a good state of preservation that it was determined to remove the bone from the matrix and mount the shell as a recent specimen would be mounted. In removing the shell the pelvic and pectoral girdles, one humerus and five posterior cervical vertebræ were found. The preparation and mounting of the parts has added several points to our knowledge of the anatomy of this long known form.

In all the published figures of *Stylemys* the shell has been shown as it occurs in the field, more or less crushed down. The general impression has been that the form was somewhat depressed though Hay has shown that the height varies in different individuals with age. This specimen mounted with the crushing corrected shows that the shell was relatively high with nearly vertical sides, quite similar to that of the Galapagos tortoise.

The pelvis, hitherto very imperfectly known, is nearly complete. It is typically that of a land turtle, resembling most closely the pelvis of *Kinixys*. The greatest peculiarity is in the extremely heavy ischial region. The symphasis is tightly closed and the posterior ends of the ischia are very rugose with the posterior end broadly concave. This posterior end or edge is sharply down-turned so that it overhangs the lower surface and forms deep pits of either side. The whole pelvis evidently stood at an angle to the inner surface of the plastron as in *Kinixys*.

The pectoral girdle presents no peculiarities.

The free vertebræ include the first dorsal and the five posterior cervicals, hitherto unknown. These are all of the testudinate type and closely resemble the corresponding vertebræ of *Gopherus* and *Kinixys*. The anterior dorsal is larger than the others, it was free in the shell with a strong neural spine for attachment to the carapace; there is a pair of small anterior ribs attached to the middle of the centrum. Similar ribs were present in the specimen of *Kinixys* examined but not in the specimen of *Gopherus;* it is said to be a variable character.

Fig. 1.

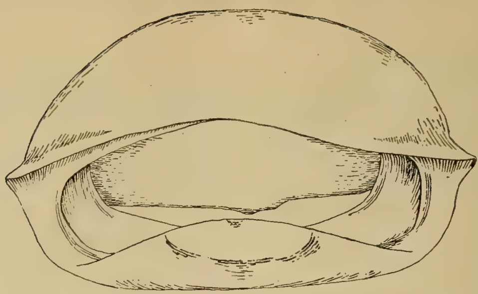

Fig. 1. Anterior view of the shell, X 1/7.

Fig. 2.

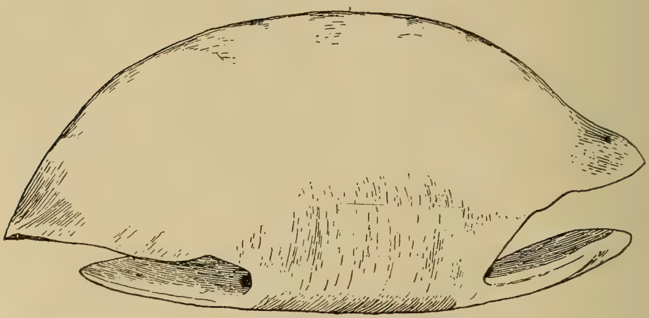

Fig. 2. Side view of the shell, X 1/7.

Fig. 3.

Fig. 4.

Fig. 3. Lateral view of the pelvis, X 1/3.
Fig. 4. Lower view of the pelvis, X 1/3.

Fig. 5.

Fig. 5. Eighth to fourth cervical vertebræ, X 1/3.

The first dorsal lay almost in line with the other dorsals and the anterior zygapophyses are not especially large.

The eighth cervical is characteristically short, biconvex with the anterior face of the centrum double; large sharply down-curved posterior zygapophyses; no neural spine; a thin keel on the lower surface. It stood nearly at a right angle to the first dorsal in the sharp downward curve of the neck characteristic of all the Testudinidæ.

The seventh cervical is longer than the eighth; biconcave with the faces of the centrum double; the posterior zygapophyses relatively longer than in *Gopherus;* the anterior zygapophyses lost; a low, thin keel runs nearly the entire length of the lower face of the centrum.

The sixth cervical has a double convex face behind and a single concave face in front; the articular portion of the convex posterior face is on the upper part of the face and there is a broad pit on the lower portion permitting of over-extension of the neck as it was straightened; the posterior zygapophyses are lost; the anterior zygapophyses rise nearly straight upward from the sides of the centrum so that the fifth and sixth cervicals would have to stand at a considerable angle to each other to permit articulation of the zygapophyses. This last character is more pronounced than in *Gopherus* showing that the neck was even more sharply curved at the posterior end than in that genus.

The fifth cervical is similar to the sixth in general form. The posterior face is single convex and the anterior single concave; the articular portion of the posterior face is even higher than in the sixth and the pit below deeper and larger; the anterior zygapophyses are a little more inclined forward.

The fourth cervical is represented by the posterior half only, the posterior face is single convex.

In all the characters of the shell the pelvis and the vertebræ recovered there is a strong resemblance to the living Testudinidæ and show that *Stylemys* was a typical land form.

Measurements	mm.
Length of the carapace	600
Length of the plastron	569
Height as mounted	262
Length symphasis of pelvis	94

Length bottom line of centrum, first dorsal	39
Length bottom line of centrum, eighth cervical .	36·6
Length bottom line of centrum, seventh cervical	39·2
Length bottom line of centrum, sixth cervical ..	49·5
Length bottom line of centrum, fifth cervical ...	51·6

University of Michigan,
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SCIENTIFIC INTELLIGENCE.

I. Chemistry and Physics.

1. *The Gravimetric and Volumetric Determination of Mercury Precipitated as Mercury Zinc Thiocyanate.*—George S. Jamieson, of the Bureau of Chemistry, Department of Agriculture, Washington, D. C., has devised a method for precipitating mercury from solutions containing the metal in the mercuric condition by producing the double salt $HgZn(SCN)_4$ and either weighing this salt or titrating it by means of potassium iodate solution in the presence of strong hydrochloric acid with the use of a little chloroform as an indicator. In order to get a quantitative precipitation of the mercury in this form there should not be more than 5 per cent of acid present in the liquid before the addition of the reagent, which contains 29 g. of zinc sulphate and 39 g. of ammonium thiocyanate per liter. In case that it is necessary to neutralize an excess of acid, sodium hydroxide rather than ammonia should be used, as large amounts of ammonium salts increase the solubility of the precipitate. It was found that copper, cobalt, bismuth and nickel are partially precipitated along with the mercuric zinc thiocyanate, hence if present they would interfere with this method of determination. The reviewer makes the suggestion here that if the copper, cobalt and nickel merely replace zinc isomorphously in the precipitate they should not interfere with the *volumetric* determination, since in that case they would not by their presence change the proportion of mercury to thiocyanogen.

For the gravimetric operation the precipitate is collected on a Gooch crucible and washed with small quantities of a solution containing 5 cc. of the precipitating reagent and 450 cc. of water, because the precipitate is appreciably soluble in pure water. Drying at 102 to 108 is recommended before weighing.

For the volumetric process the precipitate was collected on small filter-papers, washed at first with a mixture of 10 cc. of the precipitating reagent and 450 cc. of water, then with small quantities of the previously mentioned weaker mixture.

The equation for the volumetric titration is given as

$$HgZn(SCN)_4 + 6KIO_3 + 12HCl = HgSO_4 + ZnSO_4 + 2H_2SO_4 + 4HCN + 6ICl + 6KCl + 2H_2O.$$

For further details of the processes the original article should be consulted, but it may be mentioned that the test analyses gave excellent results, and that the method was applied to the examination of antiseptic tablets and other commercial preparations of mercury.—*Jour. Indust. and Eng. Chem.*, **11**, 296

H. L. W.

2. *Chemical Calculations;* by R. HARMAN ASHLEY. 12mo, pp. 276. New York, 1918 (D. Van Nostrand Company).—This is the second edition of the work, appearing only about four years after the original issue, with no changes except some slight modifications and corrections.

The problems presented are very numerous and varied, dealing with ratios, approximate numbers, interpolation, heat, specific gravity, gases, atomic weights, formulas, gravimetric analysis, volumetric analysis, and acid specific gravity tables. In general, the methods of calculation are very fully and clearly explained. Some of the problems may be regarded as rather complex and difficult, but there is an amply supply of simpler ones.

The author adopts the method of ratios in preference to the use of proportion, and he treats this topic of ratios quite elaborately; but while it must be said in justice to the author that his explanations are usually reliable, it is a curious circumstance that he makes a mistake in the statement of his reasoning in his *very first* problem, thus illustrating possibilities for mistakes in the ratio method of calculation. At the bottom of page 2 he says " . . . one part by weight of oxygen [in HgO] is given by $\frac{2(16)}{2(216{\cdot}0)}$ parts of mercuric oxide . . .," whereas it is one part of mercuric oxide that gives this amount of oxygen. However, the problem is solved correctly in spite of the faulty statement.

The chapter on approximate numbers deserves severe criticism, for the author evidently does not fully understand this subject. He states on page 29 that assuming no errors in the numbers,

$$``1{\cdot}862 \times 0{\cdot}6257 = 1{\cdot}1\underline{6}50534",$$

where the line under the figure indicates that it is uncertain. Of course, if the numbers multiplied are exact ones all the figures in the result must be exact also, and even assuming "maximum apparent errors," which the author is discussing, in these data the result would be $1{\cdot}165\overline{1}$.
$\pm\overline{3}$

The author usually carries out the decimals in the answers to the problems to a reasonable extent, but a few answers are carried out several places beyond those justified by the data, as he says in his preface,'' . . . as this involved no extra work [using six-place logarithms] and is valuable in inculcating accuracy.'' In regard to this point it may be said that the use of more than one uncertain figure at the end of a result should usually be considered unsatisfactory, if not absurd.

In spite of this criticism and one or two other minor points that will not be taken up here, the book in general gives an excellent impression. H. L. W.

3. *Quantitative Analysis;* by EDWARD G. MAHIN. 8vo, pp. 605. New York, 1919 (McGraw-Hill Book Company, Inc.).—This is the second edition, revised and enlarged, of a book which first appeared six years ago as one of the ''International Chemical Series'' of text-books.

While this book cannot be regarded as a complete reference work on quantitative analysis, or any of its special branches, it is extensive enough to provide ample practice for students in college courses, with a wide degree of latitude in the selection of methods. An excellent feature of the book is the attention given to the explanation of the scientific principles involved in the processes.

The first part of the book, comprising nearly one-half of its contents, is devoted to general quantitative analysis, presenting the principles of the operations, a course experimental gravimetric analysis, a chapter on electro-analysis, and a rather elaborate treatment of volumetric analysis. The second part deals with the analysis of industrial products and raw materials, including rocks, fuels, gas mixtures, oils, fats and waxes, boiler waters, drinking waters, steels and alloys, fertilizers, dairy products, with a chapter on the fire assay for gold and silver.

The author has followed the example of several recent high authorities in advocating the use of a long swing of the balance in weighing, with the finding of the center of equilibrium each time, and with the troublesome observations and calculations involved in this process. This is not the proper place to argue fully in regard to the relative merits of the long and short swing methods of analytical weighing, but it may be stated here that other eminent authorities have preferred, and still prefer, the use of a very short swing of the pointer and the use of the center of the scale as the zero point, while always weighing by difference, and it seems unfortunate to the reviewer that the less accurate and more cumbersome method by long swings should be used by any analytical chemist.

Naturally, in an extensive work like this, other points of detail might be criticized in connection with differences of opinion; but it may be stated that the book as a whole gives an excellent impression, and that it appears to be a very suitable one for the use of students. H. L. W.

4. *Catalytic Hydrogenation and Reduction;* by Edward B. Maxted. 12mo, pp. 104. Philadelphia, 1919 (P. Blakiston's Son & Co. Price $1.25 net).—This is the American issue of a book originating in Great Britain, one of the series of "Text-books of Chemical Research and Engineering," edited by W. P. Dreaper. It presents from a chemical point of view the numerous examples of catalytic hydrogenation which have been published from time to time. Special attention is given to experimental methods, and, in addition to simple hydrogenation of unsaturated linkages, various reductions of a less simple nature are included. A chapter is devoted also to dehydrogenation. The exceedingly important topic, the technical hydrogenation of unsaturated oils for the purpose of converting them into hardened fats, is well discussed from a theoretical standpoint.

As the book brings together much information and gives many references to the literature, it will be useful and interesting to many organic chemists and chemical engineers. H. L. W.

5. *The Dispersion of Diamond.*—In an earlier paper, entitled "Refractivity and Atomic Interaction," L. Silberstein developed a number of general formulae which may be applied, of course, to many special problems. A typical example of a special case is presented in a more recent mathematical article, by the same author, the introductory sentence of which reads: "The object of the present paper is to apply the concept of electrical interaction of atoms, . . ., to the refractive properties of diamond considered as a known assemblage of fixed 'atomic centres,' each containing a single dispersive electron and becoming a doublet in presence of an external electric field."

The final formula obtained is theoretically restricted to wave-lengths which do not greatly exceed the limits of the visible spectrum. Long infra-red radiations are excluded by the assumption of the mutual immobility of the "centres" themselves, that is, of the whole atoms. Wave-lengths as short as those of X-rays, say, are barred by the hypothesis that the electric field is homogeneous. The formula does apply to visible and to not too remote ultra-violet light since, for these radiations, a wave-length cube would contain 10^{11} or 10^{10} atomic doublets. Surface phenomena are not taken into account in the analysis, for the crystal is treated as a space lattice of points, indefinitely extended in all directions. The structural form of diamond, involved in the geometry, is that given by Bragg. More specifically, the atomic configuration of this crystal is supposed to consist of the superposition of two face-centered lattices, one of which is obtained from the other by translating it rigidly along a cube diagonal one-quarter of the length of the diagonal. Each point of both lattices is occupied by a carbon atom. The result of this superposition is that each carbon atom occupies the center of a regular tetrahedron four corners of which are occupied by the four nearest neighbors of that atom.

By means of vector analysis the author first proves that "*the resultant action* of all doublets in an unlimited diamond lattice is *nil.*" It then follows at once that $\mu^2 = 1 + Ne^2/m(\gamma_0\text{-}\gamma)$, where $\mu =$ refractive index, $N =$ number of carbon atoms per unit volume of diamond, $e =$ electronic charge, $m =$ electronic mass, $\gamma = 4\pi^2c^2/\lambda^2$, $\lambda_0 = 4\pi^2c^2/\lambda^2{}_0$, $\gamma =$ incident wave-length (*in vacuo*), $\lambda_0 =$ free wave-length belonging to the electron of the carbon atom, and $c =$ velocity of the light in free space. Putting $u = 1/\lambda^2$ and $a = Ne^2/4\pi^2c^2m$, the final formula reduces to

$$\mu^2 = 1 + \frac{a}{u_0 - u},$$

that is, the simplest, two-constant formula of the common type. When this formula was tested on the thirteen values of μ given by Martens and others, for values of λ varying from 0·3133 micron to 0·7604 micron, it was found to agree almost exactly with the experimental data. The greatest deviation was —0·0009, corresponding to $\mu = 2{\cdot}4410$. In this calculation $a = 357{\cdot}40$ micr.$^{-2}$ and $\mu_0 = 76{\cdot}691$ micr.$^{-2}$. The free wave-length λ_0 comes out 1142 A. U., which is quite plausible. The empirical formula used by Martens involved *three* constants, hence Silberstein's equation is better from all points of view. There remain a few more interesting deductions in the latter part of the paper, but these cannot be entered into in this abstract.—*Phil. Mag.*, **37,** 396, 1919. H. S. U.

6. *Resonance Radiation of Sodium Vapor.*—In collaboration with F. L. MOHLER, R. W. WOOD has repeated and extended his earlier experiments on the resonance radiation of sodium vapor excited by either one of the D lines. The apparatus used in the recent work was more powerful and efficient than that employed in the preceding investigation of the same phenomenon. For example, the spectrograph was built up with two large portrait objectives of 3 in. aperture and 24 in. focal length, and two 5 in. prisms of flint glass. Larger polarizing prisms were used, and the thick quartz plate was re-figured and polished. The entire polarizing system was kept at constant temperature by a thermostat. "A very great advance resulted from the discovery that the new 'pyrex' glass made by the Corning Co. (Corning, N. Y.) resists the action of sodium vapour far better than any other glass in the market. Bulbs blown from tubes of this glass showed scarcely any discoloration after ten hours' heating, which is sufficient to colour bulbs of soft-glass a dark brown." Elaborate precautions were taken to eliminate all known sources of error. In particular, special attention was given to the removal of hydrogen from the sodium. "We found that even after the sodium deposit had been driven across the bulb 170 times, the McLeod gauge still showed a small trace of hydrogen."

The most important results obtained will be summarized in the following sentences. (a) With D_2 excitation, and with the bulb as free from hydrogen as possible, it was found that at 210° C. there was no trace of D_1 or, more exactly, the intensity ratio of D_2 to D_1 was *at least* 20:1. At 300° C. this ratio was about 5:1. When the bulb contained hydrogen, at a pressure of about 0·25 mm. of mercury, the ratio of the intensity of D_2 to that of D_1 was approximately 4:1 at 220° C., and 3:1 at 300° C. (b) With the much weaker D_1 excitation, and with practically no hydrogen present, only a trace of D_2 was detected at 220° C., while at 300° C. the ratio of D_1 to D_2 was about 3:1. With hydrogen at 0·1 mm., and at a temperature of 220° C., the ratio of D_1 to D_2 was 2:1. At 250° C., and with hydrogen at a pressure of 0·25 mm., this ratio was approximately 3:2. "In conclusion it seems safe to say that the transfer of energy from the excited line to its companion results from molecular collision, either of sodium with hydrogen or sodium with sodium, the effect in the latter case being evident only at high temperature and increased density."—*Phil. Mag.*, **37**, 456, 1919. H. S. U.

7. *The Stark-Lo Surdo Effect in Nitrogen and Oxygen.*—The electric resolution of some of the spectrum lines of nitrogen and oxygen has been recently investigated by USABURO YOSHIDA. The spectrograph employed had only three prisms so that the dispersion in the red was relatively small. The cathodes in the vacuum tubes were usually made of tantalum, as it was found that this metal sputters less than aluminium, which has been generally used by earlier observers. The greatest gradient attained in these experiments was about $16{\cdot}5 \times 10^4$ volts per cm.

Nitrogen. The line at λ4100·3 was displaced toward the more refrangible side, and the value of the displacement was approximately the same for the parallel (p-) component as for the perpendicular (s-) component. For a field of $16{\cdot}5 \times 10^4$ volts per cm. the shift was about —1·75 angstrom units. The same remarks apply to the line at λ4110·1, save that the displacement was arithmetically greater, namely, —3·35 A. U. In the region from λ4000 to λ5000 many lines of the negative band spectrum and of the second positive band spectrum were recorded on the spectrograms, but no displacements could be detected even in the highest gradient involved. The lines λ5553 and λ5688 were displaced toward the red by about + 9 A. U. and + 4 A. U. respectively, the gradient being $8{\cdot}6 \times 10^4$ volts per cm. For each of these lines the shifts of the p- and s-components were apparently equal. The author ascribes these two lines to nitrogen, but he admits that the identification is not entirely satisfactory.

Oxygen. Many lines of the spark spectrum of oxygen were present on the negatives, but no electrical effect could be detected up to 10×10^4 volts per cm. Similarly no displacements were found for $\lambda 4368 \cdot 0$, of the doublet principal series, and for $\lambda 3947 \cdot 0$, of the triplet principal series.

Three lines of the triplet second subordinate series were investigated. Probably due to inadequate dispersion in the red, the line $\lambda 6455$ showed no sensible shift. The lines $\lambda 5436$ and $\lambda 5109 \cdot 5$ were not resolved into triplets but, when treated as singlets, they were displaced toward the red by about $+ 1 \cdot 6$ A. U. and $+ 3 \cdot 7$ A. U., respectively, corresponding to a gradient of 8×10^4 volts per cm. For each line the p- and s-components suffered the same displacement. The author concludes that the three lines of the second subordinate series experience displacements which increase as the term number becomes larger, and that this series of oxygen behaves in all respects in precisely the same manner as the corresponding series of helium and parhelium.

In the spectral region studied, three lines of the triplet first subordinate series were observed. For the line $\lambda 6157$, $\delta\lambda$ was about $+ 3$ A. U. for the p-component, and $+ 2 \cdot 5$ A. U. for the s-component, (gradient $= 7 \times 10^4$). Yoshida attributes this lack of equality to experimental error. The lines $\lambda 5329 \cdot 5$ and $\lambda 4968 \cdot 5$ had each the same shift for the p- and s-components. For the field $8 \cdot 16 \times 10^4$ volts per cm., the mean of the p- and s-displacements for the resolved components of the triplets were $-15 \cdot 8$, $+ 2 \cdot 6$, $+ 16 \cdot 4$, and $-30 \cdot 1$, $-10 \cdot 8$, $+9 \cdot 2$, and $\lambda 4968 \cdot 5$ and $\lambda 5329 \cdot 5$, in the order named.

"Each of the lines 5329·5 and 4968·5 A. U. of the first subordinate triplet series has two isolated components respectively in its immediate violet side. The isolation of the said components becomes smaller as the term number of the series increases. This is exactly similar to that of the isolated components of helium and parhelium."—*Mem. Coll. sci. Kyoto,* **3**, 287, 1919.

8. *The Principles Underlying Radio Communication.* (Radio Pamphlet No. 40, Signal Corps, U. S. Army.) Pp. 355, with 268 figures. Washington, 1919 (Government Printing Office).—This volume was prepared primarily to facilitate the intensive training given to classes in radio communication during the later part of the world war. Since many of the members of these classes had not had adequate preliminary training in electricity, magnetism, and electromagnetism it was found necessary to introduce each branch of the subject in a very elementary manner. The scope of the text may be inferred from the titles of the six chapters, which are: 1 Elementary Electricity, 2 Dynamo-Electric Machinery, 3 Radio Circuits, 4 Electromagnetic Waves, 5 Apparatus for Transmission and Reception (Exclusive of Vacuum Tubes), 6 Vacuum Tubes in Radio Communication.

Judged from the points of view of clearness of presentation and of wisdom in the selection of material, much credit is due to the six collaborators upon whom fell the difficult task of preparing the volume in as short a time as possible. The unavoidable haste in compilation affords an ample excuse for the fact that the volume contains a relatively enormous number of practical errors and inconsistencies. The following typical examples will suffice. (a) On page 49 the very commendable statement is made that: ''The term 'battery' is sometimes incorrectly used to mean one such cell.'' Nevertheless, figure 3 shows a single dry cell with the legend ''Battery,'' and this term is frequently applied to a single unit throughout the text. (b) In many cases, the cross-references to the numbered articles are incorrect and misleading, sometimes even referring to an eighth chapter which was not included in the volume. (c) In figures 37, 38, and 42 the wrong polarity is marked on the conventional symbol for a cell. This might lead to a misinterpretation of figures 246, 251, and 268, which are self-consistent and conventionally correct. Finally, the volume does not include an index. H. S. U.

II. Geology and Mineralogy.

1. *The Trias of New Zealand;* by Charles T. Trechman, Quart. Jour. Geol. Soc., Vol. **73**, pt. 3, pp. 165-246, London, 1918.—After many years, gelogists have the opportunity of comparing the Triassic of New Zealand with that of the northern hemisphere; the previous reports being meager and rather inaccurate. Only Upper Triassic faunas, of Carnic and Noric age are known there, and these, while having some faint resemblance to those already known in Europe, Asia and North America, are strikingly different. *Halobia zitteli,* long known from the Arctic region, is found in the Carnic stage along with *Halobia* cf. *austriaca, Discophyllites* cf. *ebneri,* and *Clydonautilus* cf. *spirolobus,* of Mediterranean affinities. *Pseudomonotis ochotica* in the Noric horizon, a North Pacific and Arctic species, occurs along with *Monotis salinaria* of the ancient Tethys. We have here a strange intermingling of European and Pacific types.

The greater part of the fauna, however, is wholly foreign to anything known in the northern hemisphere, with brachiopods, pelecypods and gastropods predominating. We look in vain for the rich cephalopod facies that characterizes the Upper Triassic of the Alps, California, and India. The brachiopods offer the characteristic Triassic genus *Halorella,* and *terebratuloids* are not uncommon. But the most unique element is the great number of spiriferoids, giving a Paleozoic aspect to the assemblage, *Spiriferina, Retzia, Mentzelia, Spirigera, Mentzeliopsis,* and *Hectoria,* the last two being new.

The bivalves offer less that is new, those described being mainly the conventional types, except *Hokonuia,* a new genus somewhat between *Lima* and *Myalina.* Even more interesting than new species or genera is the occurrence of characteristic northern forms of *Halobia, Daonella, Pseudomonotis* and *Monotis,* increasing their geographic range, and greatly strengthening their value for interregional correlation.

The sparse cephalopod fauna furnishes *Orthoceras, Grypoceras, Clydonautilus, Arcestes, Cladiscites, Pinacoceras, Discophyllites,* and *Aulacoceras,* all identical with, or closely related to, European species.

Mr. Trechman has done a real service in making known this southern fauna and also in straightening out formidable tangles in the stratigraphy of New Zealand. His paper will be of great value and interest to students of Triassic stratigraphy all over the world.—JAS. PERRIN SMITH, Stanford University, Cal.

2. *Seasonal deposition in aqueo-glacial sediments;* by ROBERT W. SAYLES. Pp. 67 + 16 plates. Memoir of the Museum of Comparative Zoölogy at Harvard College. Vol. **47,** No. 1. 1919.—Seasonal deposition in aqueo-glacial deposits has been a subject of much interest since de Geer succeeded in counting by that means twelve thousand years of late glacial and post-glacial time. Deposition of the coarser sediment near the ice-front is very much increased during the melting season. As a result the clay deposits in water bodies marginal to ice sheets are banded as conspicuously as the annual rings of growth in trees. Sayles some years ago published descriptions of his discoveries of striated bowlders and other evidences of glacial origin in the Squantum tillite member of the Roxbury conglomerate series of Permo-Carboniferous age near Boston, Massachusetts.

The present memoir is a very careful study of the banded slates which occur interbedded with the tillite. The plates show handsome reproductions of banding in Pleistocene clays compared with the Squantum banded argillites. The resemblance is striking. The memoir is important not only in giving further evidence of the glacial associations of the Roxbury conglomerate Series, but in proving the existence of sharp seasonal changes from summer to winter at that time and in that latitude. Furthermore the bands give graphic detail of individual years. As a meteorological record belonging to a remote geologic period Sayles' publication is unique. J. B.

3. *New Mineral Names;* by W. E. FORD (communicated—continued from vol. **45**, pp. 477-478, June, 1918):—

Chubutite. Hercules Corti, (An. soc. quim. Argentina, **6**, 65, 1918), Chem. Abs., **13**, 298, 1919. Tetragonal? H. = 2·5. G. = 7·952. Color yellow with reddish tinge. Comp.—an oxychloride of lead, $7PbO.PbCl_2$. Fusible. Soluble in nitric acid. From region of Chubut, Argentina.

Ferrierite. R. P. D. Graham, Trans. Roy. Soc. Can., **12**, 185, 1918. Orthorhombic. In thin bladed crystals, tabular parallel to $a(100)$ and elongated parallel to the c axis. $b(010)$ and $d(101)$ also present. $dd' = 44° 26'$. The crystals are grouped upon one another in nearly parallel position and a large number of such piles of slightly divergent blades radiate from a common center giving rise to spherical aggregates. Perfect cleavage parallel to $a(100)$. H. = 3-3·5. G. = 2·15. Luster pearly on a, vitreous on b and dull on d. Color white. Ax. pl. $\parallel b(010)$. $Bx_{ac} \perp c(001)$. Optically +. $\alpha = 1{\cdot}478$, $\beta = 1{\cdot}479$, $\gamma = 1{\cdot}482$. $2V = 50° \ 25'$. Comp.—A zeolite related chemically to ptilolite and mordenite except that it contains magnesium in the place of calcium. $R_2Al_2(Si_2O_5)_5.6H_2O$, where R = Mg: Na_2 : H_2 = 1 : 1 : 1. Percentage composition: Silica 67·42, alumina 11·46, magnesia 2·99, soda 4·65, water 13·48 = 100. In the bunsen burner flame whitens and thin splinters fuse to a blebby glass. Fus. = 3-3·5. Yellow flame. In C. T. whitens and gives much water. Insoluble in HCl. Found in veins traversing an olivine-basalt along a cut on the Canadian Northern Railway on the north shore of Kamloops Lake, B. C. Associated with chalcedony and calcite. Named in honor of Dr. W. F. Ferrier, formerly on the Canadian Geological Survey.

Högbömite. Axel Gavelin, (Bull. Geol. Inst. Upsala, **15**, 287), Jour. Chem. Soc, II, 324, 1917. Hexagonal-rhombohedral. Laminated. Conchoidal fracture. H. = 6·5. G. = 3·81. Uniaxial, negative; $\omega = 1{\cdot}853$, $\epsilon = 1{\cdot}803$. Comp.—$RO.2R_2O_3$; RO = MgO, $R_2O_3 = Al_2O_3$, Fe_2O_3. A part of the R_2O_3 is replaced by TiO_2. Found in the iron ores of Ruoutevari, Lapland.

Leifite. This mineral was briefly mentioned in the list published in this Journal, **42**, 504, 1916. A more complete description is now available in Jour. Chem. Soc., II, 247, 1917. Hexagonal. Prismatic crystals without terminal faces. Perfect prismatic cleavage. H. = 6. G. = 2·565-2·578. Colorless. Optically +; $\omega = 1{\cdot}5177$, $\epsilon = 1{\cdot}5224$. Comp.—A fluosilicate of aluminium and sodium, $Na_4(AlF)Si_9O_{22}$. Easily fusible with intumescence. Insoluble in hydrochloric acid. Found in the druses of the pegmatite of Narsarsuk, Greenland.

Oliveiraite. T. H. Lee, this Journal, **47**, 129, 1919. Amorphous. Greenish yellow color. Comp.—A hydrated titanate of zirconium, $3ZrO_2.2TiO_2.2H_2O$. A secondary mineral produced by the alteration of euxenite with which it is intimately associated. From Pomba, Minas Geraes, Brazil. Named in honor of the Brazilian geologist, Dr. Francisco de Paula Oliveira.

Orvillite. T. H. Lee, this Journal, **47**, 126, 1919. A hydrous silicate of zirconium having the composition $8ZrO_2.6SiO_2.5H_2O$. It occurs in intimate association with zircon, lining cavities in a rock composed almost wholly of zirconium oxide (baddeleyite) from the Caldas region, Minas Geraes, Brazil. It was separated from the zircon by treatment with a mixture of hydrofluoric and hydrochloric acids which served to completely dissolve it while the admixed zircon was unattacked. Named in honor of Orville A. Derby, late director of the Brazilian Geological Survey.

Racewinite. A. N. Winchell, Econ. Geol., **13**, 611, 1918.

Massive without crystal or cleavage faces. H. = 2·5. G. = 1·94-1·98. Color of fresh material bluish green, changing on exposure to brownish black. Biaxial, negative. Large optical angle. Refractive index about 1·51. Birefringence near that of quartz. Comp.—Essentially an aluminium-ferric silicate with large amounts of water (22 per cent). Loses its water very readily without destroying the crystal structure or materially altering the optical characters. Reabsorbs water easily. Found at the Highland Boy mine, Bingham, Utah, in irregular veins associated with pyrite and other ore minerals. Name derived from the cable address, *Racewin,* of H. V. Winchell who first called attention to the mineral.

Zebedassite. A. Brusoni, Riv. Min, **50**, 74, 1918. Orthorhombic? In fibrous aggregates. H. = 2. G. = 2·194. Color white. Silky luster. Refractive indices, 1·51-1·53. The direction of elongation of the fibers is optically positive. Comp.—$5MgO.Al_2O_3.6SiO_2.4H_2O$. Infusible. Ignited with cobalt nitrate assumes a rose-violet color. Yields much water when heated in a closed tube. Easily soluble in acids with the formation of a silica jelly on evaporation. Occurs filling fractures in a serpentine rock found at Zebedassi, near Volpedo, Piedmont, Italy.

4. *Kimberley Diamonds: especially Cleavage Diamonds;* by J. R. Sutton. Trans. Roy. Soc. So. Africa, **7**, 65-96, 1918.—This paper gives a detailed study of various aspects of the diamonds obtained from the mines of the Kimberley district. Tables are presented which show the proportions from each mine of the different sorts of diamonds produced. The question of change in amount and character of the diamonds obtained at different depths in the various mines is discussed. In regard to the cleavage fragments that are so commonly found the author suggests that the small inclusions, like garnet and zircon, that are frequently found in the diamonds, may be one of the important causes of this cleavage. These inclusions possess very different coefficients of expansion from that of the diamond and when the temperature changes from that of their original formation, internal strains would be set up, which might very well cause the breaking of the diamond crystal. W. E. F.

5. *Tear-Figures on Certain Minerals;* by Mikio Kuhara. Published in four parts in Mem. Coll. Engl. Kyoto University, vol. **1**, Nos. 8, 10, vol. **2**, Nos. 2, 3, 1916-1918.—By "tear-figures" the author means the figures produced by light percussion or pressure from a needle point upon a smooth crystal face. The figures formed on the following minerals have been studied; stibnite, galena, sphalerite, pyrite, vivianite, enargite, calcite, gypsum, barite, aragonite, alum, borax, wulfenite, copper sulphate. These figures usually have the shape of a polygon together with radiating cracks, although the latter may not

always be visible. The walls bounding the figures and the cracks are usually parallel to common crystal faces on the mineral. The symmetry of the figure is concordant with that of the mineral. The papers are illustrated with many figures and by well-executed plates showing reproductions of photographs of the "tear-figures." W. E. F.

6. *A Meteorite from Tertiary Deposits.*—It is stated that a mass of meteoric iron, found in 1901 in the "white-channel gravels" near Dawson, Klondike, is probably of Pliocene age or older (R. G. McDonnell). Another mass, inferred to have formed part of the same shower, was found in 1905 in the same region. The masses have been examined by R. A. A. Johnston and are preserved in the Museum of the Geological Survey of Canada at Ottawa.—*Nature,* March 27, 1919, p. 69.

7. *The Living Cycads;* by CHARLES JOSEPH CHAMBERLAIN. Small 12mo, 172 pp. with 90 illustrations in the text. University of Chicago Press, 1919 (price $1.50).—In this little book is given an outline of studies extending over nearly twenty years. There is first an account at once readable and entertaining of the cycads and cycad collecting in the chief habitats in Mexico, South Africa, and Australia. The life-history and phylogeny follow. The book and style are attractive and would afford a model for the treatment of various other plant groups. Greenhouse study of the cycads, at least, has little of the living interest disclosed by their field study.

Those reading this book need only go back twenty-five years to recall the signal progress made in the study of the cycads. A small living group, only a few new species have been added; but nearly all the critical studies following the earlier anatomical notes of Mettenius, Miquel and Von Mohl belong to the past twenty-five years. The first stimulus to study of the group came from the discovery of motile ciliated sperms in Ginkgo in 1896, shortly followed by their observation in *Cycas* by Ikeno. The next event of significance was of course the discovery of the cycadeoid flower and foliage in 1899.

Various primitive features of the cycads have long been more or less clearly recognized. But these more persistent studies of structure, reproduction, and the antithesis to cones seen in the cycadeoids, all go far to give botanists a renewed confidence in their discussions of some of the most fundamental problems of seed plant evolution. Speaking of the relationships between the cycads and fossil cycads [cycadeoids], Professor Chamberlain says:

"The university zone of the Northern Hemisphere has been studied with considerable care, and the amount of Triassic material obtained has not been encouraging; but the tropics and Southern Hemisphere may yield material which will solve the whole problem. The immense amount of fossil material secured by Wieland in the Mixteca Alta of Southern Mexico, although not in a condition to be sectioned, leads us to hope the missing links will be discovered."

To these conclusions we fully assent, only finding fault with the first premise. World-wide collection is always in order, although there is still plenty to do on the cycad ancestry near the University of Chicago in the Permo-Carboniferous which has already yielded the remarkable *Codonotheca*, near the University of Virginia in the finely developed Rhätic plant beds, and near Yale in the Connecticut Trias, as well as near several other places in the University belt. Workers have been here too few, means limited, and criticism meager. G. R. W.

III. Miscellaneous Scientific Intelligence.

1. *Carnegie Institution of Washington*, Robert S. Woodward, President, *Year Book No. 17, 1918*. Pp. xvi, 331. Washington, 1919.—The striking feature of the present report from the Carnegie Institution is the account of the work accomplished in various directions in the activities made necessary by the world war; a considerable part of the staff of the Institution was engaged in this way. One special work dwelt upon is the production of optical glass by the Geophysical Laboratory, which was needed at once for a variety of instruments used by the ordnance departments of the Army and Navy. It is noteworthy that, within a year, the production of uncut optical glass was by this means raised from less than a ton per month to more than one hundred tons. Another example of war activities is furnished by the work of the Nutrition Laboratory, concerning the effects of short rations. The director of the Laboratory had at his disposal two squads of men, a dozen each, of the Y. M. C. A. College of Springfield, Mass. These men maintained their regular college work but were put on a low diet and kept under observation and experiment from October 1917 to February 1918. Important among the results is the proof that "the normal adult man may subsist for some months on a severely restricted diet and during this time may undergo marked losses in body weight and in nitrogenous reserves without serious impairment of his mental and muscular efficiency."

The report also dwells in particular upon the work of the non-magnetic ship "Carnegie," which since her launching in 1909, has traversed in her surveys an aggregate of nearly 190,000 nautical miles. It is further noted that the Eugenics Record Office, established by Mrs. E. H. Harriman in 1910, and located at Cold Spring Harbor, came under the control of the Carnegie Institution on June 1, 1918, with an endowment gift of $300,000 from Mrs. Harriman to assist in its work.

The total income of the Institution now amounts to $1,112,000 and the allotments for the year amounted to about $923,000. All of this sum was devoted to the 12 major departments and divisions with the exception of $153,339 for minor grants and $60,410 for publications. The Institution, since its foundation, has distributed upwards of 171,000 volumes of its publications, aggregating nearly 103,000 pages of printed matter.

Following the reports of the president, executive committee and auditors, the major part of the volume (pages 55 to 320) is given to the account of the work accomplished by the different individual Departments with also a summary of the minor investigations completed.

2. *National Academy of Sciences.*—At the annual meting of the National Academy held at Washington on April 28 to 30 (see also this volume, p. 308) the following gentlemen were elected to membership: Edwin Bidwell Wilson, physicist, Massachusetts Institute of Technology; Reid Hunt, pharmacologist, Harvard University; George O. Squier, chief army signal officer, Washington; Garby Nathan Calkins, zoologist, Columbia University; Ernest J. Wilczynski, mathematician, University of Chicago; Winthrop John Osterhout, botanist, Harvard University; Herbert D. Curtis, astronomer, Lick Observatory; Gano Dunn, electrical engineer, New York City; Oswald Veblen, mathematician, Princeton University; William A. Setchell, botanist, University of California; Frederick H. Seares, astronomer, Mount Wilson Observatory; Joseph Barrell, late of Yale University; Lawrence J. Henderson, biologist, Harvard University; Augustus Trowbridge, physicist, Princeton University; Treat Baldwin Johnson, chemist, Yale University.

The Academy also presented the Henry Draper gold medal to Prof. Charles Fabry of Marseilles for his notable investigations in the science of astronomical physics, particularly his researches in connection with the light of the sun and other astral bodies. Further the Alexander Agassiz gold medal, established through funds provided by Sir John Murray, was awarded to Prince Albert of Monaco in recognition of his contributions to the science of oceanography.

3. *Field Museum of Natural History. Annual Report of the Director*, FREDERICK J. V. SKIFF, for the year 1918. Pp. 225-295; plates 38-62 and frontispiece portrait of Theodore Roosevelt.—It is announced in this report that the new building, which has been under construction for a considerable time, is so far completed, that the transfer to it may take place next year and possibly in the coming autumn. The war has had its influence upon the Museum in various ways and its effect probably explains the large decrease noted in the attendance. The plates representing certain exhibition groups in different departments of science, show progress which is being wisely made in this direction. An interesting part of the report is the work of

Henry Hering, sculptor, for the Museum, with the plates showing the fine execution of the various figures.

4. *Bureau of American Ethnology;* F. W. HODGE, Ethnologist in Charge.—Bulletin **59** (pp. 387), recently issued, is devoted to Kutenai Tales, by FRANZ BOAZ; these are accompanied by texts by ALEXANDER F. CHAMBERLAIN.

5. *Memoirs of the Queensland Museum.* Volume VI; edited by the *Director,* HEBER A. LONGMAN. Pp. 174; with text-figures, 32 plates and frontispiece. Brisbane, 1918.—This sixth volume from the Queensland Museum (see earlier **43**, 422) is devoted to a series of twelve papers, on zoological and ethnological subjects. Several of these are continuations of articles on the fishes of Queensland in earlier issues of this publication. The volume is liberally illustrated by a large number of excellent plates. The opening article by the Director discusses a series of human crania in the Museum. The frontispiece gives a view of the Museum building.

6. *The Elementary Nervous System;* by G. H. PARKER. Pp. 229, with 53 illustrations. Philadelphia and London, 1919 (J. B. Lippincott Company).—This is the second volume of the series of monographs on Experimental Biology written by American investigators. In it the author describes in great detail the relatively simple nervous mechanism found in the most primitive groups of multicellular animals, as sponges, sea-anemones, corals, hydroids, and jelly-fishes.

The responses of these organisms to various forms of stimuli are described and their behavior under experimental conditions are discussed with reference to such elementary muscular and nervous tissues as they possess. The work is based largely on the author's personal investigations. It is shown that while the sponges have no distinct nervous elements, they are provided with a primitive type of muscle tissue which represents the beginning of the neuromuscular mechanism of the next higher groups. The sluggish transmission of stimuli which lead to responses in the sponges is referred to the "elemental property of protoplasmic transmission from which true nervous activity has been evolved," and this property is retained by many of the tissues of the higher animals.

The gradual differentiation of the neuromuscular mechanism and the nerve net of the coelenterates is described, with experimental evidence as to the nature of the responses which this simple nervous system can effect.

The concluding chapter outlines the evolution of this elementary nervous mechanism into the synaptic nervous system of the higher forms. W. R. C.

7. *Outlines of Economic Zoology;* by ALBERT M. REESE. Pp. xvii, 316, with 194 illustrations. Philadelphia, 1919 (P. Blakiston's Son and Co.).—The increased competition caused by the great war, resulting in a concerted effort to utilize to the fullest

possible extent the natural resources of the world, has compelled a new inquiry into the economic relations existing between man and the other animals. The enormous destruction of food supplies and other property by the various groups of animals, and the immense services to man rendered by other groups have been but little realized by the general public. To supply this information to the pupil in the later years of the secondary school or in the college is the aim of this book. The economic importance of each of the groups of animals and of the common species of each of the more important groups is clearly and untechnically explained, with many practical measures for the protection of the beneficial forms and for the destruction of those that are injurious.

The book will appeal particularly to the student of agriculture, for the information which it contains is well-nigh indispensable to the success of his calling. W. R. C.

8. *Economic Entomology: Class-book of Economic Entomology, with special reference to the Economic Insects of the Northern United States and Canada;* by William Lochhead. Pp. xiv, 436, with 257 illustrations. Philadelphia, 1919 (P. Blakiston's Son and Co.).—The present world shortage of food is not alone due to the decreased crop acreage in the countries at war, but in large measure to the destruction of crops and food products by insects. The monetary loss last year in the United States alone was upwards of two billions of dollars, not to mention the alleviation of suffering in other countries which would now be possible if the food destroyed by insects could have been harvested and transported to those in need.

This book contains in untechnical language precisely the information needed for an understanding of the general structure, classification and habits of insects and their economic relation to each other, to other groups of organisms and to human industry. The subject matter is divided into four parts. Part I describes the structure, growth and economics of insects, with a concise account of their beneficial and injurious aspects and their interrelations with other groups of organisms. Part II contains convenient lists of the more important species which injure each of the cereal crops, fruits, shade-trees, greenhouse plants, domestic animals and household articles. Part III comprises the classification of insects, with descriptions of the more common species of each of the orders, with special methods of control of the most injurious species. Part IV discusses the general principles of insect control, with practical directions for the preparation and application of remedies.

While the book is perhaps designed more particularly for the student of agriculture, who will find in it about all the information he requires on the subject, it may be recommended to others who desire a really practical knowledge of our common insects in their relation to human welfare. W. R. C.

Obituary.

Professor Joseph Barrell, since 1903 a member of the Yale University geological department, died on May 4 in his fiftieth year. He was a man of extraordinary energy and originality of mind and his death is an irreparable loss both to the University and to the science of the country. A notice of him and his work will appear in a later number.

Professor Charles Brinkerhoff Richards, long a prominent mechanical engineer, and from 1884 to 1909 an active member of the faculty of the Sheffield Scientific School, Yale University, died on April 20 in his eighty-sixth year.

Dr. John Wallace Baird, professor of experimental psychology in Clark University, Worcester, Mass., died on February 2 in his fiftieth year.

Dr. George Carlton Worthen, of the Bussey Institution, Harvard University, died on April 10 at the age of forty-eight years.

Dr. Alexis Anastay Julien, from 1865 to 1907 a member of the faculty of the School of Mines, Columbia University, died on May 7 at the age of seventy-nine years.

Sir William Crookes, the distinguished English physicist, long known for his many important researches in chemistry and physics, died on April 4 in his eighty-seventh year. He was a man of rare genius, energy and originality, as shown by his early discovery of thallium with the spectroscope and his valuable work in the same line; also by his invention of the radiometer, and his study of high vacua and the phenomena of cathode rays. He was further interested in psychic phenomena and as a proof of his activity in other fields must be mentioned the fact that the well-known *Chemical News* was started by him in 1859 and he remained its editor and proprietor to the end of his life.

M. Jacques Danne, the French investigator in radio-activity, and editor of the journal *Le Radium,* died on March 8 at the age of thirty-seven years.

Dr. Lawrence M. Lambe, the well-known paleontologist of the Geological Survey of Canada, died recently in his fifty-sixth year. He became draughtsman to Professor Whiteaves of the Survey in 1884. In 1896 he published a book on the Atlantic Coast sponges, and later did considerable work on the Paleozoic corals of Canada. The greater part of his work, however, had to do with fossil vertebrates, and chiefly with the large dinosaurs of the Red River valley of Canada.

Professor Raphael Blanchard, of the Paris Medical Faculty and eminent both as a medical zoologist and medical historian, died on February 8 at the age of sixty-one years.

Dr. K. H. von Bardeleben, professor of anatomy at the University of Jena, died recently at the age of sixty-nine years.

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* This Index contains the general heads, CHEMISTRY, GEOLOGY, MINERALS, OBITUARY; under each the titles of Articles referring thereto are included.

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