THE

AMERICAN JOURNAL OF SCIENCE.

EDITOR: EDWARD S. DANA.

ASSOCIATE EDITORS
PROFESSORS WILLIAM M. DAVIS AND REGINALD A. DALY,
OF CAMBRIDGE,

PROFESSORS HORACE L. WELLS, CHARLES SCHUCHERT,
HERBERT E. GREGORY, WESLEY R. COE AND
FREDERICK E. BEACH, OF NEW HAVEN,

PROFESSOR EDWARD W. BERRY, OF BALTIMORE,
DRS. FREDERICK L. RANSOME AND WILLIAM BOWIE,
OF WASHINGTON.

FIFTH SERIES

VOL. IV—[WHOLE NUMBER CCIV].

WITH PLATE ONE

NEW HAVEN, CONNECTICUT.
1922.

THE TUTTLE, MOREHOUSE & TAYLOR CO.,
NEW HAVEN, CONN.

CONTENTS TO VOLUME IV.

Number 19.

SCIENTIFIC INTELLIGENCE.

Number 20.

SCIENTIFIC INTELLIGENCE.

Number 21.

SCIENTIFIC INTELLIGENCE.

Number 22.

SCIENTIFIC INTELLIGENCE.

Chemistry and Physics.—A Revision of the Atomic Weight of Beryllium: The Analysis of Beryllium Chloride, O. Honigschmid and L. Birlenbach: Experimental Attempts to Decompose Tungsten at High Temperatures, G. L. Wendt and C. B. Iron, 322.—A Micro-Method for the Determination of Molecular Weights in a Melting-Point Apparatus, K. Rast: Women in Chemistry: A Study of Professional Opportunities, The Bureau of Vocational Information, 323.—Spectrum of Aurora, 324.—Suspended Impurity in the Air, 325.—The Principles of Geometry, H. F. Baker, 326.

Miscellaneous Scientific Intelligence.—Smell, Taste, and allied Senses in the Vertebrates, G. H. Parker: Science and Human Affairs from the Viewpoint of Biology, W. C. Curtis, 327.—The Biology of the Sea-Shore, F. W. Flattely and C. L. Walton, 328.—New Meteoric Iron from Kentucky, G. P. Merrill, 329.

Obituary.—R. D. Salisbury: G. H. Cox, 329.

Number 23.

SCIENTIFIC INTELLIGENCE.

Number 24.

SCIENTIFIC INTELLIGENCE.

Established by **BENJAMIN SILLIMAN** in 1818.

THE
AMERICAN
JOURNAL OF SCIENCE.

EDITOR: EDWARD S. DANA.

FIFTH SERIES

VOL. IV—[WHOLE NUMBER, CCIV].

No. 19—JULY, 1922.

WITH PLATE ONE

NEW HAVEN, CONNECTICUT.

1922.

THE TUTTLE, MOREHOUSE & TAYLOR CO., PRINTERS, 123 TEMPLE STREET.

Published monthly. Six dollars per year, in advance. $6.40 to countries in the Postal Union; $6.25 to Canada. Single numbers 50 cents; No. 271, one dollar.

Entered as second-class matter at the Post Office at New Haven, Conn., under the Act of March 3, 1879.

ANNOUNCING

Huntington & Williams'

BUSINESS GEOGRAPHY

By **Ellsworth Huntington**
Research Associate in Geography, Yale University,

and **Frank E. Williams**
Professor of Geography and Industry, Wharton School of Business, University of Pennsylvania. With the co-operation of

Robert M. Brown, Professor of Geography, Rhode Island College of Education, and

Miss Lenox E. Chase, Teacher of Geography, Mount Vernon (N. Y.) High School.

This book was written by an exceptionally strong combination of authors to meet the urgent and long recognized demand for a really practical Geography text around which a "Business" course in this subject could be built. It has been prepared especially for use in commerce departments in high schools and Freshman courses in colleges, and will prove an ideal text for such work. It is scientifically sound throughout, is written in an intensely interesting way, *and answers the questions the business man would ask, in the language the student understands.*

HUNTINGTON & WILLIAMS' 'BUSINESS GEOGRAPHY' will be ready August 1st, in plenty of time for the fall classes. It will contain about 470 pages, 6 by 9, well illustrated, and will be bound in cloth. The price is not yet known.

And A New Edition—The Second—of
HUNTINGTON & CUSHING'S
PRINCIPLES OF HUMAN GEOGRAPHY

This epoch-making book, which marked a new era in the teaching of Geography, has been carefully revised and now appears in materially improved form. It is used in about 150 schools, colleges and normal schools.

430 pages. 6 by 9. Illustrated with photographs and maps. Cloth, $3.50 postpaid.

JOHN WILEY & SONS, Inc.
432 Fourth Avenue
New York

London
CHAPMAN & HALL, Ltd.

Montreal, Quebec
Renouf Publishing Company

AJS 6.22

THE

AMERICAN JOURNAL OF SCIENCE

[FIFTH SERIES.]

◆

Art. I.—*The Melting of Potash Feldspar;* by G. W. Morey and N. L. Bowen.

Introduction.

While studying systems of the alkaline oxides with silica, alumina, and water, the one of us (Morey) carrying on the thermal and chemical work and the other (Bowen) the optical examination, we succeeded in crystallizing some pure artificial orthoclase in a bomb with no flux other than water. Crystalline orthoclase, as hitherto prepared artificially, has been contaminated somewhat by the flux used in preparing it, and for this reason natural crystals have always been used in determining the melting point of orthoclase. The natural crystals never have the theoretical composition $KAlSi_3O_8$ but always contain a considerable amount of albite and sometimes other molecules. We concluded, therefore, that the pure crystals we had prepared would furnish good material for the redetermination of the melting-point of orthoclase, a point of much importance in the system under investigation.

The melting-point of orthoclase, as determined on natural crystals, has been found to be in the neighborhood of 1200°C. It has been found by Day and Allen to melt very sluggishly.[1] We expected, therefore, that long exposure to a given temperature would be necessary, before assurance of the attainment of equilibrium might be had. For such long exposures we have had the inestimable advantage of the use of a furnace-temperature regulator designed by our colleague, Mr. H. S. Roberts.[2] By means of this regulator we were enabled to maintain

---

[1] The isomorphism and thermal properties of the feldspars, Carnegie Institution of Washington, Pub. No. **31**, pp. 51-53.

[2] J. Wash. Acad. Sci., **11**, 401-409. 1921.

a constant temperature (varying less than one degree) in our furnace day and night, for a week or more.

Preliminary Results.

When we heated our artificial orthoclase for a week at the temperature noted above (1200°) we obtained a product with the appearance of a glass when examined megascopically, and with the low refractive index (about 1.485) and the isotropic character of orthoclase glass when examined under the microscope.

However, under a high power (600 diameters) and with the cone of light cut down to a small angle, this "glass" is found to show a sort of structure, visible only when it is immersed in a liquid that matches it very closely in refractive index. This structure can be described only as a sort of fine cross-lining, usually rectangular and giving therefore a grating effect. Day and Allen have suggested that orthoclase, on melting, loses the ordered arrangement characteristic of the crystalline form only very slowly.[3] Thinking, therefore, that this observed structure was inherited from the crystalline material by the extremely viscous liquid, we held it at a somewhat higher temperature (1225°), where the liquid would be more mobile, with the expectation that the structure would disappear. Instead of this we found that it became more distinct. At a still higher temperature (1250°) it became apparent that the material was not a homogeneous glass but was made up of two phases, the one occurring as skeleton crystals in widely extended, branching forms of rectangular pattern, and the other, of somewhat lower refractive index, acting as a matrix for these. This latter was subsequently shown to be glass, but under crossed nicols the whole mass appears to be doubly refracting with a grating structure recalling that of microcline. At a still higher temperature (1300°), where the crystals are present in smaller amount, they grow as more discrete grains, though retaining skeletal tendencies and appearing usually as rectangular crosses. Finally, when formed at a temperature of 1400° or higher the crystals assume definite rounded to polyhedral (icositetrahedral) forms, with indistinct patchy birefringence,

---

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

with a refractive index only a little higher than that of the glass in which they are embedded, which is about 1.49, with regularly arranged inclusions of glass; in fact, with all the characters of leucite crystals. The series of forms assumed by the leucite with increasing freedom of growth (increasing temperature) is shown in fig. 1. This series is strikingly similar to that observed by Pirsson in the small leucite crystals in the groundmass of rocks from the Bearpaw Mountains.[4] The more primitive skeletal forms are not shown in Pirsson's series.

Fig. 1.

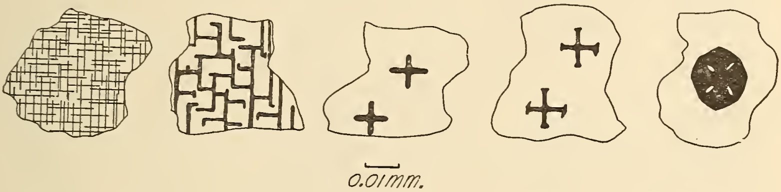


Fig. 1.—Grains of glass containing leucite. Showing increasing perfection of form, with increasing temperature, of leucite crystals as grown in a mixture of composition $KAlSi_3O_8$.

The rounded leucite crystals, obtained at higher temperatures, may have a diameter as great as 0.025 mm. and are surrounded by a rim of strained glass which is observed as a birefracting halo under crossed nicols. In fact the birefringence shown by the glass immediately adjacent to the crystals is decidedly greater than that of the crystals themselves. The birefringence of the glass fades out as the distance from a crystal increases, and when the crystals are not numerous there are areas of ordinary isotropic glass. When the crystals are closely spaced, however, all of the interstitial glass is birefracting, which accounts for the fact that, when the crystals grow as ramifying skeletal forms, the whole mass is birefracting, with the cross-grating effect analogous to that in microcline.

In the birefracting halo about the crystals γ is radially disposed, which shows that the glass is subjected to radial tension. This tension is no doubt caused by the abrupt contraction of the leucite crystals in cooling through their

---

[4] L. V. Pirsson, this Journal, 2, 145-146, 1896. Figured also by Iddings in Rock Minerals, p. 249 (2d ed., 1911).

inversion point in the neighborhood of 700°, where they experience a volume change of more than 2 per cent.[5] This may seem a small change, but it is twice as great as the whole change between 585° and room temperature.

Detailed Results with Artificial and Natural Feldspars.

The above observations showed very clearly that potash feldspar has no true melting-point, that the point in the neighborhood of 1200°, which has hitherto been regarded as its melting-point, is really the temperature at which it breaks up into liquid and leucite or, as it is commonly stated, it melts incongruently. It is perhaps not surprising that the existence of leucite in the material obtained near the decomposition-point has not been detected hitherto. Megascopically the "glass" has all the appearance of an ordinary glass; it is perfectly transparent, with only a faint suggestion of a bluish opalescence, the leucite crystallites being too minute and too closely matched in refraction by the medium in which they are embedded to cause a scattering of light. Even under the microscope the leucite appears, as we have seen, merely as an indefinite crosslining of the "glass" and only when the temperature was raised, to see if this structure would disappear, did the structure assume more definite form and finally become identifiable leucite crystals.

After obtaining these results we then proceeded to determine the temperature of incongruent melting more accurately and also to fix the temperature at which the leucite crystals disappear and the mass is entirely liquid. While carrying out these determinations we studied the similar changes as displayed by natural potash feldspars in as pure a state as we could obtain them. For this purpose we made use of three analyzed feldspars, microcline from Mitchell County, North Carolina, sanidine from Laacher See and adularia from St. Gotthard, the last being the nearest to pure potash feldspar, though even it

---

[5] So far as we are aware the volume change has not been measured, but it may be estimated from the change of refractive index between 585° and 750° as observed by Rinne and Kolb, Neues Jahrb. 2, 157. 1910.

contains about 10 per cent albite. The composition of these minerals is shown in Table I. The last two analyses were made by Dr. H. E. Merwin in connection with an investigation he has not yet published. The results of his analyses, together with some of the material, he has kindly turned over to us.

TABLE I.—*Analyses of natural feldspars.*

	I Microcline (Mitchell County, North Carolina, U. S. A.)	II Sanidine (Laacher See, Rhineland)	III Adularia (St. Gotthard, Switzerland)
SiO_2	65.83	64.21	64.24
Al_2O_3	18.07	19.10	19.21
Fe_2O_3	.36	....	....
CaO	.42	.24	none
Na_2O	2.30	1.76	1.45
K_2O	13.02	14.60	14.90
	100.00	99.91	99.80

I. E. T. Allen analyst. Recalculated to anhydrous basis. Day and Allen, op. cit. p. 48. The microscope shows that a very little of the albite is present as perthitic stripes.

II and III. H. E. Merwin analyst.

The details of the experiments on these three natural feldspars and our artificial material are given in Table II. It may be noted here that all four show the breaking up of the feldspar into liquid and leucite. The temperature at which this occurs is not greatly different in the different feldspars, being lowered only a little by the presence of albite. The evidence points to about 1170° as the proper temperature for pure potash feldspar. There is moreover no appreciable difference of behavior connected with the difference in form of orthoclase and microcline.

All of the feldspars show a very large temperature interval in which the mass consists of leucite and liquid. A full discussion of the change of habit of the leucite with increase of temperature has already been given for the pure artificial material. Natural crystals usually give more perfect leucite forms than the pure material when exposed to a given temperature for an

TABLE II.—*Results of heating experiments on potash feldspars.*

Microcline.

Temperature °C.	Time of exposure.	Result.
1140	8 days	Little change except formation of rare stripes of glass corresponding with original stripes of albite.
1179	8 days	About half unchanged microcline; other half glass showing cross-lining (leucite).
1204	8 days	All changed to glass showing cross-lining (leucite).
1252	5 days	All changed to glass and definite skeletal forms of leucite.
1307	3 days	Glass and definite skeletal leucites, often as rectangular crosses.
1400	3 days	Glass and rounded to subhedral leucites (0.02 mm. diameter) with regularly arranged inclusions of glass.
1435	3 days	Glass and rare subhedral leucites.
1452	3 days	All glass.

Sanidine and Adularia.[a]

Temperature °C.	Time of exposure.	Result.
1140	8 days	Mostly unchanged. Small percentage glass showing cross-lining (leucite).
1179	8 days	About one quarter unchanged feldspar; rest glass showing cross-lining (leucite).
1204	8 days	All changed to glass showing cross-lining (leucite).
1252	5 days	All changed to glass and definite skeletal forms of leucite.
1400	3 days	Glass and minute rounded leucites.
1452	3 days	Glass and very rare minute leucites.
1465	2 days	Glass only.

[a] The results obtained with these are practically identical and can be given together as above.

Pure synthetic potash feldspar (initially crystalline).

1140	8 days	No change.
1179	8 days	About half changed to glass showing cross-lining (leucite.)
1204	8 days	All changed to glass showing cross-lining (leucite).
1252	5 days	Glass and definite skeletal forms of leucite.
1400	3 days	Glass and definite leucites, principally rectangular crosses.
1510	2 hrs.	Glass and minute rounded leucites.
1510	20 hrs.	Glass and rounded leucites (0.02 mm. diameter).
1525	20 hrs.	Glass and rare leucites.
1535	2 hrs.	Glass only.

Pure synthetic $KAlSi_3O_8$ *(initially glass).*

1252	5 days	Glass and definite skeletal forms of leucite.
1400	3 days	Glass and definite leucites, principally rectangular crosses.
1510	2 hrs.	Glass and minute rounded leucites.
1510	20 hrs.	Glass and rounded to subhedral leucites.

equal period. The foreign matter apparently lowers the viscosity of the liquid appreciably. Notably typical leucite crystals were obtained by holding the North Carolina microcline at 1400° for 3 days.

The upper limit of temperature at which leucite crystals are obtained varies greatly in the different feldspars. As is to be expected, the presence of other compounds lowers the temperature of complete melting. Thus the Carolina microcline is all liquid at about 1440°, the sanidine and adularia at about 1460°, but the pure potash feldspar is not completely liquid until a temperature of about 1530° is reached. Therefore, between the temperatures 1170° and 1530°, an interval of 360°, a mass of the composition of pure potash feldspar, $KAlSi_3O_8$, consists, at equilibrium, of leucite crystals and liquid. That we have obtained equilibrium is unquestionable, for we were able to approach it from opposite directions. Whether we started with crystalline potash feldspar or with a glass of that composition we always obtained leucite crystals and glass in this 360° temperature-interval. When held at 1510° for 2 hours glass and small crystals of leucite were obtained. When the heating was continued at this temperature for 20 hours the leucite crystals became larger and less numerous. They evidently grew freely in equilibrium with the liquid. On the other hand when the same material was held at 1535° for only 2 hours the crystals completely disappeared. There can, therefore, be no question that the persistence of crystals at 1510° for 20 hours is the result of the fact that they are in equilibrium with the liquid. Incidentally it may be noted, too, that, for the attainment of equilibrium, prolonged heating is unnecessary at the higher temperatures (in the neighborhood of 1500°).

Incongruent Melting.

Definite crystalline compounds may melt in one of two different ways. A compound of one class melts completely at a definite temperature, giving a liquid of the same composition as the crystals, for which reason it is said to melt congruently. The temperature at which this occurs is a true melting point. A compound of the other class forms, at a definite temperature, a liquid of different composition from its own and at the same time one or more new crystalline compounds. Such a compound is said to melt incongruently or, sometimes, to melt with decomposition. The temperature at which this occurs is not a true melting point. Thus the compound $CaAl_2Si_2O_8$ (anorthite) has a true or congruent melting point at 1550°. At that temperature crystals of the composition $CaAl_2Si_2O_8$ are in equilibrium with a liquid of the same composition. It constitutes, by itself, a one-component system.

The compound $MgSiO_3$ is a familiar example of a compound of the other class. At 1557° the crystalline clinoenstatite ($MgSiO_3$) melts incongruently or breaks up into liquid and another crystalline compound Mg_2SiO_4 (forsterite). There is no temperature at which clinoenstatite is in stable equilibrium with a liquid of its own composition. It, therefore, has no true melting point. The compound $MgSiO_3$ does not constitute, by itself, a one-component system but can be treated only as a part of a two-component system. In order to represent its behavior graphically one must construct a two-component diagram. Thus fig. 2 represents equilibrium in mixtures of Mg_2SiO_4 and SiO_2 and shows $MgSiO_3$ as a compound of these with an incongruent melting point at 1557°. From the diagram we may read off that $MgSiO_3$ breaks up at 1557° into Mg_2SiO_4 and liquid somewhat more siliceous than $MgSiO_3$. Above 1557° a mass of the composition $MgSiO_3$ is made up of crystals of Mg_2SiO_4 (forsterite) and liquid, the forsterite gradually dissolving as the temperature is raised, until at 1577° the forsterite completely disappears and only then is a liquid of the composition $MgSiO_3$ obtained.[6]

Fig. 2.

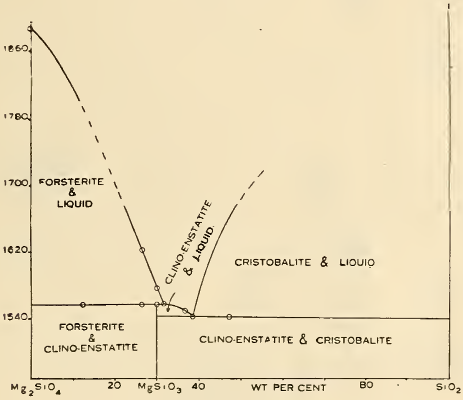


Fig. 2.—Equilibrium diagram of the system Mg_2SiO_4—SiO_2.

A compound of three oxides may melt incongruently in such a way that it breaks up into a liquid and two new crystalline compounds. Monticellite ($CaMgSiO_4$) shows this behavior. At 1498° it breaks up into Ca_2SiO_4, MgO, and liquid. It can be treated only as a part of a three-component system.[7] However, a compound of three oxides, which melts incongruently, does not necessarily break up in such a way that it must be treated as a three-component system. It may form liquid and only

---

[6] For a full discussion see Bowen and Andersen, this Journal, 37, 487-500. 1914.

[7] Ferguson and Merwin, this Journal, 48, 116. 1919.

one new crystal phase, in which case it can be treated as a two-component system with relations in every respect analogous to those of the binary compound $MgSiO_3$.

Fig. 3.

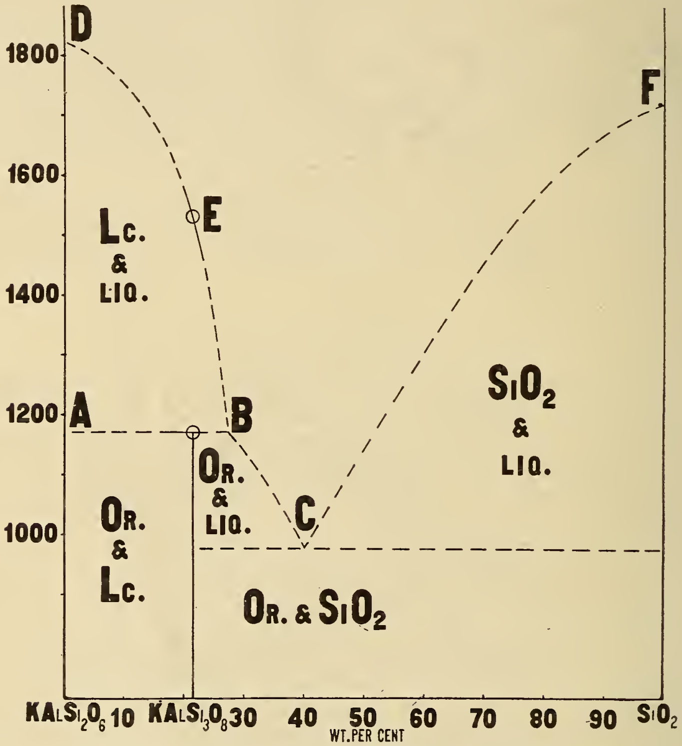


Fig. 3.—Diagram illustrating the melting of orthoclase.

The compound, $KAlSi_3O_8$, with which we are here concerned, breaks up in this latter manner. At 1170° it forms leucite, $KAlSi_2O_6$, and liquid, and its behavior can be completely described in terms of a diagram in which $KAlSi_2O_6$ and SiO_2 are taken as components, when $KAlSi_3O_8$ (orthoclase) becomes a binary compound of these. In fig. 3 the general form which this diagram must assume is shown. We have accurately determined the temperatures on this diagram only at the composition $KAlSi_3O_8$. Work is now being carried out on the whole system, but it presents many difficulties. On the leucite side of orthoclase the temperatures are very high, on the silica side the mixtures react very sluggishly and require excessively long heating. In the meantime we have thought it well to place on record our results on orthoclase.

The point E (fig. 3) is accurately fixed as is also the temperature of the line AB. The composition of the liquid B, which is in equilibrium with both orthoclase and leucite, we have not yet fixed accurately. The proportion of leucite in a mixture of composition $KAlSi_3O_8$, held at about 1250°, is very difficult to estimate, but appears to be about 20 per cent. We have placed the point B in accordance with this estimate. The melting point of leucite we know to be very high, above that of platinum (1755°).[8] The melting point of SiO_2 (cristobalite) has been fixed at 1710°.[9] Of the temperature and composition of the indicated eutectic between orthoclase and SiO_2 we know nothing. Except at the composition $KAlSi_3O_8$ we wish to stress only the general form of the diagram, not its details. That it must assume this general form cannot be doubted.

PETROGENIC SIGNIFICANCE OF THE INCONGRUENT MELTING OF ORTHOCLASE; by N. L. BOWEN.

The discovery of the fact that orthoclase melts with decomposition into leucite and liquid is of great significance to petrogenic theory. It is the first definite experimental demonstration of a genetic relation between a mass consisting of feldspar and feldspathoid and a mass consisting of feldspar and free silica, in other words, between what may be termed an alkaline and a sub-alkaline mass. Moreover, it shows plainly the nature of this relation as a fractional crystallization phenomenon.

Before going into this matter more specifically it is desirable to discuss the course of crystallization in mixtures of various compositions shown in fig. 3.

Reference to that diagram shows that crystallization of a liquid of composition $KAlSi_3O_8$ takes place under equi-

---

[8] Leucite crystals were prepared by one of us some years ago when investigating kaliophilite. To melt the leucite it was found necessary to use an iridium container (N. L. Bowen, this Journal, 43, 117. 1917).

[9] Ferguson and Merwin, this Journal, 46, 424. 1918.

librium conditions in the following manner. At 1530° (E) leucite begins to crystallize and it increases in amount as the temperature falls, until at 1170° orthoclase begins to separate and leucite to redissolve, or, stated better, perhaps, the liquid reacts with the leucite, transforming it into orthoclase. This continues at constant temperature until the liquid and leucite are entirely used up and the mass consists entirely of orthoclase.

A mixture lying on the leucite side of $KAlSi_3O_8$ begins to crystallize at a temperature higher than that of the point E. In this case when the temperature 1170° is reached the reaction between liquid and leucite proceeds as before, but all the liquid is used up while still some leucite remains and the completely crystalline mass consists of orthoclase and leucite.

A mixture on the silica side of orthoclase, if not richer in silica than that represented by the point B (probably corresponding to about 10 per cent free silica), also begins to crystallize with separation of leucite but at a temperature lower than that of the point E. At 1170° the reaction is completed as a result of the disappearance of leucite and the mass now consists of orthoclase and liquid of composition B. The liquid then proceeds to crystallize along the curve BC, with separation of orthoclase, until at C free silica separates as well and the whole mass is now solidified as a mixture of orthoclase and free SiO_2. The exact temperatures and compositions are in these parts quite unknown. Only in mixtures with a greater excess of free silica than that represented by the point B does the early separation of leucite fail.

Such is the behavior of the various liquids when perfect equilibrium obtains. Now in any of these mixtures leucite might fail to react completely with the liquid at the reaction point (1170°) as a result of the formation of an armor of orthoclase about it. The consequence of this would be that some liquid of the composition B would be left over in all of the mixtures above discussed, even that on the leucite side of orthoclase, and this liquid would then form orthoclase and free silica. Or if leucite crystals were locally segregated that part of the mass from which they were removed would crystallize as orthoclase and free silica, even though the composition of the original liquid were on the leucite side of orthoclase. Conversely, too, even though the composition of the original liquid were a moderate distance on the silica side of orthoclase, the early formed leucite crystals might collect locally and if so they would not be completely used up by reaction with the liquid and a localized leucite-bearing mass would result.

Now this early separation of leucite from a mixture of the composition of orthoclase cannot be immediately negatived by the addition of other components. Excess silica rapidly neutralizes the tendency, of course, but other substances cannot have a comparable effect. Our microcline from North Carolina shows that 25 per cent foreign material (mainly albite) is insufficient to neutralize this tendency, in fact the interval in which leucite appears is as much as 270°, so that it would plainly require a considerably larger amount of albite to bring about the disappearance of the leucite field. Therefore, in magmas rich in orthoclase, and even in those containing much albite as well, if at the same time they contain not more than a small excess of free silica, it is to be expected that this early separation of leucite may occur. The leucite crystals should disappear with falling temperature but the two factors noted in the foregoing may intervene to bring about their persistence. The factors are the armoring of the leucite crystals or their local collection, or indeed both.

Evidence of the Existence of Similar Relations in Natural Leucite Rocks.

Certain described rocks give evidence of the occurrence, under natural conditions, of the phenomena noted. Hussak describes a rock from Brazil consisting of phenocrysts of leucite (now pseudoleucite) in a groundmass of quartz and feldspar, which rock he terms a leucite granite porphyry. Evidently strongly influenced by the dictum of Rosenbusch and Zirkel that leucite and quartz cannot occur together, Hussak suggests the possibility that the leucites are remnants of fragments of a foreign rock, caught up by the granitic dike. In his final conclusions, however, he inclines towards the opinion that it is an ordinary igneous rock from which the mineral combination quartz-leucite-orthoclase has crystallized.[10] Our results show plainly that such a mineral combination is possible, particularly with the relations he notes, namely, phenocrysts of leucite in a groundmass of quartz and feld-

---

[10] E. Hussak, Neues Jahrb., 1, 27. 1900.

spar. To be sure, if perfect opportunity for reaction were presented, either quartz or leucite should be absent, but it is easy to conceive of conditions under which such opportunity would fail.

Cross describes a rock from Wyoming which contains leucite. Bulk analysis of this rock shows, however, that the silica present is entirely adequate to have formed orthoclase with the potash and alumina present. It seems necessary, therefore, to assume that the glassy groundmass is highly siliceous.[11] Such an assumption would be entirely justified in the light of our results.

There is one occurrence that appears to illustrate in a convincing manner the separation of leucite under the influence of gravity and the consequent formation of a quartzose differentiate in those parts from which the leucite has moved. Near Loch Borolan in Scotland there is a differentiated laccolith which is described by Shand as being made up of the following in stratiform arrangement, as stated below, and shown in fig. 4:[12]

I. Quartz syenites (nordmarkite with 12 per cent. quartz and other more quartzose types).
II. Transition zone of quartz-free syenites.
III. Feldspathoid-bearing syenites.
IV. Probable ultra-basic zone (noted in one locality).

The syenites of III are in part demonstrably pseudoleucite bearing. If it can be imagined that the laccolithic chamber was filled with a magma very rich in alkaline feldspars, and with not more than a moderate excess of free silica, this magma might, as our results show, begin to crystallize with separation of leucite. The actual proportions of the various rock types in the composite mass (see fig. 4) show that the general liquid would be very rich in feldspar, principally orthoclase, and excessively poor in the molecules that go to make up the heavy minerals. The density of such a liquid as a glass at ordinary temperatures would probably be not far from that of rhyolitic obsidian (2.37).[13] The density of leucite

---

[11] W. Cross, this Journal, 4, 122 and 132. 1897.

[12] S. J. Shand, Trans. Edin. Geol. Soc., 9, pt. III, p. 202, 1909, and pt. V, p. 376, 1910. See also Horne and Teall, Trans. Roy. Soc. Edin., 37 pt. 1, p. 163, 1892.

[13] H. S. Washington, Rhyolites of Lipari, this Journal, 50, 449. 1920.

FIG. 4.

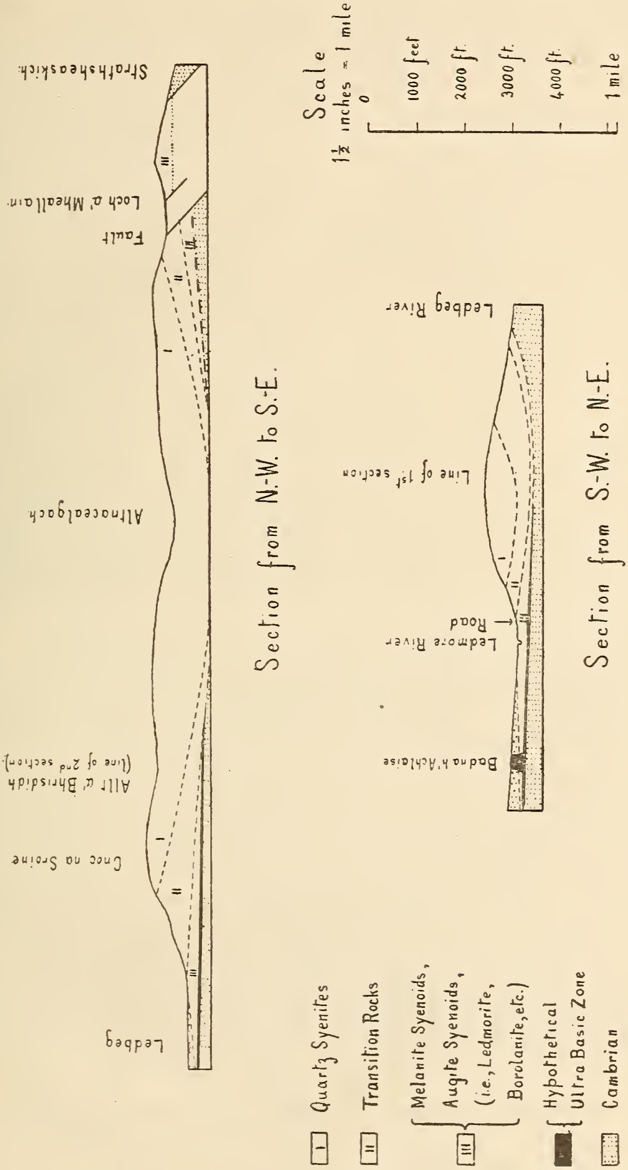


FIG. 4.—Sections of the laccolith at Loch Borolan, Scotland (after Shand).

at ordinary temperatures is 2.46. At higher temperatures, then, there would probably be a definite though small margin of density in favor of leucite crystals, especially since the liquid would, no doubt, contain a considerable amount of volatile substances, whereas the obsidian noted above is nearly free from these. Presumably the leucite crystals could settle under the influence of gravity; indeed, the general arrangement of zones can scarcely leave room for doubt that they did and gave a lower zone (III) much enriched in that mineral. When the time of reaction of the leucite with liquid arrived there would be an amount of leucite above that requisite for the reaction and some would be left in excess. The excess leucite was, during the further crystallization of the mass, transformed into pseudo-leucite (orthoclase + nephelite) which is the normal fate of natural leucites when cooled slowly under deep-seated conditions. On the other hand, in the zone from which the leucites were entirely removed (I) there were no crystals to react with the liquid (which would be the natural analogue of our liquid B, fig. 3) and it crystallized appropriately with an excess of free silica.

We are thus able not merely to accept Shand's interpretation of the differentiation as gravitative, but we may go further and connect the differentiation with the course of crystallization; in short, we may state that the differentiation was due to *fractional crystallization* under the influence of gravity. One may still accept the possibility that the magma was affected by absorption of limestone, but the formation of both a quartzose and a feldspathoid-bearing portion from a homogeneous mass shows plainly that desilication of feldspar molecules by limestone was not essential to the production of feldspathoids. The fact that leucite can exist under certain conditions in equilibrium with a liquid containing excess silica is the secret of the coexistence of two such differentiates.

Bearing of the Results on the Origin of Nephelite Syenites.

Now the rocks of zone III, while undoubtedly at one time leucite rocks, in part, at least, are now simply nephelite syenites. This is the result of the usual change of the leucite to orthoclase and nephelite, already noted.

Plainly, then, in the early separation of leucite, itself a consequence of the incongruent melting of orthoclase, lies the key to the origin of these nephelite syenites.

This conclusion opens up the whole question as to whether many other nephelite syenites may not have been formed in a similar way. Leucite may have formed at a certain stage and the evidence of its formation, after its breakdown into orthoclase and nephelite, may not always have been preserved in the form of the pseudo-leucite structures. Even in the example described by Shand the nephelite of the pseudo-leucites has suffered a further change to muscovite and a zeolite. Through such further changes, not necessarily exactly of this kind, the evidence of the former existence of leucite may frequently, perhaps, have been entirely destroyed. Moreover, upon the change of leucite into orthoclase and nephelite the course of crystallization will follow lines upon which our work throws no light and it may be possible that even the more common, highly sodic, nephelite syenites could form as further differentiates.

Examining nephelite syenites and their associates with these considerations in mind, we find a considerable amount of evidence that the formation of leucite may have occurred as an intermediate step in their genesis.

The Ilimausak batholith in Greenland is stratified in a manner closely related to that shown by the Loch Borolan mass. At the top is a quartzose phase, arfvedsonite granite, which passes downward into quartz-free syenite and finally into sodalite and nephelite syenites of great variety.[14] In one of these, the so-called lujavrites, which are the lowest exposed rocks of the mass, there are large crystals of analcite which Ussing presents reasons for believing were formerly leucite.[15] The nature of the stratification and the existence of these pseudo-leucites (?) is so strikingly similar to the conditions at Loch Borolan that one must consider the possibility that the early separation of leucite has been a factor controlling the differentiation of the mass (see fig. 5).

---

[14] N. V. Ussing, Geology of the Country around Julianehaab, Greenland, Med. om Grönland, vol. 28, p. 322, fig. 29, 1911.

[15] Op. cit. pp. 164, 165.

The igneous massif of Bezavona in Madagascar, as described by Lacroix, consists of quartz syenites, nephelite syenites, monzonites, and other types, including various dike and flow rocks. In the coarse granular rocks there is apparently nothing suggesting the formation of leucite, but in quickly chilled facies, which may be regarded as quenched, leucite appears. Thus there are microsyenites with leucite and also leucite phonolites.[16] These facts again suggest the possibility that the formation of leucite may have been an intermediate step in the genesis of the nephelite rocks.

Fig. 5.

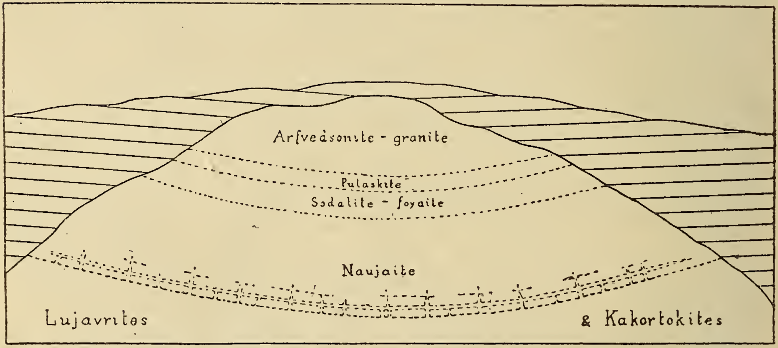


Fig. 5.—Section of the Ilimausak mass, Greenland (afer Ussing).

Still less definite as evidence, and yet worthy of consideration, are certain structures observed in nephelite rocks that suggest the former presence of leucite. In some members of the Ice River complex of British Columbia there are spots of a ''finger-print-like'' intergrowth[17] of orthoclase and nephelite that is practically identical with the ''dactylotype'' intergrowth of these minerals when they form pseudo-leucites. Structures that are perhaps of similar origin are described by Lacroix from the nephelite syenites of the Los Archipelago[18] and by Brouwer in rocks from the Transvaal.[19]

[16] A. Lacroix, Les Roches Alcalines d'Ampasindava, Nouv. arch. du muséum, Paris. Série 4, 5, 197 and 207, 1903.

[17] J. A. Allan, Geology of the Field Map-area, B. C. and Alberta. Geol. Surv. Can., Mem. 55, p. 133 and p. 285, 1914, Plate XVIIB.

[18] A. Lacroix, Les syénites népheliniques de l'archipel de Los. Nouv. arch. du muséum, Série 5, 3, p. 53, 1911.

[19] H. A. Brouwer, Transvaal Nephelien-Syenieten. p. 40, Pl. I, Fig. 1.

An intimate relation between leucite and nephelite rocks is observed in many fields. A striking example is shown by the Magnet Cove complex. In particular it is noteworthy that a leucite porphyry and a foyaite, associated there, have nearly identical chemical composition, at least in some specimens. Washington has called attention, also, to a similar relationship of a leucite-rich rock (leucite phonolite) of the Sabatinian district, Italy, with a nephelite syenite of Beemerville, N. J.[20]

In volcanic fields the frequent intimate association of trachyte, leucite-trachyte and phonolite is suggestive in this connection. We may mention only the Laacher See area from which region came one of the feldspars (sanidine) which we used in our investigation and which shows in a typical way the decomposition into leucite and liquid.

On the whole, then, there is a considerable body of evidence pointing to the importance of the incongruent melting of orthoclase as a factor not merely in the formation of leucite rocks but of other feldspathoid-bearing rocks as well. It is not intended here to set this up as the sole factor involved in the formation of feldspathoid rocks. There are many indications that some leucitic rocks are formed as a result of differentiation along lines which produce a liquid rich in mica molecules and that then the extrusion of the liquid places it in surroundings where it is unable to retain the water necessary for the formation of mica, with the result that leucite is formed just as it is when mica is melted in an open crucible.[21] The more basic leucite rocks, leucite basalts, etc. may perhaps have formed in some such way.

In former papers the writer has presented reasons for believing that in the reactions which are revealed by the presence, side by side in a rock, of alkaline feldspar, mica, and quartz, there is evidence of the breakdown of the polysilicate (feldspar) molecules into less siliceous (feldspathoid) molecules and free silica. This was believed to be due to the hydrolyzing action of water in the magma.[22] It was not then anticipated that it would be found that potash feldspar breaks down in a similar

---

[20] H. S. Washington, Igneous complex of Magnet Cove, Arkansas, Bull. Geol. Soc. Amer. 11, 399, 1900; and Roman Comagmatic Region, Carnegie Institution of Washington, Pub. No. 57, 1906, p. 47.

[21] H. S. Washington, The formation of leucite in igneous rocks. J. Geol., 15, 379, 1907; and N. L. Bowen, The later stages of the evolution of the igneous rocks, J. Geol. Suppl. to vol. 23, 60, 1915.

way even in the dry melt. The discovery of this fact should not, however, lead us to reject the effects of water as important in promoting such behavior of the polysilicates.[23] Nor need we abandon the suggestion that in the preparation in the liquid of feldspathoid molecules, under the influence of water, there enters the possibility, with appropriate fractional crystallization, of the formation of feldspathoid-bearing rocks. However, these reactions represent, as the writer has always admitted,[24] a considerable extrapolation from any facts that have yet received laboratory demonstration. It is with considerable satisfaction, therefore, that we announce a laboratory demonstration of the fact that a mass consisting in one part of feldspar and quartz and in another of feldspar and feldspathoid can form from a single homogeneous liquid. The method of formation of these contrasted parts, which may be referred to as subalkaline and alkaline, respectively, is the method of fractional crystallization, which has also been shown fairly definitely to be adequate for the production of all varieties of subalkaline rocks from one liquid.[25]

Summary.

A pure synthetic orthoclase was prepared by crystallizing glass of the composition $KAlSi_3O_8$ in a bomb with water vapor. This material is particularly suitable for the determination of the melting-point of pure orthoclase and was used for that purpose. The temperature ordinarily given as the melting-point of orthoclase is about 1200° and has been determined on natural crystals. When our artificial crystals were held at 1200° for a week they gave a product which had the appearance of a glass, *megascopically,* but which, examined under the microscope, showed a structure described as a very fine cross-lining. At higher temperatures this structure became more distinct, taking the successive forms shown in fig. 1,

---

[22] N. L. Bowen, The later stages of the evolution of the igneous rocks, J. Geol., Suppl. to vol. 23, 60. 1915.

[23] In dry melts albite shows no tendency to decompose in a manner analogous to that shown by orthoclase.

[24] N. L. Bowen, Crystallization-differentiation in magmas, J. Geol. 27, 395. 1919.

[25] N. L. Bowen, The later stages of the evolution of the igneous rocks, J. Geol., Suppl. to vol. 23. 1915.

and finally becoming typical leucite crystals. The point at about 1200° is therefore not the true melting-point of orthoclase but is the temperature at which it melts incongruently, breaking up into liquid and leucite. The exact temperature of this decomposition we have determined as somewhat lower than 1200°, namely, about 1170°. The temperature of final disappearance of leucite is about 1530°, so that the interval of incongruent melting is remarkably large, viz., 360°. Three natural potash feldspars, microcline from North Carolina, sanidine from Laacher See, and adularia from St. Gotthard show the same kind of behavior, though in these the upper limit of melting (disappearance of leucite) is lowered somewhat through the presence of foreign matter.

This incongruent melting of orthoclase is of particular importance in petrogenic theory because it shows plainly how, by fractional crystallization, a homogeneous liquid could form a differentiated mass consisting of orthoclase and leucite in one part and of orthoclase and free silica in another. It shows, too, that leucite can form from a liquid containing an adequate amount of silica to form orthoclase and that a mass may have leucite as early crystals (phenocrysts) together with free silica as late crystals (groundmass). These considerations explain the occurrence of such a rock as the leucite granite porphyry of Brazil and such a differentiated mass as the syenite laccolith at Loch Borolan, Scotland. It is to be noted that both these occurrences show pseudo-leucites, formed secondarily after leucite, and consisting, as do the leucites of intrusive rocks in general, of an intergrowth of orthoclase and nephelite (or secondary products after nephelite). This regular behavior of leucite in breaking up into orthoclase and nephelite suggests that the early separation of leucite, with a subsequent change of that nature, may afford a key to the origin of many nephelite rocks as well as leucite rocks.

Geophysical Laboratory,
Carnegie Institution of Washington,
Washington, D. C.,
March, 1922.

Art. II.—*The Triassic Reptilian Order Thecodontia;* by F. von Huene.

During the last several years the writer has been much occupied with reptiles of the order Thecodontia (see Nos. 10-20 of the literature list at the end of this paper) and allied groups. In the present paper I am going to give briefly the results as regards classification and relationship. The latest literature is given at the end, and all other papers will be found quoted in these.

The order Thecodontia (R. Owen 1859) consists of three suborders: Pseudosuchia (Zittel 1889), Parasuchia (Huxley 1875) and Pelycosimia (Huene 1911). The animals constituting these three suborders are of very dissimilar form and size, but are anatomically very nearly related. The Pseudosuchia form the radicle stock of the whole group. Both of the other suborders spring from early Pseudosuchians, but have no descendants themselves; the Pseudosuchians give rise probably to all Archosauria.

The Pseudosuchia I propose to classify as follows:

Proterosuchidæ	*Proterosuchus fergusi* *Dyoplax arenaceus* *Erpetosuchus granti*
Sphenosuchidæ	*Sphenosuchus acutus*
Ornithosuchidæ	*Ornithosuchus woodwardi* *Ornithosuchus taylori* *Saltoposuchus connectens* *Saltoposuchus longipes* *Pedeticossaurus leviseuri*
Scleromochlidæ	*Scleromochlus taylori*
Euparkeriidæ	*Euparkeria capensis* *Browniella africana*
Aëtosauridæ	*Aëtosaurus ferratus* *Aëtosaurus crassicauda*
Stegomosuchidæ	*Stegomosuchus longipes*

With regard to the last of these forms, it was first described as *Stegomus longipes* by Emerson and Loomis.[6] Then the writer re-investigated it at Amherst in 1911 and published his results in 1914.[13] The skull now agreed with some of the other Pseudosuchians, but extremities and dermal plates were different. It has a long skull and less than half of its length is preserved. This form cannot go generically with the older animal described by Marsh as *Stegomus arcuatus* (see also [13]), which I now take for a primitive Parasuchian. Therefore I propose to call the former *Stegomosuchus* (n. gen.) *longipes* and its Pseudosuchian family Stegomosuchidæ (n. fam.).

The classification of the Parasuchia is mostly based upon features of the skull. The essential points are: relative length of the base of the skull, relative length of the snout, position of the narial openings, condition of the supratemporal opening, and palate. The posterior part of the skull (beginning in front with the anterior margin of the nares) in different genera has a relative length of from 48 to 33.3 per cent of the whole skull. In some very primitive genera, however, it cannot yet be measured as the tip of the snout is missing in the known specimens.

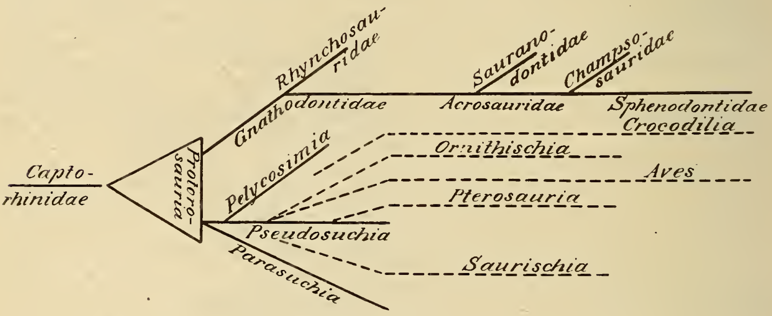
The Parasuchia may be classified in the following manner:

Desmatosuchidæ	*Desmatosuchus*
Stagonolepidæ	*Mesorhinus*
	Stagonolepis
	?Stegomus (*arcuatus*)
Phytosauridæ	*Phytosaurus*
Mystriosuchidæ	*Angistorhinus*
	Palæorhinus
	Machæroprosopus
	Rutiodon
	?Episcoposaurus
	?Parasuchus
	Rileya
	Angistorhinopsis, n. gen.
	Mystriosuchus

The Desmatosuchidæ and the Stagonolepidæ I regard as the most primitive families, of not later than Middle Triassic age. The European *? Phytosaurus* I take as a persistently primitive form retaining an early stage of Parasuchian evolution in the very long posterior part of the skull and the dermal armature. But the shifting backward of the supratemporal groove and the short base of the skull nevertheless indicate a terminal member of this branch of the Parasuchia. The Mystriosuchidæ are a big group which probably in the future will be divided into at least two families, as their feet show very different structures, but the evidence is not yet complete enough to do this. Further, it might be noted that "*Rutiodon*" *manhattanensis* probably does not belong to this genus but to another.

In a paper still in press[20] an extensive discussion is given of the history of the Parasuchia, and in another a general view of the Thecodontia.

The writer holds[13] that the Pseudosuchia give rise to the Archosauria. The reasons for this need not be repeated here. From forms probably nearly related to the Ornithosuchidæ, the Ornithischia and the Aves probably arose through adaptations and the Pterosauria not very far from them. The Crocodilia also probably came from that part of the stem. But the Saurischia the writer takes to be an offshoot of the very earliest Pseudosuchians in the most ancient Triassic time.



In 1920[17] the writer expressed the opinion that the Rhynchocephalia (with the taxonomic rank of an order) are descendants of the same root as the Thecodontia. If that is true, it would be easy to understand why so many characters are common to both phyla. From this viewpoint, the Gnathodontidæ (*Howesia, Mesosuchus, Brachyrhinodon, Polysphenodon* and probably *Eifelosaurus*) would form the most primitive family of the Rhynchocephalia. The contemporaneous family Rhynchosauridæ (*Rhynchosaurus, Hyperodapedon* and *Stenometopon*) is little more specialized. The stem of the Rhynchocephalia is represented in later times by the Acrosauridæ in the Upper Jurassic and by the Tertiary and present Sphenodontidæ. In the Upper Jurassic the

Sauranodontidæ, and in the uppermost Cretaceous the Champsosauridæ, branched off from the main line.

As an Upper Permian Thecodont Broom has described[4] the genus *Youngina*. But this form seems to the writer very nearly related to *Broomia* Watson.[27] Watson has pointed out that *Broomia* is nearly related to *Heleosaurus* and *Heleophilus*. They are also allied with *Adelosaurus*, *Aphelosaurus* and even with the much more specialized *Protorosaurus*, further with "*Eosuchus*" (Watson = *Noteosuchus* Broom). All of these genera should apparently be united in a single inclusive group, the Protorosauria. Watson has pointed out[27] that *Broomia* possibly might be related to the Lower Permian Captorhinidæ, and through these to the more typical Cotylosaurians. If this chain of connections be true, the Protorosauria would form an intermediate link between a group of the primitive Cotylosaurians and the Thecodonts, or, in general, the Archosauria.

Tübingen, 7. January 1922.

LITERATURE.

[1] Broom, R.: On a new reptile (*Proterosuchus fergusi*) from the Karroo beds of Tarkastad. Ann. S. Afr. Mus., 4, 1904, 159-163, pl. 19.

[2] Broom, R.: The South African diaptosaurian reptile *Howesia*. Proc. Zool. Soc. London, 1906, 591-600, pls. 40-41.

[3] Broom, R.: On the South African Pseudosuchian *Euparkeria* and allied genera. Ibid., 1913, 619-633, pls. 75-79.

[4] Broom, R.: A new Thecodont reptile. Ibid., 1914, 1072-1077, 3 figs.

[5] Case, E. C.: Preliminary description of a new suborder of Phytosaurian reptiles, with a description of a new species of *Phytosaurus*. Journ. of Geol., 28, 1920, 524-535.

[6] Emerson, B. K. and Loomis, F. B.; *Stegomus longipes*, a new reptile from the Triassic sandstones of the Connecticut Valley. This Journal (4), 17, 1904, 377-380, pl. 22.

[7] Haughton, S. H.: A new Thecodont from the Stormberg beds. Ann. S. Afr. Mus., 12, 1915, 98-105, 3 figs.

[8] Haughton, S. H.: On the reptilian genera *Euparkeria* Broom and *Mesosuchus* Watson. Trans. R. Soc. S. Afr., 10, 2, 1921, 81-88, pls. 2-3.

[9] Hoepen, E. C. N. van: A new Pseudosuchian from the Stormberg beds. Ann. S. Afr. Mus., 5, 1915, 83-87, pls. 13-14.

[10] Huene, F. v.: Ueber einen echten Rhynchocephalen aus der Trias von Elgin, *Brachyrhinodon taylori*. N. Jahrb. f. Min., etc., 1910, 2, 29-62.

[11] Huene, F. v.: Ueber *Erythrosuchus*, Vertreter der neuen Reptil-Ordnung Pelycosimia. Geol. u. Pal. Abh., 10, 1, 1911. 1-60. Tf. 1-11.

[12] Huene, F. v.: Beiträge zur Kenntnis u. Beurteilung der Parasuchier. Ibid., 10, 1, 1911, 61-122, Tf. 12-17.

[13] Huene, F. v.: Beiträge zur Geschichte der Archosaurier. Ibid., 13, 1, 1914, 1-53, Tf. 1-7.

[14] Huene, F. v.: On reptiles of the New Mexican Trias in the Cope Collection. Bull. Amer. Mus. Nat. Hist., 34, 1915, 485-507, 64 figs.

[15] Huene, F. v.: Bemerkungen zur Systematik u. Stammesgeschichte einiger Reptilien. Zeitschr. f. indukt. Abstammungs- u. Vererbungslehre, 22, 3, 1920, 209-212.

[16] Huene, F. v.: Ergebnisse einiger stammesgeschichtlicher Untersuchungen an fossilen Reptilien. Ibid., 24, 1920, 160-163, Tf. 7.

[17] Huene, F. v.: Die Osteologie von *Aëtosaurus ferratus*. Acta Zoologica, 1, 1920, 465-491.

[18] Huene, F. v.: Ein Parasuchier im oberen Muschelkalk von Bayreuth. Senckenbergiana, 2, 5, 1920, 143-145, 2 figs.

[19] Huene, F. v.: Neue Pseudosuchier u. Cœlurosaurier aus dem Württembergischen Keuper. Acta Zoologica, 2, 1921, 329-403, 4 Tf.

[20] Huene, F. v.: Neue Beiträge zur Kenntnis der Parasuchier. Abh. Preuss. Geol. Landesanst. (Still in press.)

[21] Jaekel, O.: Ueber einen neuen Belodonten aus dem Buntsandstein von Bernburg. Sitz. ber. Ges. nat. Freunde, Berlin, 1910, 197-229.

[22] Lees, J. H.: The skull of *Palæorhinus*. Journ. of Geol., 15, 1907, 121-151.

[23] Lull, R. S.: Triassic life of the Connecticut Valley. Conn. Geol. and Nat. Hist. Surv., Bull. 24, 1915.

[24] MacGregor, J. H.: The Phytosauria, with especial reference to *Mystriosuchus* and *Rhytidodon*. Mem. Amer. Mus. Nat. Hist., 9, 1906, 29-101, pls. 6-11.

[25] Mehl, M. G.: The Phytosauria of the Trias. Journ. of Geol., 23, 1915, 129-165. 20 figs.

[26] Mehl, M. G.: The Triassic fossil bearing horizons near Wingate, New Mexico, with a description of *Acompsosaurus wingatensis*. Bull. Univ. Oklahoma, Studies, 5, 1916, 29-39, 1 pl.

[27] Watson, D. M. S.: *Broomia perplexa* gen. et sp. nov., a fossil reptile from South Africa. Proc. Zool. Soc. London, 1914, 995-1010, pl. 6.

ART. III.—*A Discussion of Triple Salts;* by HORACE L. WELLS.

[Contribution from the Sheffield Chemical Laboratory of Yale University.]

The object of this article is to present a few points in regard to triple salts, particularly in connection with the regularity and irregularity of their types, without attempting to give a complete list of those that are known, or to discuss them fully.

There are many instances where analogous triple salts are known, and in some cases these occur in rather extensive series, but there are a great many cases where analogy is lacking between salts of analogous metals, so that there appear to be no definite laws, based upon the valency or other characters of the constituent salts, according to which they appear to be formed. A similar conclusion was reached by the writer[1] in connection with a discussion of double halogen salts.

To give examples, the triple chlorides recently described by the writer,[2]

$Cs_4Ag_2Au_2Cl_{12}$, $Cs_4Au'_2Au'''_2Cl_{12}$,
$Cs_4ZnAu_2Cl_{12}$, $Cs_4HgAu_2Cl_{12}$,
$Cs_4CuAu_2Cl_{12}$,

show analogous formulas and isomorphism, even where two atoms of a univalent element and one of a bivalent element replace each other, but Pollard's salt,[3] $(NH_4)_6Ag_2Au_3Cl_{17}$, fails to agree with them, as do also two triple bromides,

$$KFe''Fe'''_2Br_9.3H_2O \text{ and } RbFe''Fe'''_2Br_9.3H_2O,$$

described in this laboratory by Professor P. T. Walden,[4] although, in this case, there are agreements in the valencies of the metals.

Among the considerable number of triple thiocyanates described by the writer and his associates,[5] many analogous salts were found, but the number of types that

---

[1] *Amer. Chem. Jour.*, 26, 389.

[2] *This Journal*, May, 1922.

[3] *This Journal*, April, 1922.

[4] *This Journal*, 48, 283, 1894.

[5] H. L. Wells, O. G. Hupfel, H. F. Merriam, C. S. Leavenworth, R. T. Roberts, *Amer. Chem. Jour.*, 28, 245; F. L. Shinn and H. L. Wells, *Ibid.*, 29, 474; H. L. Wells, *Ibid.*, 30, 144.]

occurred with metals of corresponding valency is remarkable. A list of these thiocyanates, according to their types, is as follows:

2 : 1 : 2 salts.

$Cs_2MgAg_2(SCN)_6.2H_2O$
$Cs_2MnAg_2(SCN)_6.2H_2O$
$Cs_2CoAg_2(SCN)_6.2H_2O$
$Cs_2CdAg_2(SCN)_6.2H_2O$
$Cs_2CdAg_2(SCN)_6$
$Cs_2CaAg_2(SCN)_6.2H_2O$
$Cs_2NiAg_2(SCN)_6.2H_2O$
$Cs_2NiCu'_2(SCN)_6.2H_2O$
$Rb_2BaAg_2(SCN)_6.2H_2O$

3 : 1 : 2 salts.

$Cs_3SrAg_2(SCN)_7$
$Cs_3SrCu'_2(SCN)_7$
$Cs_3BaAg_2(SCN)_7$
$Cs_3BaCu'_2(SCN)_7$

4 : 1 : 2 salts.

$K_4BaAg_2(SCN)_8.H_2O$
$Rb_4BaAg_2(SCN)_8.H_2O$

1 : 1 : 1 salt.
$CsZnAg(SCN)_4.H_2O$
1 : 1 : 3 salt.
$CsCdAg_3(SCN)_6.2H_2O$[6]

2 : 1 : 4 salt.
$Cs_2CdAg_4(SCN)_8.2H_2O$

2 : 1 : 1 salt.
$Cs_2ZnAg(SCN)_5$
1 : 2 : 3 salt.
$CsZn_2Ag_3(SCN)_8$

1 : 2 : 4 salt.
$CsZn_2Ag_4(SCN)_9$

In most cases only a single triple salt could be prepared from the same three simple thiocyanates, but Rb, Ba,Ag gave two of them, one of which is analogous to the K,Ba,Ag salt, while neither of them corresponds to the single Cs,Ba,Ag compound. With Cs,Zn,Ag and Cs, Cd,Ag four different salts were prepared in each case, but there is no correspondence between these compounds of such closely related metals as zinc and cadmium. It is a curious circumstance also that while two of the cadmium salts, as hydrous and anhydrous forms, belong to the most common, 2 : 1 : 2, type, the other two cadmium compounds and all four of the zinc salts are unique in type, and thus comprise six out of the nine kinds of formulas shown in the above table.

A series of analogous triple nitrites was described in this laboratory by Professor George S. Jamieson.[7] Their formulas are as follows:

---

[6] Described as $Cs_4Cd_3Ag_{10}(SCN)_{20}.6H_2O$, which varies but little from the simpler formula given here.

[7] *Amer. Chem. Jour.*, 38, 614.

$Cs_3BaAg(NO_2)_6.2H_2O$	$Cs_3PbAg(NO_2)_6.2H_2O$
$Cs_3SrAg(NO_2)_6.2H_2O$	$K_3PbAg(NO_2)_6.2H_2O$

It is to be observed that the compounds in the first column contain the same metals as two of the triple thiocyanates, but the formulas do not correspond, nor was the 3 : 1 : 1 ratio, which these nitrites show, found at all among the triple thiocyanates. Triple nitrites appear to be formed with particular facility, and a few others will be mentioned here to show their types.

The salt $K_2CaNi(NO_2)_6$ was described by Erdmann,[8] and the analogous strontium and barium compounds are known also. The compound $K_2NaCo'''(NO_2)_6$ is well known as the precipitate obtained in a qualitative test for potassium, while the analogous salts $(NH_4)_2NaBi(NO_2)_6$, $Rb_2NaBi(NO_2)_6$ and $Cs_2NaBi(NO_2)_6$ have been described by Ball.[9]

A triple chloride described by Bonsdorff[10] a very long time ago is worth mentioning on account of its irregular, complex formula, $K_6CuHg_3Cl_{14}.2H_2O$. Its composition was confirmed in this laboratory by H. F. Merriam,[11] who prepared and partially analyzed it.

Triple cyanides are known, such as the precipitate, $K_2CaFe(CN)_6.3H_2O$, obtained with potassium ferrocyanide in Baubigny's test for calcium. Of course this may be called a double ferrocyanide.

The following are examples of triple salts that occur as minerals:

Pachnolite, $NaCaAlF_6.H_2O$
Polyhalite, $K_2Ca_2Mg(SO_4)_4.2H_2O$
Thaumasite, $CaCO_3.CaSiO_3.CaSO_4.15H_2O$
Sulphohalite, $2Na_2SO_4.NaCl.NaF$.
Hanksite, $9Na_2SO_4.2Na_2CO_3.KCl$
Kainite, $K_2SO_4.MgSO_4.MgCl_2.6H_2O$
Northuptite, $MgCO_3.Na_2CO_3.NaCl$.

The first two of these show that fluorides and sulphates are capable of forming triple salts, the next two are triple

---

[8] *J. prakt. Chem.*, 97, 395.

[9] *J. Chem. Soc.*, 87, 761; 95, 2126. To the cesium salt, which is obtained as a precipitate in Ball's test for sodium, the formula $Cs_9Na_6Bi_5(NO_2)_{30}$ was ascribed, but the simpler formula, differing but slightly from it and analogous to the others, appears preferable after a careful consideration of the original description.

[10] *Pogg. Ann.*, 33, 81, 1834.

[11] *Amer. Chem. Jour.*, 28, 256 (1902).

salts of single metals with three acids, while the last three show combinations with two metals and three acids, and with two of each.

Enough examples have been given to show that triple salts of analogous metals may have corresponding formulas in some cases, but that there are many irregularities, leading to a large variety of formulas. Some of the variations depend, as is the case with the Cs-Zn-Ag and Cs-Cd-Ag thiocyanates, upon the proportions of the three simple salts in the solutions from which they are deposited, but this appears to be exceptional, since in most cases only a single triple salt can be obtained under such variations.

A great many of the triple salts show simple numerical ratios in their formulas, but a few of them have undoubtedly complex compositions. The frequent occurrence in the formulas of 6 and 12 negative atoms or radicals seems worthy of mention as suggesting related molecular structures in such compounds, but there are many varieties of formulas not corresponding to these numbers.

New Haven, Conn.,
March, 1922.

Art. IV.—*Horned Eocene Ungulates;* by Edward L. Troxell.

[Contributions from the Othniel Charles Marsh Publication Fund, Peabody Museum, Yale University, New Haven, Conn.]

In the Eocene period two distinct forms of rhinoceros-like animals are found to have rugose and thickened nasal bones which appear to be the beginning of horn supports analogous to those of our modern rhinoceros. The first of these is the well known *Colonoceras agrestis* Marsh; the second is *Metahyrachyus bicornutus,* new genus and species.

In Oligocene time we see nothing again of horned rhinoceroses until late in the period, when the diceratheres come in, and one concludes therefore that we either have no record of the intervening members of one single, great, and continuous race, or that the earlier branch was cut off and that nature wrought the later forms from another, a hornless group leading through *Trigonias* Lucas and *Cænopus* Cope.

Colonoceras agrestis Marsh.

(Figs. 1-3.)

Holotype, Cat. No. 11082, Y. P. M. Eocene (Bridger), near Fort Bridger, Wyoming.

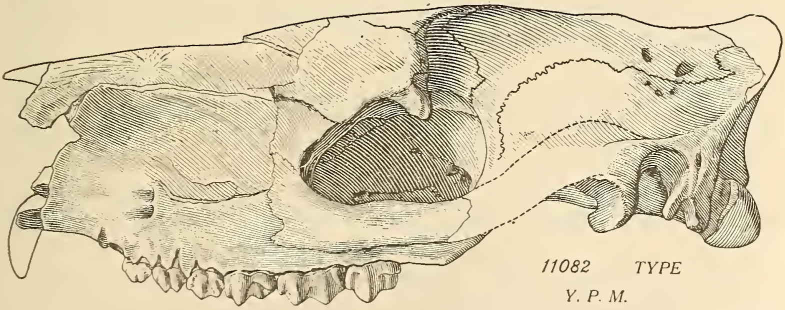


Fig. 1.—*Colonoceras agrestis* Marsh. A small specimen closely related to *Hyrachyus,* but having rugosities on the nasals. Eocene (Bridger). ×½.

The original description of this species is as follows:[1]

---

[1] O. C. Marsh, This Journal (3), 5, 407, 1873.

‘‘In its cranial characters and dentition, this genus resembles most nearly *Hyrachyus* Leidy, and *Helaletes* Marsh. It differs especially from these genera, so far as they are known, in the presence of a pair of dermal horns on the nasal bones, which were strengthened to support them. These horns were placed opposite each other, and their position, in a nearly perfect skull in the Yale Museum, is indicated by two rugosities, which have their surfaces marked by radiating lines. In the present species, which was about as large as a sheep, the horns were widely divergent.

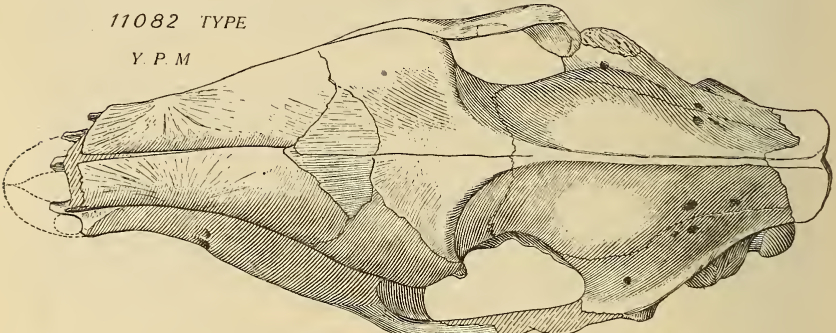


FIG. 2.—*Colonoceras agrestis* Marsh. ×½.

Measurements.

	mm.
Space occupied by seven teeth in upper molar series........	77
Extent of three true molars	41
Distance between orbits	62
Distance between apices of horn rugosities................	27
Length of frontals on median suture	62
Expanse of occipital condyles	40

‘‘The remains of this species at present known are from the Eocene of Wyoming.’’

So far as one may judge from the teeth, the species here described by Marsh is very close to *Hyrachyus affinis*. There are slight variations in the form of the third upper molar, but the premolars are of the typical *Hyrachyus* sort, with the strong anterior cross crests, the protoloph, enveloping the thin short metaloph which lies transversely across the center of the tooth.

These contrasts may be made:

Colonoceras agrestis	*Hyrachyus affinis*
Strong ribs on metacone of molars.	Ribs faint or absent.
M^3 rounded, ant. and post. sides not parallel.	M^3 subquadrate, ant. and post. sides straight.
M^3 heavy projecting post. cingulum.	Short cingulum, not extended backward.
Transverse valley of molars not blocked.	Cingula across valleys.
Peculiar metastyle on molars.	Metastyle inconspicuous.

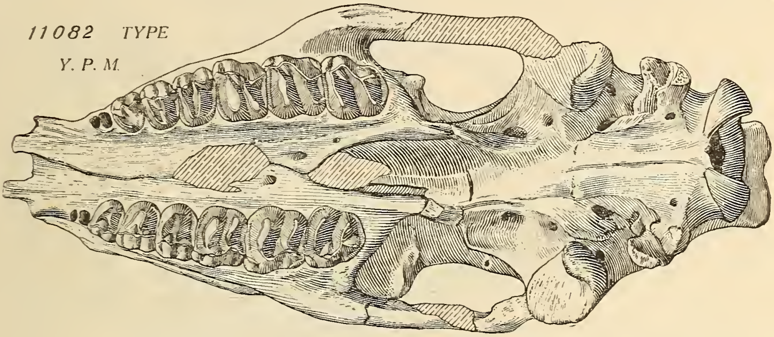


Fig. 3.—*Colonoceras agrestis* Marsh. ×½.

As compared with the more complete skull of *H. affinis gracilis* nobis, Cat. No. 11170, Y. P. M., one sees these differences: *C. agrestis* has more slender condyles, broader frontals, especially between the orbits, and finally has the incipient horn rugosities as the generic name implies.

Except for the presence of horns, none of these features separates *C. agrestis* widely from *H. affinis,* and only in a most rigid splitting of groups can the two be distinguished generically. It has been suggested that the horns of the early rhinoceroses indicate sex distinctions, and this may be true in the present case.

Metahyrachyus bicornutus, gen. et sp. nov.

(Figs. 4, 5.)

Holotype, Cat. No. 10258, Y. P. M. Eocene (Bridger), Millersville, near Fort Bridger, Wyoming.

One of the rarer skulls of early rhinoceroides in the collection is this specimen found by R. E. Son in 1873.

The first incisor is absent, otherwise every tooth of the superior series is represented. The lower jaws are not present.

In two important respects this specimen is different from any *Hyrachyus*. It has the double internal cone on the third and fourth premolars, and has incipient horn rugosities on the nasals.

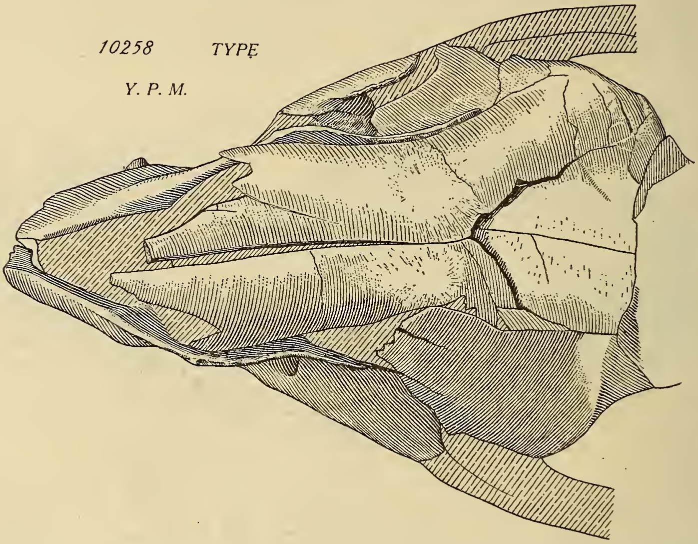


FIG. 4.—*Metahyrachyus bicornutus,* gen. et sp. nov. Top view of skull showing what appears to be the beginning of the horn supports in the great family of the rhinoceroses. ×½.

The first feature, the separation of the tetartocone from the deuterocone, at once reminds us of many species of the later rhinoceroses, in which there is a tendency for the premolars to become molariform. Because the metaloph is so abbreviated, we find its nearest comparison with *Cœnopus* (see *C. platycephalus* (Osborn and Wortman)).

The second important feature, the appearance of horn rugosities on the nasals of this species, is a matter of great significance; for some such race must have given rise to *Diceratherium armatum* Marsh and to *Menoceras cooki* (Peterson) in the later Oligocene and Miocene periods, in which we see the same transverse arrangement of the two elements. This may mark the beginning of the horn-supports seen in the modern rhinoceroses, but here the horns, when there are two of them, are placed one in front of the other.

It is well known that *Colonoceras agrestis* had similar thickenings of the nasal bones, even more rugose; they probably had a common ancestry, but that species is far separated from the present one in other respects: *C. agrestis* is about two thirds the size; the premolars have the simple internal cone; the strong transverse ridge on P^3 is anterior and not medial in position; and finally the rugose areas are midway on the nasals and not posterior as in the new species.

Detailed Morphology of M. bicornutus.—The upper incisors increase in size from front to rear, and there is a progressively larger space between each and between the last incisor and the canine. The third incisor is subcaniniform, being rather long and slightly recurved, but it is narrow transversely. The canine is only moderately long; it is compressed and recurved and therefore bears no resemblance to those of the later rhinoceroses except *Hyracodon* Leidy.

The first premolar, although elongated fore and aft, is much broader than that in *Hyrachyus.* This tooth has the one main protocone and on the inner side an incipient deuterocone with minor ridges. The second premolar is nearly circular in form, consisting mostly of the large strong outer cone (protocone), with a small tritocone behind it, and of one prominent inner cone, the deuterocone. A thin ridge runs from the latter to the middle of the ectoloph and divides the tooth equally; this is a distinctive feature of the genus.

Undoubtedly the most important feature of the skull is the double inner cone on each of the larger premolars. It shows the beginning of the separation of the tetartocone from the deuterocone, and a first step toward the assumption of the molariform condition which was actually realized both in *Hyracodon* cf. *H. leidyanus,* and in *Cænopus* cf. *C. tridactylus metalophus.* This partial separation is brought about by a vertical groove on the inner side of each tooth which, theoretically, is the predecessor of the normal, transverse, median valley. There is a small internal basal cingulum cutting across the base of this groove on P^4.

The protoloph, the anterior cross ridge, on $P^{3.4}$ is patterned after the molars; but the metaloph is extremely small and irregular. It consists of a small tubercle situated between two folds of enamel extending inward from the proto- and tritocones, and is distinctly separated at the ends from both the ecto- and protolophs

From the drawings it may be seen that the main valleys of the premolars open backward instead of inward and in this respect are like those of *Cænopus platycephalus nanolophus.*

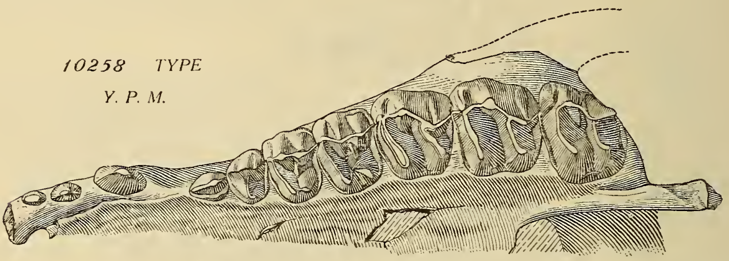


FIG. 5.—*Metahyrachyus bicornutus,* gen. et sp. nov. Crown view of upper teeth and part of skull. The diastema between the canine and molar is reduced to half its normal length of 25 mm. by the distortion of the skull. The chief distinguishing features are found in the unusual premolars. ×½.

Of the teeth of the cheek series the second molar is largest; it approaches in size that of *Hyrachyus princeps* Marsh. The third molar is relatively small and its outer and posterior sides form a fairly smooth curve, with the ectoloph extending slightly beyond its edge. On this third molar the posterior cingulum is conspicuous; a small overlapping cingulum across the median valley corresponds to the small cusp which lies on the base of the protocone of M^2.

The inner side of the ectoloph of M^3 is nearly straight in this specimen. Back of the point of union of the metaloph, only, does it curve outward and away from the straight line, where it forms a thin, prominent edge. The small crista is far back on the paracone and lies low on its base. On M^1 it is higher and farther forward.

On all the molars, the parastyle, antero-exterior corner, is rather small and is not set off from the adjacent protoloph by such sharp grooves as one sees in *Hyrachyus princeps.*

The posterior extension of the ectoloph on M^3, the form of the slender premaxillaries and of the nasals, the presence of erect canines, the deep posterior nares, all remind one of *Amynodon erectus* nobis, and it seems that there must have been a rather near relationship. The notches on the anterior ends of the nasals are found also in *Cænopus allus* nobis.

The following are important measurements of *Metahyrachyus bicornutus:*

	mm.
Molar-premolar length	111
Molar series, length	64.5
P^4, width	21.7
P^4, length	16.5
M^2, width	26.3

SUMMARY.

Two Eocene specimens are figured and described here which are unusual in having on the nasals slight thickenings, or centers of ossification, which resemble the horn supports in later rhinoceroses. One is the type of the well known *Colonoceras agrestis* Marsh and the other the type of *Metahyrachyus bicornutus,* gen. et sp. nov. The latter may be distinguished by the caniniform I^3, the large P^1, the median cross ridge on P^2, and the odd forms of P$^{3.4}$ with their strong development of the tetartocone and much reduced metaloph.

ART. V.—*The Genus Hyrachyus and its Subgroups;* by EDWARD L. TROXELL. (With Plate I.)

[Contributions from the Othniel Charles Marsh Publication Fund, Peabody Museum, Yale University, New Haven, Conn.]

CONTENTS.

INTRODUCTION.

As early as the Eocene period in America we find representatives of the great group of animals called the rhinoceros. With them, and not far removed, we see also the ancestors of the horse and of the tapir, and still other closely related forms which were early blotted out, and whose line has been discarded from the material of the great evolutionary structure.

Within the great family Rhinocerotidæ, there was already a differentiation in the Middle Eocene which gave rise to later subdivisions: (1) *Amynodon,* leading to the Amynodontidæ, extinct with the Middle Oligocene; (2) *Metahyrachyus* nobis, a possible progenitor of the true rhinoceros through *Trigonias* and *Cænopus;* and (3) *Hyrachyus,* giving rise to the Hyracodontidæ, which existed throughout the Oligocene.

The present study deals with the last of these three groups, the cursorial hyracodonts, and with the single genus *Hyrachyus* Leidy.

As to what constitutes *Hyrachyus* there need be little doubt; there are about one half dozen valid species which may be combined into a harmonious genus with certain well defined features and yet with certain individualities which indicate a rather wide variation.

As to what constitutes the *type* of the genus, there has been much misunderstanding. Through a passive tolerance, authors have come to accept *H. agrarius* Leidy as the type, following Leidy, who himself chose to eliminate *H. agrestis,* a species founded upon the lower jaw of a young animal with milk teeth.

Although Leidy stated specifically in his first description of the genus (1871 A, p. 357) that *Hyrachyus* "an extinct genus, allied to *Hyracodon,* is founded on a fragment of a lower jaw of a young animal," yet in a later paper (1873, p. 60) he figures this jaw but says that he regards it as the same species as *H. agrarius,* and substitutes the latter as the genoholotype. This has been followed in the literature with only one or two exceptions. It is of no great moment which of these species represents the genus, but the rules of nomenclature demand that we adhere strictly to the original type in spite of the desires of later writers, including the nomenclator himself, and so *H. agrarius* must give place to *H. agrestis.*

This species is reinstated as the genoholotype with greater confidence because of the following statement from Doctor O. P. Hay, who has recently looked into this question and says in a letter dated June 18, 1921, "It is evident that Leidy meant to base his genus on *H. agrestis.*"

Neither the holotype of *H. agrestis* nor that of *H. agrarius* is specifically determinable. The first is based on a lower jaw fragment containing the first and fourth deciduous premolars, the roots of the intervening two, and also the first molar of the permanent series; the second type is founded upon a lower jaw without the crowns of any teeth.

Definition of the Genus.—Hyrachyus Leidy may be distinguished as having smooth nasals without horn rugosities; diastemata separating the canines and premolars; canines moderately long, pointed, and only slightly flattened; premolars with cross crests not parallel but forming a loop, the metaloph encircled by the protoloph; molars with strong parastyles constituting isolated cones, with median valleys open, metacones receded, with parallel cross ridges leading from points anterior to the two main outer cones respectively, and finally with a strong posterior extension of the ectoloph on the last upper molar; dental formula 3. 1. 4. 3.

All the species of the genus are from the Bridger beds of the Middle Eocene.

THE SUBDIVISIONS OF HYRACHYUS.

Hyrachyus agrestis Group.

Hyrachyus agrestis Leidy 1871, genoholotype.
Hyrachyus agrarius Leidy 1871, synonym.
Hyrachyus bairdianus (Marsh) 1871.

This group, besides the two species of Leidy already discussed, includes also *H. bairdianus* Marsh, probably a subspecies under *H. agrestis*.

Leidy's types, inadequate for accurate specific determination, serve only to define the genus. Marsh's type, although also far from being complete, offers some distinguishing characters and is here redescribed along with a nearly complete skull and jaws in the Yale collection (Cat. No. 11081, Y. P. M., apotype).

Hyrachyus bairdianus (Marsh).

(FIGS. 1, 2.)

Cotypes, Cat. Nos. 11035 and 11057, Y. P. M. Eocene (Bridger), near Fort Bridger, Wyoming.

The first type consists of a portion of the left maxillary with the three molars (fig. 1), of which M^1 and M^2 are so worn and broken that one gets little character of the species from their study. M^2 shows a strong internal cingulum across the transverse valley. The third molar is, however, well preserved, and shows certain important specific features. The tooth is wide on the inner side, narrow on the outer; thus the ectoloph is short, and its posterior end, making up the metacone and style, does not extend beyond the bulging posterior cingulum.

The posterior fossette cuts deeply, forming a sharp angle between the ectoloph and metaloph. A strong cingulum surrounds all of the tooth except the outer side and the base of the hypocone.

The second specimen (fig. 2) described by Marsh consists of a portion of the left mandibular ramus with the three lower molars. Although the teeth agree closely in their width, M_3 is 3 mm. larger than M_1. The cross ridges of M_1 are most nearly parallel, those of M_3 least so.

FIG. 1.

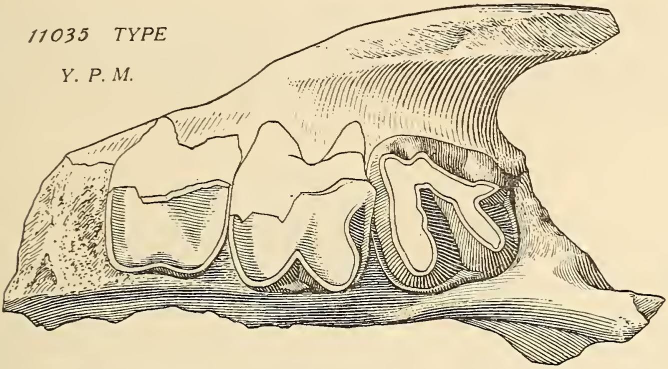


FIG. 1.—Cotype, *Hyrachyus bairdianus* (Marsh). Part of the maxillary with three molars. Nat. size.

FIG. 2.

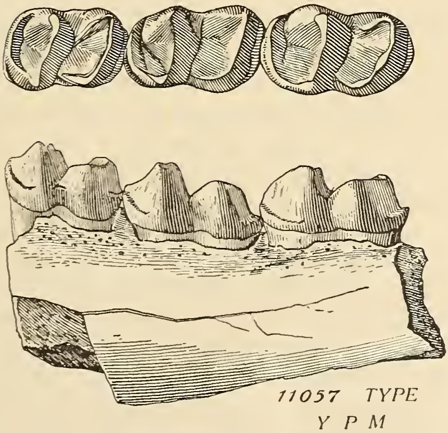


FIG. 2.—Cotype, *Hyrachyus bairdianus* (Marsh). Crown and side view of the lower molars, facing to the left. Note the uniform size of these teeth. Nat. size.

The new specimen of *H. bairdianus,* apotype, Cat. No. 11081, Y. P. M., discovered in the Bridger beds near Fort Bridger, Wyoming, by O. Harger in 1871, consists of a fairly complete skull and jaws, with all the dentition except $I_{2\cdot 3}$ and P_1. The series of lower teeth measure precisely the same as do those of the type of *H. agrarius* Leidy; the specimen therefore serves as a unit of measure for this group so ill defined by the types, and in addition gives us an idea of the character of the anterior teeth.

Hyrachyus affinis Group.

Hyrachyus affinis (Marsh) 1871.
Hyrachyus implicatus Cope 1873.
Hyrachyus intermedius Osborn, Scott and Speir 1878.
Hyrachyus crassidens Osborn, Scott and Speir 1878.
Hyrachyus paradoxus Osborn, Scott and Speir 1878.
Hyrachyus affinis gracilis, subsp. nov.
?Hyrachyus modestus (Leidy) 1870.

This group of species, here associated about *H. affinis* (Marsh) as a center, represents the smallest of the hyrachyids. Seven names are listed, only four of which are thought to be of value in our classification of the early rhinoceroses; *H. crassidens, H. paradoxus* and *?H. modestus* are based on imperfect specimens, inadequate as types. The three others are here considered as subspecies. *H. affinis intermedius* Osborn, Scott and Speir, founded on the upper molars, is slightly smaller than *H. affinis affinis,* especially in the antero-posterior dimension, due probably to wear; it is noted for the cingulum which nearly encircles the tooth, the obscure crista, the cross ridges arched forward, and the position of the postero-external lobe far to the rear. *H. affinis implicatus* Cope has for cotypes three specimens, the first of which varies in measurements from *H. affinis affinis* in having a shorter last molar but otherwise being larger; it has been referred by Cope (1884, p. 675) and others to *H. agrestis* Leidy, while the second cotype is presumed to stand for a species under the same name. It is the opinion of the writer that the species must stand on the merits of its first type, and that, in order to make the second specimen a valid type, it must be renamed.

Hyrachyus affinis affinis (Marsh).

(Fig. 3.)

Holotype, Cat. No. 12530, Y. P. M. Eocene (Bridger), near Grizzly Buttes, one mile from Marsh's Fork, Wyoming.

Marsh, in his first description (1871, p. 37), characterizes this species by the small size, by the contour of the crown of M³ which has a deep notch in the posterior margin of the base, and by the small, prominent antero-external tubercle not closely connected with the adjoining ridge.

Fig. 3.

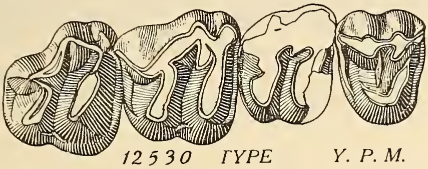


Fig. 3.—Holotype, *Hyrachyus affinis* (Marsh). Crown view of the molars and fourth premolar. This is one of the smallest species of the genus. Nat. size.

In addition to this, one notes the squared form of the last molar, the rather weak posterior extension of the ectoloph, the large second molar, and the weak metaloph on the fourth premolar.

Hyrachyus affinis gracilis, subsp. nov.

(Pl. I and text fig. 4.)

Holotype, Cat. No. 11170, Y. P. M. Eocene (Bridger), Henry's Fork, Wyoming.

The type consists of a good skull and jaws, without the anterior teeth, fore and hind feet and fore limbs, together with parts of the hind limb bones, pelvis, ribs and vertebræ. This specimen, previously on exhibition for several years in the old Peabody Museum, has just been remounted (see pl. I) on a large slab representing the original rock matrix; the preparation was done by Mr. Hugh Gibb. Professor Lull has made a restoration of the animal in the flesh in low relief, one-fourth the natural size, modelled after the mounted specimen (in pl. I, about one thirteenth nat. size). The posture selected for the restorations is that of an extreme phase of a fast trot, with alternate front and hind feet advanced, the whole purpose being to emphasize the idea that this is a light, agile animal, a *cursorial rhinoceros.* The missing parts were restored in plaster and the bones arranged on the flat base; the position of each was carefully worked out by the study of other skeletons, photographs, and observations on living animals.

This interesting specimen, found probably in the early seventies, drew the attention of Professor Marsh, who apparently intended to make it the type of a new species; his observations follow, but of course the species name, here quoted from his manuscript, has no standing:

''Notes on *Hyrachyus bairdi* M.

''No. 1170. Skull and skeleton nearly complete (H. Fork, Wy.).

''1. Hind feet longer and stouter than fore feet. (Reverse true in tapir.) Metatarsals *curved.*

''2. No supratrochlear foramen in humerus (as in tapir).

''3. *Navicular sesamoids* present, but minute, in all three toes behind, and at least II, III and IV in front. (Not present in tapir or rhinoc.)

''4. Ulna smaller than in tapir.''

Additional points on the new type.—The dental formula is 3. 1. 4. 3. P^2 has a strong cross ridge anteriorly like the larger premolars; it is slightly wider (8.7 mm.) than it is long (8 mm.). $P^{3 \cdot 4}$ are very similar in proportions; the latter is larger. P^1 was probably as wide transversely (6.4 mm.) as it was long; the anterior part is broken away. The lower premolars show a gradual change from the first to the fourth. P_1 has a single cusp with a small internal ridge leading from the apex; P_2 shows an antero-internal groove set off by what may be called the paraconid; $P_{3 \cdot 4}$ both have the two cross crests and, the latter especially, take on the form of a true molar.

The molars increase gradually in length from the first to the third, but change very little in width. There is practically no difference in height between the anterior and posterior cross crests. In the worn condition these crests come to show the typical "L" of the rhinoceros-like animals because of the low ridges extending from them on the outer forward side. The ridge from the anterior crest continues on into an upfolded edge or cingulum.

Fig. 4.

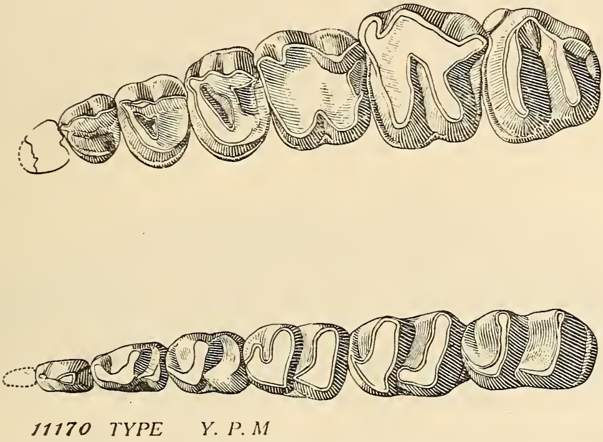


Fig. 4.—Holotype, *Hyrachyus affinis gracilis,* subsp. nov. Crown views of the upper and lower teeth. Note the odd-shaped P^4 and M^3 and the rhinoceroid lower teeth with the strongly L-shaped cross crests. Nat. size.

This new subspecies is put under *H. affinis* (Marsh) on account of the agreement in size. Such parts as can be compared exhibit some notable differences: the new form may be distinguished (1) by the weaker paracone on M^3, which blends into the metacone without such a deep groove on the outer side; (2) by the less prominent base of the metacone, giving a more nearly rounded outline to the posterior and outer sides; and (3) by the longer P^4 with its heavier metaloph continuous with the end of the curved protoloph.

Hyrachyus princeps Group.

Hyrachyus eximius Leidy 1871.
Hyrachyus princeps Marsh 1872.
Hyrachyus imperialis Osborn, Scott and Speir 1878.

These species are grouped together because they can not be distinguished specifically. Leidy's type was the first studied and named; it is based on a fragment of the mandibular ramus with two teeth, one partly broken away and both well worn. The species shown by Leidy on his plate IV, figures 19, 20, is clearly inadequate as a type; it is somewhat smaller than *H. princeps.*

Hyrachyus imperialis Osborn, Scott and Speir (1878, p. 50) was "established on the second and third molars of each upper jaw, and three premolars, and one lower molar, portions of the skull and vertebræ." The measurements agree precisely with the type of *H. princeps,* and so far as one can judge the description also tallies. *H. imperialis* is either a synonym or at most only a subspecies of *H. princeps.*

Hyrachyus princeps Marsh.

(Fig. 5.)

Holotype, Cat. No. 11157, Y. P. M. Eocene (Bridger), Fort Bridger, Wyoming.

In the first description of this species (1872, p. 125) Marsh characterizes it as the "largest of the Tapiridæ yet found in this country." He further says:

> "The remains representing it indicate an animal nearly three times the bulk of *Lophiodon* [*Hyrachyus*] *Bairdianus* Marsh, and probably twice that of the individual named *Hyrachyus eximius* by Dr. Leidy. The specimens on which the species is based consist of a nearly complete series of upper teeth, and several lower molars, ... remarkably well preserved. The last two upper molars are unusually large in proportion to the rest of the series, and have the antero-external lobe quite separate, and with its apex incurved."

The following additional features will serve to define the type of *H. princeps* more specifically. On the posterior side of M^3 there is no deep fossa; the cingulum is weak here and is almost lacking on the inner side of the tooth, leaving the median valley practically unobstructed. The antero-external lobe is heavy and broad, and though distinct, is not far removed from the curved protoloph. The anterior and posterior sides of the tooth are parallel, squaring the tooth to a degree duplicated in *H. affinis affinis* only, within the genus. The straight exterior and posterior sides unite to form a prominent angle which makes the posterior end of the ectoloph seem small in comparison. The crista, the fold of enamel on the inner side of the paracone, is relatively small on each molar.

The first and second molars have forms quite different from the third, due mostly to their larger metacones and the greater posterior extension of the ectolophs which reach out beyond the general border of the crown, in a strong inwardly curved fold. Just behind the point of union of the meta- and ectolophs is the distinct metacone, on the outer side of which is a basal ridge or cingulum.

Fig. 5.

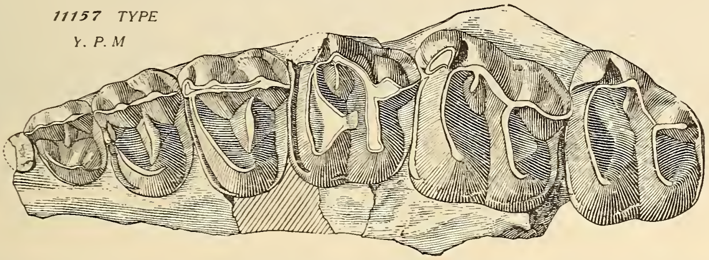


Fig. 5.—Holotype, *Hyrachyus princeps* Marsh. Molars and premolars of a very large hyrachyid. M^3 is transposed from the right maxillary. ×2/3.

Marsh has mentioned the small size of M^1; its diameters are 26 mm. transverse and 21 mm. fore and aft.

On the premolars the anterior and posterior sides converge inward. They are rounded on the inner side, not angular as in the rhinoceroses; they are squared on the broad outer sides, where distinct grooves separate the two main cones and the anterior and posterior styles. The deuterocone dominates the inner half of the tooth, and the protoloph supersedes the metaloph, which is small and thin and resembles that of certain species of the early rhinoceroses. The inner slope of the deuterocone is not encircled by a cingulum. The parastyle of the premolar is distinct but much smaller than in the molar.

On P^3 the protoloph does not actually join the ectoloph; both it and the anterior cingulum are somewhat broken and interrupted.

P^2 has an incomplete metaloph, as in *Cænopus nanolophus,* which does not reach the deuterocone, and the protoloph is entirely severed from the ectoloph by the deep valley running longitudinally.

The third lower molar is broad on its posterior half. There is a strong basal ridge both fore and aft, the true cingulum, in addition to the sharp ridge running inward from the antero-exterior corner of the crown.

SUMMARY.

The genus *Hyrachyus* Leidy, taken as a whole, is made up of a number of groups, each of which, in the writer's opinion, belongs to a single species. *H. affinis* (Marsh) represents the smallest of these, then in the order of size come *H. bairdianus* (Marsh) (=*H. agrestis* Leidy, indet.), and the very large *H. princeps* Marsh.

Under the name *H. affinis gracilis* a new subspecies is described which, because of the completeness of the skeleton upon which it is based, serves admirably as a protype, or reference type, further to establish the group. This specimen has recently been remounted.

Measurements of Types.

	H. bairdianus Cotypes No. 11035 mm.	Apotype No. 11081 mm.	*H. gracilis* Holotype mm.	*H. affinis* Holotype mm.	*H. princeps* Holotype mm.
Superior dentition:					
Molar-premolar series, length		94	74		? 128
Molar series, length	51.8	53.5	43.5	44	70
P^4, width, transverse		18	14.5	14.2	25
P^4, length		13	10.5	11.3	19.5
M^2, width		21.6	18.0	17.3	30.5
M^2, length		20.3	16.7	16.7	25.5
M^3, width	22	20.4	17.5	17.3	31
M^3, length	18.6	19	15.5	15.2	26
Inferior dentition:	No. 11057				
Molar-premolar series, length		? 92.5	78		
Molar series, length	52.3	53.7	45		
P_4, width		9.5	8		
P_4, length		13.2	11.6		
M_1, width	10.5	11	9.6		
M_1, length	15.5	15.5	13.6		
M_2, width	11.6	12	10.2		17.5
M_2, length	17.5	18	15.3		
M_3, width	11.7	12.5	10.6		17.5
M_3, length	19.3	20	12		28.5

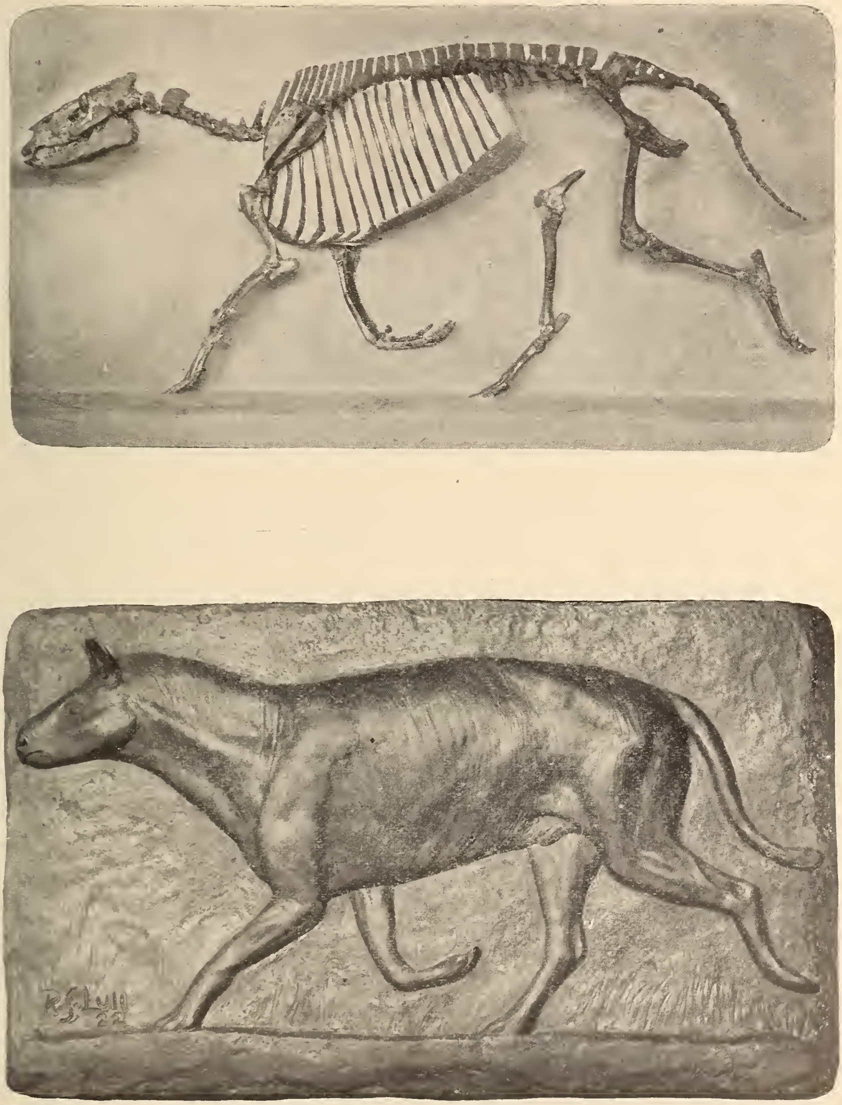


PLATE I.—*Hyrachyus affinis gracilis,* subsp. nov. Above, mounted skeleton. Below, flesh restoration by Professor R. S. Lull. × 1/13.

References.

Cope, E. D. 1873. On some Eocene mammals obtained by Hayden's Geological Survey of 1872. Pal. Bull. No. **12**.

—1884. The Vertebrata of the Tertiary formations of the West. Rept. U. S. Geol. Survey Terr., **3**, 657-77.

Leidy, Joseph. 1870. [Remarks on a collection of fossils from the western territories.] Proc. Acad. Nat. Sci. Philadelphia, **22**, 109.

—1871A. Report on the vertebrate fossils of the Tertiary formations of the West. U. S. Geol. Survey Wyoming and portions of contiguous Territories, 2d (4th) Ann. Rept.

—1871B. Remarks on fossil vertebrates from Wyoming. Proc. Acad. Nat. Sci. Philadelphia, **23**, 229.

—1873. Contributions to the extinct vertebrate fauna of the western territories. Rept. U. S. Geol. Survey Terr., **1**.

Marsh, O. C., 1871. Notice of some new fossil mammals from the Tertiary formation. This Journal (3), **2**, 35-44.

—1872. Preliminary description of new Tertiary mammals. Ibid. (3), **4**, 122-128.

Osborn, H. F., Scott, W. B., and Speir, Francis, Jr. 1878. Palæontological report of the Princeton scientific expedition of 1877. Contrib. Mus. Geol. and Arch. Princeton Coll., **1**.

Art. VI.—*A New Occurrence of Ilsemannite;* by Chas. W. Cook.

The molybdenum-bearing mineral ilsemannite seems to be of sufficiently rare occurrence to make such occurrence worthy of note. It has been reported from Bleiberg, Carinthia;[1] Cripple Creek, Colorado;[2] Natal, S. Africa;[3] Ouray, Utah;[4] and as possibly occurring in the mine waters at Idaho Springs, Colorado.[5] During an extensive investigation of molybdenum deposits, in which a large number of localities in the United States and Canada were visited and hundreds of specimens from localities not visited were examined, the writer observed the occurrence of ilsemannite at but two points; one at Ouray, Utah, mentioned above, and the other in Shasta Co., California, four miles west of Gibson, a station on the Southern Pacific R. R.

In the Gibson locality molybdenite, associated with pyrite, occurs disseminated in what appear to be bowlders of aplite, no definite connection between the molybdenite-bearing masses and other rocks having been established. Dikes of similar lithological character were found in the district but in no instance, where it was certain that the rocks were in place, was any molybdenite found. Not infrequently the molybdenite has been completely altered to molybdite and this mineral may be seen entirely filling the cavities formerly occupied by the molybdenite. In other instances, where the molybdenite has not been completely altered, a bluish-colored zone shows around the molybdenite nucleus. This zone is plainly a staining of the quartz and feldspar by ilsemannite or some closely allied substance.

At the time of the examination of the property, something over one hundred tons of ore had been removed, according to reports, and some of this ore was still on the ground at the railroad awaiting shipment. This broken rock had been exposed to the action of the atmosphere for several months and many pieces had been completely discolored blue on the surface, giving them an entirely different appearance from that of the freshly

---

[1] Hofer, N.: Jahrb. Min., 1871, p. 566.
[2] Lindgren and Ransome: U. S. G. S. Prof. Paper No. **54**, p. 154, 1906.
[3] duToit: So. African Jour. Sci., vol. **13**, p. 153, 1917.
[4] Hess: U. S. G. S., Min. Res., 1917, p. 913, 1920.
[5] Horton: U. S. Bur. Min., Bull. **111**, p. 15, 1916.

broken rock. It would seem, therefore, that the alteration of the molybdenite to ilsemannite had been relatively rapid.

According to different authorities, ilsemannite has been formed in different ways. Cahen and Wooten[6] state that it is formed by the alteration of jordisite; Dana[7] says that ilsemannite is "a product of the decomposition of metallic molybdates"; while Lindgren and Ransome[8] indicate their belief that at Cripple Creek it has been formed by the direct oxidation of molybdenite.

The exact composition of ilsemannite is likewise subject to discussion. Dana[9] gives the formula ($MoO_2.4MoO_3$); Schaller[10] has proposed the formula ($MoO_3.SO_3.3H_2O$); while Yancey[11] believes that Guichard's formula for the synthetic blue oxide ($MoO_2.4MoO_3.6H_2O$) most closely, although not exactly, expresses the composition of the blue of ilsemannite and for the present prefers to consider it is a chemical mixture of molybdenum dioxide with relatively larger amounts of the trioxide. In support of the latter supposition, the writer wishes to advance some observational evidence which may also shed some light on the nature of the alteration process in the case of molybdenite.

On the crystal and cleavage faces of the molybdenite in specimens from Gibson, a phenomenon has been observed which the writer has not seen on specimens from any other locality, namely a tarnish or iridescence which immediately reminds one of the "peacock colors" on bornite. A closer examination shows the color to vary from a bronze-brown to a violet brown to blue. Apparently the product is identical with that obtained near the assay on charcoal when molybdenite is subjected to the action of the oxidizing flame. Also the writer has produced this tarnish artificially by gently touching crystals and cleavage faces of molybdenite with an oxidizing flame. Guichard[12] has shown that the true color of molybdenum dioxide is brown or violet brown although this color is easily obscured by the blue of the mixed oxides. It, therefore, seems to the writer quite probable that this bronze to violet brown coating on the molyb-

---

[6] The Mineralogy of the Rare Metals. 1912, p. 51.
[7] System of Mineralogy. 6th edition, p. 202.
[8] Loc. cit.
[9] Loc. cit.
[10] Wash. Acad. Sci., vol. 7, p. 417, 1917.
[11] Chem. and Met. Engr., vol. **19**, p. 189, 1918.
[12] Compt. Rend., vol. **129**, p. 722, 1899.

denite from Gibson is molybdenum dioxide. All material so far examined indicates a thickness for the coating no greater than that of one of the cleavage laminæ of the molybdenite. Hence, the definite determination of its composition or of its properties other than color and luster, the latter being metallic, has been impossible.

One other observed phenomenon should also be mentioned since it may have a direct bearing not only upon the composition of both the coating and ilsemannite but also upon the nature of the decomposition process. In some instances the blue colored material which has been designated as ilsemannite does not appear to be water soluble. This might be expected if the following stages were passed through in the alteration of molybdenite to molybdite.

If the molybdenite was first altered by the oxidation of the sulphur, molybdenum dioxide, a brown substance insoluble in water (Muthmann),[13] would result. This would represent the tarnish stage mentioned above. The subsequent oxidation of a small portion of the molybdenum to the hexavalent form would result in a change of color from brown to blue although the compound would still remain insoluble in water, and would correspond to the substance referred to in the preceding paragraph. The existence of such an insoluble blue compound might be expected from the fact that for many years after its original preparation, the color of molybdenum dioxide was thought to be blue. Further oxidation, with an increase in the relative amount of the trioxide, and hydration would then transform this insoluble blue compound into the soluble blue compound, ilsemannite. Finally, complete oxidation to the trioxide, on combination with iron, would yield the yellow compound, molybdite.

The above interpretation of the observed facts would seem to indicate the composition proposed for the coating and also to support Yancey's suggestion regarding the composition of ilsemannite. Further, it has a direct bearing upon the question of the secondary enrichment of molybdenite, a subject now under investigation by the writer.

University of Michigan,
Ann Arbor, Mich.,
February 14, 1922.

---

[13] The process of Ullik described by Muthmann (Liebigs Annalen vol. 238, p. 114, 1887) involves purification with hydrochloric acid and potassium hydroxide so that it seems probable that it is insoluble in water.

ART. VII.—*On the Zonal Division and Correlation of the Silurian of Bohemia;* by J. PERNER, with the collaboration of O. KODYM.

The Silurian formation in central Bohemia (= Upper Silurian in the sense of European geologists) is represented by three "bandes," designated by Barrande as E_1, E_2, and F_1. The boundaries of these beds were originally not sufficiently defined, and especially that between the most important beds, E_1 and E_2, which was somewhat arbitrary owing to the gradual passage of one into the other; there has also been a change of opinion as to where and how the boundary line should be drawn between E_1 and E_2. No attempts have been made to divide all these beds, formed chiefly of very fossiliferous shales and limestones and attaining at several localities a thickness of at least 500 feet, into minor divisions or zones, as has been very successfully done in other countries. However, Marr[1] and Tullberg,[2] in discussing Barrande's theory of the so-called "colonies," have ascertained the existence of several graptolitic zones in E_1 similar or analogous to those in England and Sweden. Wenzel,[3] on the contrary, comparing the Lower Paleozoic deposits of Bohemia with those of Great Britain, endeavored to prove that the geological distribution of graptolites in Bohemia is quite different, and quoted associations of graptolites in E_1 (on the same slab) which in other countries appear separately in altogether different horizons, and declared that the fauna in the Silurian basin of Bohemia was so concentrated that no such zones could be distinguished.

In order to get a reliable basis for a more detailed division of our Silurian and a closer comparison with that in other countries, I undertook a revision of the Bohemian graptolites,[4] which had been neglected from the paleontological standpoint since 1850.[5] I found in many cases that Barrande had included more than one species under a single specific name, and in some instances had even

---

[1] Quart. Jour. Geol. Soc., London, 1880.

[2] Sveriges geolog. Undersökning, Ser. C, No. 50, 1882; Zeits. deut. geol. Gesell, 1883, 2.

[3] Jahrb. d. geol. Reichsanstalt, Wien, 41, 1, 1891.

[4] Études sur les graptolites de Bohême, I, II, IIIa, b, with 17 plates. Prague, 1894-1899.

[5] J. Barrande, Graptolites de Bohême, with 4 plates, Prague, 1850; E. Suess, Ueber böhmische Graptoliten. Haidiger's naturwiss. Abhandl., 11, 1851.

included three species confined to different, vertically widely separated horizons. Consequently correct identifications could not be made until such a revision had been finished, and this explains not only the quite erroneous assertions of Wenzel as to the non-existence of zones in the Silurian of Bohemia, but also the incongruous views on graptolitic zones in Bohemia held by other authors. In addition, a more detailed division and comparison of Bohemian strata could not be systematically worked out until this revision of species had been made. After redefining the world-widely distributed species of Barrande in accordance with his type specimens, I was able to ascertain in the Silurian beds E_1, E_2, and F_1 many new species, and to note the presence of forty forms heretofore known only from Great Britain and Scandinavia. Additional studies regarding the vertical distribution of other fossils and different facies in the beds named above have led to results here communicated.[6]

The limit between the Upper Ordovician (Barrande's Bande D_5) and the Lowest Silurian beds in central Bohemia is a very sharp one, both from the petrographic and the paleontologic standpoint. The lowest Silurian beds, black graptolitic shales of E_1, rest at some rare localities with a slight unconformity on the soft yellow or olive-green, sometimes argillaceous, shales of D_5, which are interstratified, especially toward the top, with quartzites, gritty shales, and graywackes. The fauna of D_5 is also completely different from that in E, having no species in common, and being characterized by *Trinucleus, Remopleurides, Carmon, Dindymene, Homalonotus, Æglina, Asaphus, Agnostus, Areia,* and *Dicellograptus,* as against the E_1 shales bearing *Diplograptus, Rastrites,* and *Monograptus,* so that a hiatus seems to be evident between the Ordovician and Silurian in Bohemia.

---

[6] It was my intention immediately after the completion of my paleontological studies on Bohemian graptolites to publish as their final part a paper dealing with the zonal division of the graptolitic rocks of Bohemia. But my official duties connected with the Bohemian Museum and with working out the Gastropoda of Barrande prevented my doing this before the outbreak of the Great War. During the past few years I have been greatly aided by my pupil, Mr. Od. Kodym, with whose collaboration a preliminary report on this subject was published in the Journal of the Bohemian Museum for 1919 (in the Czech language). In the present English communication I hope to enable foreign workers to get the review and comparison of the Bohemian Silurian beds before the more detailed paper on this subject appears, since I have no idea when this latter can be accomplished, because of the desolate situation of the scientific institutions of Czekoslovakia.

Bande E_1 is composed chiefly of black graptolitic shales, but becomes calcareous toward the top, passing into the limestones of E_2. This passage is marked by the appearance of calcareous concretions (anthracolites) and thin seams of bituminous limestones in the higher graptolitiferous shales. These intercalations become more numerous toward the top of E_1, until the shales gradually disappear and limestone-beds prevail, followed by thickly bedded compact or crystalline limestones. The boundary between E_1 and E_2, formerly uncertain, was proposed by J. Jahn[7] almost wholly on the basis of petrography, and the horizon of shales with concretions and limestone intercalations was classed as E_1. I myself defined the same boundary paleontologically,[8] taking the zone with *Monograptus colonus, M. dubius* and *M. roemeri* as the highest horizon of E_1. This limit agrees in many localities with the petrographic one of Jahn, and I compiled at the same time a list of 230 more common molluscs, brachiopods, and crustaceans, indicating their true horizon, E_1 or E_2, based on the new material collected from the chief exposures zone by zone; this will, I hope, aid in correcting the designations in many collections abroad (see pp. 64-66).

BANDE E_1.

E_1, as now limited, can be divided into three chief subdivisions, which in general correspond to three "zones" recognized by Marr, and for which I propose accordingly (as in use for other Lower Paleozoic rocks of Bohemia) the following designations:

$E_1\alpha$ = *Diplograptus* beds.
$E_1\beta$ = *Priodon* beds.
$E_1\gamma$ = *Dubius* beds.

About thirty years ago Jahn (l. c.) proposed to designate as $E_1\alpha$ the graptolitic shales in which the calcareous concretions are absent, and the upper part of E_1 (shales with concretions and limestone intercalations) as $E_1\beta$. I could not accept this purely lithological division, as it is inaccurate and unreliable. As the far more reliable graptolite fauna demonstrates in many sections, there are shales containing *Monograptus priodon, M. vomerinus, Stomatograptus grandis, Cyrtograptus murchisoni,* and

---

[7] Jahrb. d. geolog. Reichsanstalt, Wien, 42, 3, 1892.
[8] Bohemian Acad. Sci., Jubileum Memoirs, XX, 1915.

Retiolites geinitzianus in some localities without nodules and limestone intercalations; in others, however, they are crowded with them, although they both correspond to Marr's "*priodon* zone." The same thing occurs in some upper zones. The division into three parts is, I am convinced, more appropriate to the three distinct graptolitic faunas existing in E_1 and in general fits to the facts known from other countries.

E_1a—Diplograptus Beds.

E_1a or the *Diplograptus* beds is characterized by the frequent occurrence of many species of *Diplograptus* and other genera of the Diprionidæ, which are all absent in the upper beds. It contains four zones, as follows:

a. Zone of Diplograptus vesiculosus Nich.—Soft, light yellow or brown, lilac-shaded shales, known only from Bělec* and Libomyšl. Aside from *D. vesiculosus* and an undeterminable *Climacograptus,* no other graptolites are known from this zone, demonstrating that in Bohemia, beds of Lower Llandovery age are also represented. In the other localities this zone can not be ascertained, as for instance, in the vicinity of Tmán, where similar shales resting directly on D_5 (Ordovician) have so far yielded no graptolites. At Korno and elsewhere black shales lying on D_5 are metamorphosed by diabase intrusions into hard hornstone-like shales without a trace of graptolites. At several localities this zone is certainly absent (for instance, at Zadni Trebán), because the black shales lying directly on D_5 belong already to the next higher zone (*Rastrites peregrinus*). It seems that the transgression which began after the close of Ordovician time gradually reached different places in the "Silurian basin" of Barrande.

b. Zone of Rastrites peregrinus Barr.—This zone also contains shales but of different petrographical characters, and is developed in the entire area of the Silurian. For example, at Trebán, Motoly, and colony "Haidinger"[9] between Radotin and Kuchelbad, the zone consists chiefly of soft micaceous, somewhat arenaceous, black or gray shales; in the vicinity of Tmán, of yellow or grayish, lilac-

---

* In this and other cases beyond, the accent is from necessity omitted.

[9] The names of Barrande's colonies are used here only as designations of localities.

shaded, non-micaceous, fine shales; in most localities, however, are found hard, gritty, hornstone-like, black shales, especially in the neighborhood of diabases (Karlik, Reporyje).

Faunistically, this zone is the richest one, and it is relatively thick enough to be divided into subzones. Besides *Rastrites peregrinus,* which is everywhere the most common species, the following forms occur: *Diplograptus modestus* Lapw., *D.* (*Glyptograptus*) *sinuatus* Nich., *D.* (*G.*) *bellulus* Törnq., *Climacograptus scalaris* Lin. (auct.), *Cephalograptus folium* His., *C. cometa* Gein., *Retiolites* (*Gladiograptus*) *perlatus* Nich., *Monograptus lobiferus* M'Coy, *M. communis* Lapw., *M. fimbriatus* Nich., *M. leptotheca* Lapw., *M. convolutus* His., *M. triangulatus* Harkn., *M. distans* Portl., and *Corynoides* sp.

None of these species appears in the next higher zone.

c. Zone of Rastrites linnéi Barr.—Very fine-grained, fissile shales, almost without mica, mostly of gray-greenish color; the graptolites in them have a bright silver-like luster; the best locality is at Zelkovice, where occur: *Diplograptus palmeus* Barr., *D. ovatus* Barr., *Monograptus becki* Barr., *M. clingani* Carr. var. *hopkinsoni* Per., *M. halli* Barr., *M. holmi* Per., *M. marri* Per., *M. jaculum* Lapw. var. *variabilis* Per., *M. planus* Barr., *M. proteus* Barr., *M. runcinatus* Lapw., *M. turriculatus* Barr. var. *minor,* and *Rastrites linnéi* Barr.

d. Zone with Monograptus turriculatus Barr.—Similar hard dark shales, in some localities clayish and of dark brown color. Characteristic graptolites are: *Monograptus palmeus* Barr. var. *tenuis* Barr., *M. turriculatus* Barr. (typical large form), *M. jaculum* Lapw., and *Retiolites* (*Plegmatograptus*) *obesus* Lapw. Some graptolites of the preceding zone occur sporadically here also, as *M. proteus, M. runcinatus* and *M. marri.*

$E_1\beta$—*Priodon Beds.*

The commonest fossils in these beds are Monograpti of the group of *M. priodon* Bronn; for the first time appear here the genera *Cyrtograptus* and *Stomatograptus;* totally absent are *Rastrites, Diplograptus,* and *Climacograptus.* In this horizon we find already in the graptolitic shales calcareous concretions (nodules of ellipsoidal shape, 2-15 inches in diameter), often forming almost continuous beds; thin beds of shaly limestone and compact or crystalline limestone often alternating with shales are also a common feature in many localities. Sometimes these calcareous intercalations contain trilobites, brachiopods, various molluscs, etc., and graptolites in them are often preserved "en relief." As already suggested, these intercalations do not occupy a definite horizon; in some sections they are not to be met with until the much higher beds. Some of these limestones are very similar to those from Barrande's Bande E_2, and many fossils which are confined to these E_1 limestones have indeed been erroneously cited as occurring in E_2.

Three zones can be distinguished in $E_1\beta$:

a. Zone with Monograptus spiralis Gein. var. subconicus Törnq.—Dark brown fissile shales, or grayish and dark flagstones; no calcareous nodules present. Characteristic graptolites are: *Monograptus priodon* Brn., *M. vomerinus* Nich., *M. spiralis* Gein. var. *subconicus* Törnq., *M. griestonensis* Lapw., *M. sacculiferus* n. sp.,[10] and *Retiolites geinitzianus* Barr.

b. Zone with Cyrtograptus murchisoni Carr.—Shales of similar lithological character to those in the former zone. First appearance (in the same localities) of calcareous nodules. In the western part of Barrande's "Silurian basin"[11] these shales alternate with dark compact limestones or light crystalline limestone; the latter occurrence seems to be in connection with the nearby coral reef, forming an almost continuous seam between Tachlovice and Tetin, and reaching vertically into higher zones (see section on the coral-reef facies). The shales of this zone yielded: *Monograptus priodon* Brn., *M. vomerinus* Nich., *M. latus* M'Coy, *M. kettneri* n. sp., *M. remotus* Törnq., *Cyrtograptus murchisoni* Carr., *M. purkyněi* n. sp., *M. centrifugus* n. sp., *M. insectus* n. sp., *M. evolvens* n. sp., *Retiolites geinitzianus* Barr., and *Stomatograptus grandis* (Suess). In the limestone and calcareous shales and mudstones at Loděnice I have found, in association

---

[10] In recent years many new graptolites have been found in E_1, descriptions of which are being prepared by my pupil and collaborator, O. Kodym.

[11] R. Kettner has proposed and is using the term "Barrandien" for the area in Bohemia in which are developed the Paleozoic rocks included in Barrande's old and inappropriate term, "bassin Silurien du centre de la Bohême," viz., his Étages A-H (Algonkian to Devonian).

with *M. priodon, M. vomerinus, Cyrtograptus murchisoni,* and *Retiolites geinitzianus,* the trilobites *Arethusina konincki* Barr., *Acidaspis mira* Barr., *A. prévosti* Barr., *A. roemeri* Barr., and *Bronteus planus* Corda, which have been many times quoted as E_2 fossils, although they are confined to E_1. With them are associated a few brachiopods, as *Leptæna transversalis* and *Atrypa sappho,* which are also met with in E_2; and several cephalopods extending into higher zones occur here.

c. Zone with Monograptus riccartonensis Lapw.—Chiefly brown or dark fissile calcareous shales with nodules and intercalations of dark compact limestones. Best localities: Loděnice, Vyskocilka, colony "Krejci," Koněprusy. Here have been found: *M. riccartonensis* Lapw.,[12] *M. vomerinus* Nich., *M. dubius* Suess var. *proæva, M. solitarus* n. sp., *M. validus* Per., and *M. priodon* Brn. Associated are: *Slava bohemica* Barr., *Aptychopsis prima* Barr., and *Arethusina konincki* Barr.

$E_1\gamma$—*Dubius Beds.*

These are characterized by the occurrence of Monograpti of the type of *M. dubius* Suess, and allied forms, such as *M. colonus* Barr., etc.[13] The shales of these beds very often alternate with seams of calcareous nodules and limestones, in which, besides the rarer graptolites, sometimes occur brachiopods, various molluscs, and crinoidal remains. In the northwestern region of Barrande's "Silurian basin" these beds are developed as coral-reef limestones (see section beyond).

Two zones can be distinguished:

a. Zone with Monograptus testis Barrande.—Brown or grayish yellow, argillaceous, slightly calcareous shales without concretions or nodules (Barek), or dark shales with concretions and limestone intercalations (Dvorce,

---

[12] Most of the specimens of this species I formerly considered to belong to *M. flemingi* Salter and allied forms. The admirable monographs of British graptolites by G. E. Elles and E. M. R. Wood (Mrs. Shakespear) in Paleontogr. Soc. London 1901-1913 now enable me to undertake a revision of all the British species formerly recorded in my "Études," and to correct some previous determinations.

[13] The original designation, Marr's "*colonus* zone", I think should be changed to "*dubius* beds" since *M. dubius* occurs in the whole of $E_1\gamma$, while *M. colonus* is absent in the lower part.

Kozel). This zone yielded: *Monograptus testis* Barr., *M. bohemicus* Barr., *M. flemingi* Salt., *M. nilssoni* Barr., *M. dubius* Suess, *Cyrtograptus lundgreni* Tullb., and *Retiolites* (*Gothograptus*) *nassa* Holm. In addition have been found associated: *Ampyx rouaulti* Barr., *Dalmanites orba* Barr., *Proëtus* (*Phætonellus*) *dentatulus* Novák, *Discina unguis* Barr., *D. nana* Barr., *Orthis honorata* Barr., and *Orthotheca fragilis* Nov.

b. Zone with Monograptus colonus Barrande.—Lithological character nearly the same, brown, somewhat argillaceous shales prevailing, concretions frequent; the alternating limestones here more frequent, dark, noncrystalline, compact (in contrast to the majority of the very similar E_2 limestones), sometimes with numerous cephalopods or crinoid fragments. Associated occur here: *Monograptus colonus* Barr., *M. nilssoni* Barr., *M. bohemicus* Barr., *M. roemeri* Barr., *M. gotlandicus* Per., and *M. unguiferus* Per. In the same zone, the concretions and limestones yield, sometimes in association with the graptolites named above: *Cyrtoceras vestitum, Gomphoceras clava, Ophidioceras proximum, Orthoceras epulans, O. socium, O. illudens, O. pleurotomum, O. styloideum, Ascoceras* cf. *murchisoni, Cirropsis* spp., *Cyrtolites eximius, Euryzone tuboides, Orthonychia ampla, O. elegans, Platyceras longipes, Polytropis* (*Poleumita*) *potens, Spirina patula, S. tubicina, Avicula glabra, Slava bohemica, Cromus beaumonti, Cyphaspis,* and *Illænus bouchardi.* The shales of $E_1\gamma$ also sometimes contain *Orthoceras,* some Acephala, and brachiopods, but these are mostly undeterminable.

REEF-FACIES IN BARRANDE'S ÉTAGE E.

The upper E_1 beds in the northwestern Silurian region are developed as coral-reef facies, with coarse crystalline limestones of gray or brown color (never white as in F_2), sometimes indistinctly stratified, or nodular. The lowest part of these limestones must be attributed to E_1 beds, as their base is formed by the zone of *Cyrtograptus murchisoni* ($E_1\beta$). They extend up from $E_1\gamma$ to the highest E_2 beds, and it is most probable that they existed in some localities without a noteworthy interruption until the middle part of Barrande's Bande G_1, which is of Lower Devonian age.

A boundary between E_1 and E_2 can not easily be drawn in these limestones, as their lithological character is the same through the whole thickness of these deposits. Graptolites are almost absent and the fauna bearing a decided coral-reef character is for the greater part unknown from the other "normal" parts of E_1 or E_2. From the rich characteristic coral fauna, which occurs chiefly at Kozel and Tachlovice, may be named: *Halysites catenularia, Favosites asper, F. tachlovicensis, Cyathophyllum prosperum, Cystiphyllum bohemicum*, and *Omphyma grande.* Besides these corals, there frequently occur in these deposits: *Orthoceras caduceum, O. endymion, O. pedum, O. valens, O. currens, Modiolopsis pupa, Spanila cardiopsis, Cardiola persignata, Conocardium dorsatum, Atrypa obolina, A. inelegans, A. reticularis, A. squamma, A. dormitzeri, Rhynchonella niobe, R. nympha*, and *R. princeps.* The greater part of the Mollusca and Brachiopoda mentioned above are apparently confined to these coral limestones.[14]

In the immediate neighborhood of these coral reefs there seems to be a peculiar trilobite fauna, represented by *Bronteus planus, Cheirurus insignis, Sphærexochus mirus, Deiphon forbesi, Lichas*, etc., the true horizon of which belongs to E_1, as I have found them in the mudstones and limestones associated with *Retiolites geinitzianus, Cyrtograptus murchisoni, Monograptus priodon*, and *M. vomerinus.*

BANDE E_2.

As already stated, the boundary between E_1 and E_2 was proposed by me on a paleontological basis, taking the horizon characterized by *Monograptus dubius, M. colonus* and *M. roemeri* as the highest in E_1. As in E_1, there are to be distinguished in E_2 two different developments of deposits or facies: (a) normal, stratified limestones with intercalated shales and mudstones; (b) reef facies, with nodular, indistinctly or irregularly stratified coral limestones, a direct continuation of the reef facies mentioned above in E_1, and not divisible into zones, the faunal character remaining the same.

---

[14] *Atrypa reticularis, Rhynchonella nympha*, and *R. princeps* occur also in the coral limestones of the Devonian stage F_2 and extend to G_1.

In the normal E_2 there are three chief horizons which are recognizable in the entire Silurian area, as follows:

1. Cephalopod horizon.[15]
2. Brachiopod horizon.
3. Crinoid horizon.

Between them can be distinguished several subordinate zones, which in one locality, where the exposure can be described in detail, can be characterized by their fauna; but in another, not far distant, can not be demonstrated. A majority of the E_2 fossils occur in all the E_2 beds; some species, however, very characteristic for one limited locality, are totally unknown in others. A detailed scheme of sequence applicable to the whole horizontal extent of E_2 can not be given at present, but I hope future detailed comparative studies of numerous exposures, like those of Kiaer made in Norway's Silurian, will throw more light on this subject.

Cephalopod Limestones.

These are usually grayish or bluish, compact limestones, in thick beds, that in some localities have intercalations of brown shales and shaly limestones. Abundant species are: *Orthoceras nobile, O. bohemicum, O. janus, O. explanatum, Cyrtoceras murchisoni, C. vernum, Gomphoceras cylindricum,* and *Lituites* (*Ophidioceras*) *simplex.* This horizon is also the chief source of other well known fossils at Dlouhá Hora and Hopanina, among them being *Cromus beaumonti, Calymene baylei, Harpes ungula, Cyphaspis burmeisteri, C. depressa, Cheirurus insignis, Proëtus striatus, Lytospira subuloidea, Murchisonia latona, Loxonema beraunense, Cardiola bohemica, C. interrupta, C. grandis, Dualina excisa,* and *Atrypa sappho.* A characteristic graptolite is the rare *Monograptus transgrediens* Per.

Brachiopod Horizon.

White-gray limestones without shaly intercalations (Dlouhá Hora), or dark, thinly bedded limestones alter-

---

[15] These designations do not mean that, for instance, cephalopods in E_2 are confined to the lowest beds; they are intended only to indicate the sudden and striking appearance of the three groups of animals, so that the sequence named above would mean rather a sequence of different bionomic conditions.

nating with shales (Lochkov). The majority of the limestones are finely crystallized. In certain localities, some of the limestone beds consist almost exclusively of the shells of *Atrypa linguata,* in other horizons this species is rare. Very common are *Pentamerus, Cyrtia, Merista,* and *Rhynchonella.* Graptolites are represented by *Monograptus ultimus* Per., which, however, continues up to the highest E_2 beds. Records of the occurrence of *M. priodon* or *M. colonus* in E_2 are quite erroneous.

Crinoid Horizon.

Dark bituminous limestones in thick and thin beds with numerous crinoid remains (chiefly stem fragments, often even loboliths or *Camarocrinus*), forming locally true crinoid limestones.[16] They are followed by brown or gray, sometimes nodular limestones, alternating with brown shales or shaly limestones, with flat calcareous concretions. In this horizon occurs *Monograptus ultimus* Per., associated with *Cardiola interrupta,* cephalopods, dendroids (*Dictyonema, Callograptus, Desmograptus, Rhodonograptus*), and Gigantostraca. Some of the limestone beds yield gigantic Orthocerata, as *O. neptunicum, O. severum, O. potens, O. pelagicum, O. temperans, O. extenuatum, O. socium,* and *O. rivale.* In general, the E_2 beds with their frequent alternations of limestones with shales and mudstones, and their changing fauna seem to suggest that they are deposits of a shallow sea-basin, not distant from islands or coral reefs, where the bionomic conditions changed rapidly.

Distribution of Fossils in E_1 and E_2.

As already mentioned, many fossils have been described by Barrande and others as occurring in E_2 although they are confined to E_1 or at least are common to both levels; this is true chiefly of Mollusca and Crustacea in the limestones. These errors have been due not only to the uncer-

---

[16] These limestones are often very similar to those in $E_1\gamma$ (zone with *Monograptus colonus*), which also bear in many localities numerous crinoid fragments (stems, loboliths, rarely cups).

tainty in delimitation of E_1, but also to the similar aspect of the limestones occurring both in E_1 and in E_2.[17]

After collecting at the chief localities with due regard to the present boundaries between E_1 and E_2, and comparing with Barrande's material, I was able to compile the following list of the more important fossils found in E_1 and E_2, indicating their true range. Graptolites which have been treated more in detail in describing the E_1 zones are omitted here, but special attention is given to other fossils which have not been known at all from E_1 or not with certainty, and which occur in the limestones. The fauna of E_1, as it is now delimited, therefore appears much richer than has hitherto been supposed.

CEPHALOPODA: *Cyrtoceras abstinens* (E_1)[18], *formidandum* (1-2), *lepidum* (1-2), *nigrum* (1-2), *phillipsi* (1), *plutos* (1-2), *potens* (1), *serratum* (1), *superbum* (1-2), *vestitum* (1), *victor* (1); *Gomphoceras agassizi* (1-2), *amygdala* (1-2), *atrophum* (1-2), *billingsi* (1-2), *bohemicum* (1-2), *clava* (1-2), *contrarium* (1-2), *halli* (1-2), *imperiale* (1-2), *mumia* (1-2), *nuciforme* (1-2), *ovum* (1-2), *rigidum* (1-2), *sphærosoma* (1-2), *vespa* (1-2); *Ophidioceras amissus* (1), *proximus* (1), *rudens* (1-2), *tener* (1-2); *Orthoceras æquabile* (1), *annulatum* Sow. (1-2), *bohemicum* (1-2), *compulsum* (1-2), *currens* (1-2), *decurtatum* (1-2), *docens* (1-2), *duponti* (1-2), *egregium* (1-2), *endymion* (1-2), *epulans* (1), *extensum* (1), *germanum* (1-2), *illudens* (1), *inchoatum* (1-2), *innotatum* (1-2), *jucundum* (1-2), *magister* (1-2), *minus* (1-2), *murchisoni* (1-2), *particeps* (1-2), *pectinatum* (1), *poculum* (1-2), *pseudocalamiteum* (1-2), *simois* (1), *socium* (1-2), *steiningeri* (1-2), *tenuicinctum* (1), *transiens* (1-2), *trecentesimum* (1); *Phragmoceras callistoma* (1-2), *imbricatum* (1), *panderi* (1), *perversum* (1); *Trochoceras amicum* (1), *nodosum* (1-2), *placidum* (1-2), *pulchrum* (1-2?).

GASTROPODA: *Cirropsis bohemica* Per. (1-2), *C. disjuncta* Per. (1-2), *C. præstans* Per. (1-2), *Conotoma eximia* (1), *Conradella inopinata* (1), *Cyrtolites eremita* (1), *C. eximius* (1), *C. tuboides* (1), *Dyeria carens* (1), *Epiptychia dusli* Per. (1), *Euryzone tuboides* Per. (1), *Holopea irregularis* (1), *Naticopsis*

---

[17] In the latter period of his paleontological activity, Barrande used to refer the majority of the Silurian fossils imbedded in limestone to E_2, although his collectors, workers in quarries, who brought the fossils to Prague, were getting them chiefly from E_1 limestones, which on the old weathered exposures yielded the fine, entire specimens with well preserved sculpture, such as are now seen in the Bohemian Museum. Many such rich localities have disappeared or become nearly inaccessible; others yield from the fresh exposures chiefly fragments, hardly determinable, so that it is now a difficult task to ascertain the true horizon of all Barrande's species.

[18] The author is Barrande, unless otherwise stated. To save further space, E_1 and E_2 are hereafter written simply 1 and 2.

insculpta(1), *Orthonychia ampla*(1-2), *O. cuneus*(1), *O. elegans* (1-2), *O. nobilis*(1-2), *O. togata*(1), *Platyceras æsopus*(1-2), *P. complanatum*(1-2), *P. concors*(1-2), *P. conviva*(1-2), *P. exsurgens*(1-2), *P. formosum*(1-2), *P. forte*(1-2), *P. inchoans*(1-2), *P. longipes*(1), *P. œdematosum*(1-2), *P. sanum*(1-2), *P. subcarinatum*(1), *P. vexatum*(1-2), *Polytropis dives*(1), *P. potens*(1), *P. pulchra*(1), *P. robusta*(1), *P. ventricosa*(1), *Spirina patula*(1-2), *S. tubicina*(1-2).

ACEPHALA: *Astarte minuscula*(1), *Aviculopecten cybele*(1), *Avicula glabra*(1), *A. manulia*(1), *Cardiola expectans*(1-2?), *C. fortis*(1-2), *C. gibbosa*(1-2), *C. intermittens*(1-2), *C. interrupta*(1-2), *C. migrans*(1-2), *C. petasina*(1-2), *C. pulchella* (1), *C. radiata*(1-2), *Dualina bella*(1-2), *D. branikensis*(1), *D. extracta*(1-2), *D. fidelis*(1-2), *D. humilis*(1-2), *D. incongruens*(1-2), *D. nympharum*(1-2), *D. secunda*(1-2), *Goniophora phrygia*(1-2), *Grammysia præcox*(1-2), *Maminka comata*(1-2), *M. tenax*(1-2), *Mila consanguis*(1-2), *M. insolita* (1-2), *Modiolopsis involuta*(1-2), *M. pupa*(1), *M. rebellis* (1-2), *Panenka capitata*(1-2), *P. gyrans*(1-2), *P. insocialis*(1-2), *P. vendita*(1), *Paracardium complicatum*(1-2), *P. delicatum* (1-2), *P. filiferum*(1-2), *P. incipiens*(1-2), *P. mundum*(1-2), *P. rarissimum*(1), *Posidonomya eugyra*(1-2), *Præcardium adolescens*(1-2), *P. bohemicum*(1-2), *P. complacens*(1), *P. fidens*(1-2), *P. ministrans*(1), *P. primulum*(1-2), *P. quadrans* (1-2), *Slava aberrans*(1), *S. bohemica*(1-2).

BRACHIOPODA: *Atrypa insolita*(1-2), *A. sappho*(1-2), *A. squamma*(1-2), *A. thetis*(1-2), *Crania*(?) *bohemica*(1), *Discina nana*(1), *D. propinqua*(1-2), *D. unguis*(1), *D. truncata*(1-2), *D. vexata*(1-2?), *Eichwaldia bohemica*(1), *Lingula albicans* (1-2), *L. comes*(1-2), *L. dilatata*(1), *L. nigricans*(1-2), *Orthis cognata*(1), *O. honorata*(1), *O. venustula*(1), *Pentamerus perditus*(1), *Rhynchonella niobe*(1-2), *Strophomena bracteola*(1-2).

TRILOBITA: *Acidaspis dufrénoi*(1-2?), *A. mira*(1), *A. prévosti*(1), *A. rara*(1), *A. roemeri*(1), *Ampyx rouaulti*(1), *Arethusina konincki*(1), *Bronteus partschi*(1-2), *B. planus* Cda.(1), *Cheirurus insignis* Beyr.(1-2), *Cromus beaumonti*(1-2), *Cyphaspis burmeisteri*(1-2), *C. depressa*(1-2?), *Dalmanites orba*(1), *Deiphon forbesi*(1-2?), *Harpes naumanni*(1-2?), *Illænus bouchardi*(1-2), *Lichas scabra* Beyr.(1-2), *L. palmata*(1-2), *Phacops glockeri*(1-2), *Proëtus decorus*(1-2?), *P. dentatulus* Nov. (1), *P. nasutus* Nov.(1), *Staurocephalus murchisoni*(1-2).

CRUSTACEA DIVERSA: *Aptychopsis prima*(1-2), *Ceratiocaris beraunensis*(1-2), *C. bohemica*(1-2), *C. decipiens*(1), *C. grata* (1), *C. inæqualis*(1-2), *C. leptoglypha* N. (1), *Cryptocaris pulchra*(1), *Discinocaris dusliana* N.(1), *Eurypterus acrocephalus* S.(1), *Holocaris univalvis* N.(1), *Plumulites minimus*(1), *P. squamatula*(1), *Pterygotus beraunensis* S.(1-2), *P. barrandei* N. (1), *P. cyrtochela*(1), *P. hellichi* N. (1).

DIVERSA: *Scyphocrinus decoratus* W. & J.(1), *S. excavatus* (Schl.)(1), *S. subornatus*(1), *Bohemicocrinus pulverens*(1-2), *Aulopora disjecta* Poč.(1), *Desmograptus plexus* Poč.(1-2?), *D. giganteus* Jahn(1), *Dictyonema bohemicum*(1-2), *D. confertum* Poč.(1-2?), *D. grande*(1-2?), *D. graptolithorum* Poč.(1), *Inocaulis attrita* Poč.(1).

BANDE F_1.

The highest member of the Silurian series in Bohemia is the dark limestones which have been referred by Barrande to his Etage F and designated as F_1. Their lithologic and faunistic characters place them much nearer to the E_2 beds than to the F_2 limestones, which are undoubtedly of Lower Devonian age.[19] In addition, a faunistic hiatus between F_1 and F_2, signifying the boundary line between the Silurian and Devonian in Bohemia, together with the decidedly Silurian aspect of the F_1 fauna, points out the closer connection of F_1 with E_2.

The boundary line between E_2 and F_1 is marked by the occurrence of hornstones in the limestone, and by a change of fauna. As in E_1 and E_2, there are two facies developed in F_1. The reef facies, which in F_1 has a far greater extension, is formed of limestones with very subordinate shales. The limestones in the lower part of F_1 are dark, nearly black, fine-grained or compact, thickly bedded, and contain dark hornstones of irregular shape; shaly reddish intercalations occur only in the lowest beds. In the upper part the limestones are lighter, gray or whitish, thinly bedded, finely or coarsely grained, resembling the white limestones of F_2, but contain yellowish or reddish hornstones. Opposite Tetin this facies is fossiliferous, bearing almost the same coral fauna as in E_2.

The other, ''normal'' facies is more shaly, and is limited chiefly to a seam between Prague and Kosor (valley of Radotin). Characteristic are dark fine-grained limestones, splitting into flat plates and alternating many times with dark or brown shales; hornstones are rare or completely missing.

As for the fauna, it is quite different from the contemporaneous coral fauna, and differs also from the ''nor-

---

[19] It would perhaps be more appropriate to call the F_1 beds E_3, so that the Silurian of Bohemia would correspond to Barrande's Étage E, and the letters F, G and H could be reserved for the Devonian. Some Bohemian geologists have already accepted this proposition.

mal" E_2 fauna; a considerable part is, however, common to E_2 and F_1. It is characterized by numerous species of *Hercynella,* which are regarded by some paleontologists as pelagic Pulmonata.[20] Moreover, cephalopods (40 species, badly preserved, enumerated by Barrande and Novák), large lamellibranchs (*Panenka, Prælucina, Modiolopsis, Dalila, Cypricardinia, Hemicardium, Avicula*), gastropods (*Strophostylus, Rotellomphalus, Stylonema*), *Conularia,* and *Tentaculites,* are other prominent groups; a noteworthy feature is the thin shell of the molluscs mentioned. Graptolites are represented by two last species, *Monograptus hercynicus* and *M. kayseri* Per.

Concerning the more detailed division of these F_1 beds, I must content myself with giving a brief recapitulation of results published elsewhere,[21] and adding some further remarks. In the "normal" F_1 can be distinguished three horizons, which are not sharply delimited, as follows:

1. The lowest consists of dark or black thick limestones, alternating with thick beds of shales; it contains rare fish remains (*Machæracanthus,* and some new genera resembling *Ateleaspis, Aspidichthys, Cyathaspis, Dinichthys, Macropetalichthys,* and *Mylostoma*). Other fossils are also rare.
2. Fine-grained limestones, thinly bedded, alternating with shales. The greater part of the F_1 fossils occur here. Characteristic ones are: *Hercynella nobilis, H. radians, H. bohemica, H. paraturgescens, Rotellomphalus tardus, Strophostylus gregarius* var. *proëva, Stylonema solvens, Dalila obtusa, D. resecta, Lunulicardium analogum, L. evolvens, Panenka amœna, P. grata, Ceratiocaris, Aristozoe, Pygocaris,* and Gigantostraca.
3. Shaly limestones and shales (black, brown or gray), with *Monograptus hercynicus* and *M. kayseri. Spirifer inchoans* is very abundant, and the following species are common: *S. nerei, Atrypa canaliculata, Pentamerus janus, P. linguifer, Cyrtia trapezoidalis, Avicula migrans, A. pusilla,* and *Conocardium aptychoides.* In the upper part of this horizon also appear trilobites. Common among them and very characteristic (confined to F_1) is

---

[20] These are wanting in the reef limestone of F_2 (Koněprusy) and reappear in the shaly limestones of G_1.

[21] Centralblatt f. Min. u. Geol., 19-20, 318-322, 1918.

Bronteus umbellifer; others are rare and mostly fragmentary. Their geological distribution in other Silurian and Devonian beds of Bohemia is very interesting and important, as may be seen from the following table:

	E_2	F_1	F_2	G_1	G_2
Acidaspis vesiculosa Beyr.		x	x		
Bronteus umbellifer Beyr.		x			
Crotalocephalus gibbus (Beyr.)		x	x	x	
Crotalocephalus sternbergi (Boeck)		x	x	x	x
Cyphaspis hydrocephala A. Roem.		x	x	x	
Harpes microporus Novák		x			
Harpes venulosus Corda		x	x		
Phacops miser Barr.		x			
Proëtus heteroclytus Barr.		x			
Proëtus lepidus Barr.		x			
Proëtus micropygus Corda	x	x			

We see that besides five species confined to F_1, there are five which pass into the Lower Devonian (F_2); they are very rare in F_1, but common in the reef limestone of F_2 (Koněprusy). It may be that the uppermost trilobite-bearing beds of this horizon belong already to the Lower Devonian. This possibility is also indicated by other circumstances, such as the absence of the reef limestones of F_2 above the true F_1 beds, which are in turn succeeded directly in many places by the upper division of F_2 beds. It would thus seem that these uppermost trilobite-bearing F_1 beds are merely "normal" shaly deposits, contemporaneous with the Lower Devonian white reef limestones of F_2, a theory which might also explain the other great differences between upper F_1 and F_2.[22]

---

[22] Without dwelling longer on the Hercynian question in Bohemia, I will restrict myself here to the following remarks: (1) O. Novák (Sitz. d. kgl. böhm. Ges. d. Wissensch., 1886) endeavored to prove that all of F_1 is equivalent to F_2 and therefore of Devonian age, a view which can no longer be sustained; (2) the F_1 fauna exhibits a Silurian aspect (many species common to E_2, frequent graptolites, absence of goniatites, see the faunal list given by Novák and additions to it by Želizko (Verh. geol. Reichsanst., Wien., 9-10, 1898)); (3) the different opinions on F_1 and F_2 contained in the papers of Kayser, Holzapfel, Katzer, Frech, Seeman, etc., are to be corrected in accordance with the researches of Kodym (Bohem. Acad. Sci., 1918), which prove that $F_2\alpha$ (white reef limestone of Končprusy) is a distinct lower horizon, succeeded by $F_2\beta$ (red marbles of Slivenec), the latter being identical with Kayser's and Holzapfel's "Měnaner-Facies" of F_2 (crinoidal limestones).

The surprising results of Barrois and Pruvost on the passage beds and boundary between Silurian and Devonian in the Calais coal basin, accepted by Stamp for Shropshire and southern Wales, became known to me too late to be taken into consideration in discussing and correlating the F_1 beds in the present paper.

CORRELATION OF BOHEMIAN STRATA.

A detailed and definite parallelization of Silurian strata in Bohemia with those in foreign countries can not yet be made, therefore only a scheme of approximate correlation is inserted here, based chiefly on the geological distribution of graptolitic and other faunas and on the zones connected therewith. Further investigations in Barrande's area will surely reveal many important details and solve questions either merely mentioned or omitted in the present communication; moreover, future progress in zonal division and correlation in other countries will also modify the scheme here given. Because of limited space, two or three smaller districts of the chief countries are combined in single columns. The greatest changes will probably take place when future investigations are made with due regard to the principles, facts, and views discussed in Ulrich's "Revision of the Paleozoic systems."[23]

To the scheme above, in which only the "normal" shaly facies and not the aberrant reef deposits are concerned, a few remarks can now be added. There is in the main divisions and succession of faunas in Bohemia a general harmony with those of other countries; in particular, $E_1\alpha$, $E_1\beta$, and $E_1\gamma$ correspond well enough with the *Rastrites-*, *Cyrtograptus-*, and *colonus*-shales in Sweden. But in the subordinate zones, there are considerable differences in their vertical limits, a feature not surprising when we consider the great geographic separation of the Bohemian basin and the varied development of its deposits (see for instance, the relative frequency of graptolites in limestones in association with various molluscs and brachiopods). The higher the zones, the greater the differences; this seems to be partly due to the fact, observed in graptolitic faunas in Great Britain by Miss E. M. R. Wood, that graptolites of the highest Silurian zones show an extended vertical range and limited geographic distribution. There seem to be considerable differences in the association of some graptolites in the higher Bohemian zones, as compared with those of Wen-

---

[23] Bull. Geol. Soc. America, 22, 1911. I confess freely that Ulrich's work made so strong an impression upon me that I hesitated to publish the present communication and was about to review all my former studies from the standpoints of that work. This would, however, cause another considerable delay, so that I preferred to print the present article (cf. footnote 6), the purpose of which is to offer at once a general orientation to foreign students.

Correlation Table of

		Bohemia		England and Scotland		
				(Lapworth)	(Elles, Wood, Lake)	
Silurian	f_1	Monograptus hercynicus			Downtonian ?Temeshill ?	
	e_2	Crinoid zone	M. ultimus		Upper Ludlow	
				M. nilsoni	Lower Ludlow	M. leintwardinensis
		Brachiopod zone				M. tumescens
		Cephalopod zone	M. transgrediens			M. scanicus
						M. nilsoni
	$e_{1\gamma}$	Monograptus colonus				M. vulgaris
		Monograptus testis		M. testis	Wenlock	C. lundgreni
	$e_{1\beta}$	Monograptus riccartonensis		C. linnarsoni		C. rigidus C. linnarsoni C. symmetricus M. riccartonensis
		Cyrtograptus murchisoni		C. murchisoni ?		C. murchisoni
		Monograptus spiralis subconicus		C. grayae ?	Bala-Tarannon	
	$e_{1\alpha}$	Monograptus turriculatus		M. exiguus		
		Rastrites linnei		R. maximus	Up. Llandovery	
		Rastrites peregrinus		M. spinigerus M. gregarius		
		Diplograptus vesiculosus		D. vesiculosus	Low. Llandovery	
		Hiatus		D. acuminatus		
Ordovician	d_5	Dicellograptus anceps		D. anceps	Up. Bala-Caradoc (Onny, Trinucleus sh.) Up. Hartfell	

EUROPEAN SILURIAN

Sweden, Skåne, Gotland			Norway (Kiaer)	France (Bergeron, Barrois, Kerforne)	Esthland (Schmidt)
Colonus and Cardiola shales	?	?	Ludlow = Etage 9	Sh. and qu. of Plougastel	K
		Ascoceras beds Megalomus and Trimerella		(Possid. eugyra 9(Ling. lewisii (Goniop. reluctans	
		Ilionia Spongiostroma Sphaerocodium		(M. clavulus 8(Card. interrupta (Slava bohemica	
		Oolite Sphaerocodium		(M. salweyi 7(Bolbozoe bohemica (B. anomala	
	M. gothlandicus M. dubius	?		6(M. colonus, M. nilsoni, Hy. simplex	J
Cyrtograptus shales	C. carruthersi M. testis		Wenlock = Etage 8	5(M. dubius, M. priodon, C. rigidus	H
	C. rigidus M. riccartonensis	M. riccartonensis		4(M. riccartonensis	
	C. murchisoni	C. murchisoni C. grayae		3(M. jaekeli (Ret. geinitzianus ?	
	M. spiralis	M. spiralis			
Rastrites shales	M. exiguus M. turriculatus	M. runcinatus	Up. Llandovery = Etage 7	(M. exiguus 2(M. densus (D. palmeus	G$_3$
	M. sedgwicki	R. maximus			
	Ceph. cometa Ceph. folium M. triangulatus M. revolutus	C. cometa M. leptotheca M. gregarius M. cyphus	L. Llandovery = Etage 6	(M. lobiferus 1(R. peregrinus (Clim. scalaris	
	D. vesiculosus D. acuminatus	D. acuminatus		?	
Brachiopod shales and D. anceps beds			Etage 5	Upper Ordovician (Orthis actoniae, Trin. pongerardi)	

lock or Lower Ludlow age in Great Britain, or in corresponding strata in different Scandinavian districts; but as the limits of higher zones in all countries are not as sharp as those of the lower ones, and hence the range of many of the youngest graptolites is not everywhere coincident, it would exceed the scope of the present communication to dwell longer on the particulars. Interesting data along this line may be found in papers by J. Marr,[24] Lake,[25] E. M. R. Wood,[26] and G. Elles,[27] as regards the British Silurian, and in the papers of Tullberg (l. c.), Munthe, Warburg, Hedström, Wiman, Moberg,[28] and Kiaer[29] for Scandinavian districts.

In spite of this, however, the graptolites are, generally speaking, more reliable zonal guides than other groups in these beds. Thus, for instance, the world-wide *Cardiola interrupta* appears already in $E_1\beta$ and survives until the highest E_2 beds, while in other countries it is recorded up to much higher beds than those of $E_1\beta$, and has a more limited range. Further discussion on the correlation of Bohemian beds will be deferred until more facts shall have been gathered by new investigations.

Prague, Czekoslovakia, July, 1921.

---

[24] Geol. Mag, 534, 1892.

[25] Quart. Jour. Geol. Soc., London, 51, 22, 1895.

[26] Ibid., 56, 415, 1900.

[27] Ibid., 56, 370, 1900.

[28] For the five preceding authors see Guides for Excursions, XIth Internat. Geol. Cong., Stockholm, 19-22, 40, 1910.

[29] Videnskabs-selsk. skrifter, 2, *Kristiania,* 1908.

SCIENTIFIC INTELLIGENCE

I Chemistry and Physics.

1. *A New Process for the Industrial Production of Barium Hydroxide for the Treatment of Molasses in Sugar Refining.*—Since the discovery of the sparingly soluble barium sucrate by Péligot in 1838 many attempts have been made to extract the cane sugar from molasses by the precipitation of this compound, but up to the present time the cost of converting the barium carbonate produced in the process into the hydroxide has been too great to render the operation remunerative, although it is stated that in the French beet-sugar industry about 15% of the sugar fails to crystallize directly. Deguide and Bode have now found a promising method for carrying out this process. They ignite the barium carbonate with an addition of silica in the proper proportion to yield $3BaO.SiO_2$. This mixture does not fuse at the temperature of about 1300° C. necessary for the transformation, and when the product is treated with water a very large proportion of the barium goes into solution as barium hydroxide. The process has been tried on a rather large scale, but has not yet been put into commercial operation. The authors state that the mother-liquors from the filter-presses containing barium sucrate allow the recovery of nitrogen and potassium taken from the soil, representing 1% and 6%, respectively, of the molasses employed. *Comptes Rendus,* **174**, 1177. H. L. W.

2. *An Advanced Course of Instruction in Chemical Principles;* by Arthur A. Noyes and Miles S. Sherrill. 8vo, pp. 310. New York, 1922 (The Macmillan Company).—This is a very notable and unusual textbook of advanced physical chemistry. Instead of presenting the subject in the usual descriptive manner, the course is so planned as to give an intensive training in the application of the principles of the science to concrete problems. The text is interspersed with numerous problems, which generally require clear, logical thinking and a thorough understanding of the principles for their solution. These problems are the important feature in the course of instruction.

The subjects treated in the course have been selected on account of their fundamental and practical importance to chemists. For certain reasons, chiefly to avoid making the course of study too long, some topics such as radiation, atomic structure, colloidal solutions, etc., have not been included. The course of study laid out is evidently not an easy one for the student, but it should be of much value in developing his reasoning-power as well as in equipping him for a career in educational, research, or industrial chemistry in which the principles of physical chemistry may be applied. It is the opinion of the authors that 120-

150 exercises are required for covering satisfactorily the whole course as presented, but a provision is made for employing the book for a shorter course by the omission of certain designated articles and problems that are less important or more difficult than the others. H. L. W.

3. *The Determination of Sulphur in Iron and Steel;* by H. B. Pulsifer. 8vo, pp. 160. Easton, Pa., 1922 (The Chemical Publishing Company).—The determination discussed in this book is an exceedingly important one, since sulphur has a deleterious effect upon the metals even in small amounts, and small variations in the amounts present may have important effects upon quality. As the total amount of sulphur present, except in certain crude pig-irons, is usually less than 0.100%, and often below 0.010%, the analytical problem is a delicate and difficult one. A vast amount of research has been devoted to methods of making this determination, and an excellent feature of the book under consideration is an extensive and evidently very complete bibliography of the subject, with many interesting comments and citations of results. The bibliography covers practically the whole period of modern chemistry, as it begins with the year 1797. It takes up about two-thirds of the book, and it is not only interesting historically, but it should be of great value to future workers on this problem.

The author has made and records here a very large number of sulphur determinations by several methods, and he recommends the use of an ''evolution'' method, where the sulphur is first converted into hydrogen sulphide by the action of concentrated hydrochloric acid upon the metal in an apparatus of his own modification, then the hydrogen sulphide is absorbed in an ammoniacal solution of cadmium chloride, and after acidifying the latter the sulphur is determined by titration with iodine solution. It does not appear to the reviewer that the author has definitely shown that his preferred method is the most reliable one, and it must be admitted that his results by different methods show unexpectedly wide variations. H. L. W.

4. *Organic Chemistry;* by Victor von Richter. *Vol. II. Chemistry of the Carbocyclic Compounds.* Translated from the 11th German edition by E. E. Fournier D'Albe. 8vo, pp. 760. Philadelphia, 1922 (P. Blakiston's Son & Co.).—This translation appears ten years later than the corresponding German edition, but it is to be heartily welcomed as a work of much importance to English-reading students of organic chemistry. For many years the various editions of Richter's Organic Chemistry have been very valuable sources of study and reference to advanced students in the subject, as they have given excellent presentations of the theories, as well as descriptions of very large numbers of compounds. Our older chemists will remember that

the earlier English translations of the work were made in a very satisfactory way by Dr. Edgar F. Smith of the University of Pennsylvania.

At present the work appears in two volumes, the first of which deals with the aliphatic compounds. The recent German editions have been prepared under the direction of Dr. Richard Anschütz of Bonn. H. L. W.

5. *Friction and Lubrication.*—In discussing lubrication two cases are to be distinguished: (1) When two surfaces are floated apart by a lubricant, static friction is absent and the resistance to motion varies directly as the viscosity of the lubricant. (2) Where two solid surfaces are near enough together so that the friction depends not only upon the lubricant but also upon the chemical nature of the surfaces, the resistance varies as some inverse function of the viscosity of the lubricant. This second case is termed boundary lubrication. It has recently been studied by HARDY and DOUBLEDAY using polished surfaces of steel, glass, and bismuth lubricated with liquids of the paraffine series. To assure definiteness of contact area, one of the surfaces was made of spherical form, and the other a plane. The coefficients of friction were first determined for the "clean" state where all possibly removable impurities had been abstracted. This is to be judged from the fact that the friction has a high and constant value.

The variables studied were (a) the weight of the slider, (b) the curvature, (c) the thickness of the layer of the lubricant, (d) the chemical nature of the lubricant and the solids respectively. The authors find that the friction is strictly proportional to the weight or that the coefficient of friction is (a) independent of the weight and (b) of the curvature. In studying (c) three methods of lubrication were adopted: (1) the flooded state, where the slider stood in a pool of the fluid; (2) the primary film. When a drop of lubricant with sensible vapor pressure is placed on a clean plate, although the drop to all appearance remains where placed without change, an invisible film nevertheless spreads so as to cover the whole plate as is evidenced by the fall in friction; (3) lubrication by deposit from the saturated vapor alone.

The results showed that the friction was independent of the quantity of lubricant present provided there was enough to cover the surfaces with the invisible primary film. Where the amount was less than this critical value the fall of friction was proportional to the concentration of the molecules in the gaseous phase, indicating that each molecule exerts the same influence as every other. The influence of chemical constitution (d) was found to be unexpectedly simple. If μ denote the coefficient of friction and M the molecular weight, their relation is given by

$$\mu = b - a\,\mathrm{M}$$

where a and b are parameters. The parameter a is independent of the nature of the solid faces and depends only on the chemical type of the lubricant, varying from one chemical series to another. The parameter *b* however depends both upon the chemical series and the nature of the solid face. The interpretation of these results is difficult. The authors do not accept the current view that friction is due to interlocking asperities of molar dimensions but rather depends upon molecular attraction across an interface. If asperities are to be considered they must be the atoms and the molecules of the substances. The effect of a tangential force is not merely to move the atoms and molecules in the tangential plane but also to rotate them.

The mental picture which the authors offer is that the primary film of lubricant consists of a single layer of molecules which have been oriented by the attractive fields of the solids so that their long axes are perpendicular to the solid faces. When two such surfaces are brought together the friction represents the maximum tangential stress which can be supported at some median plane of slip which is an imaginary surface parallel to the surface of the solid. This resistance is obviously conditioned by the attractive field of the solids which must vary rapidly along the normal, and also by the nature of the molecular chain of the lubricant used.—*Proc. Roy. Soc.* **100**, 550, 1922. F. E. B.

6. *Power Alcohol;* by G. W. MONIER-WILLIAMS. Pp. xii, 323. London, 1922 (Henry Frowde and Hodder & Stoughton).—In view of the possible insufficiency of the world's petroleum reserves the investigation of alternative motor fuels is an important subject which is very fully examined in this book. The first chapter passes in review the questions of the supply, the production and the economy of the various motor fuels, and reaches the conclusion that there is strong probability that before many years the supply of gasolene will be permanently unequal to the demand, and that power alcohol has an undoubted future before it as a supplementary if not as a competitive fuel. Chapter 2 discusses the way in which various organic constituents of plants are elaborated, and the chemical processes by which sugars are converted into alcohol by the yeasts. Chapter 3 treats of the raw materials from which fermentation alcohol is produced, namely, plants supplying starch, plants containing ready formed sugars, and cellulose, and also of the commercial processes of mashing, saccharification, fermentation and distillation. Chapter 4 surveys the more important starch or sugar-bearing raw materials from the point of view of yield, availability and related economy of alcohol production. Chapter 5 is devoted to the commercial treatment of cellulose materials for the production of alcohol. Chapter 6 explains the ways of making synthetic alcohol and its production on a commercial scale.

Chapter 7 reviews the methods of denaturation and various matters in connection with excise supervision in Great Britain. Chapter 8 discusses the principles of the internal combustion engine and its efficiency. In Chapter 9 the chemical and physical properties of alcohol are presented in full detail both by tables and by diagrams. Chapter 10 summarizes with considerable detail the results of alcohol-engine tests with regard to performance and efficiency. These compare very favorably with gasolene-engine tests except in the matter of fuel consumption. Apparently the price of alcohol will have to fall considerably below that of gasolene before it can be regarded as a commercial competitor.

Another and more promising line of attack on the motor fuel problem is in the direction of mixtures of alcohol with other easily volatile substances such as ether or benzol, or even with gases such as acetylene.

The final chapter (11) discusses various proposals of this nature but the subject is too extensive to receive adequate treatment in a book of this character. Appended to each chapter will be found a useful and numerous list of references to the particular topics which have been under discussion. F. E. B.

7. *The Journal of Scientific Instruments.*—The *Institute of Physics* (England) in connection with the *National Physical Laboratory* proposes to publish a journal devoted to the theory, construction and use of instruments as an aid to research in all branches of science and industry. The preliminary number appeared in May. To assure its continued existence a subscription list of about 3,000 is desired. F. E. B.

8. *La Théorie Einsteinienne de la Gravitation;* by GUSTAVE MIE, translated from the German by J. ROSSIGNOL. Pp. xi, 118. Paris, 1922 (J. Hermann).—This little volume contains a clear and readable exposition of the relativity theory and Einstein's theory of gravitation couched in simple language and free from mathematical symbols. It should appeal to the reader who has a knowledge of the principles and laws underlying the subject of physics, but who is not conversant with the somewhat complicated differential geometry involved in a detailed presentation of the general relativity. The author's emphasis on the philosophical aspects of the subject should make the book particularly interesting to those philosophers who are looking for a clear and simple account of the revolutionary changes in our concepts of space and time which the relativity principle has occasioned.

A short mathematical appendix (11 pages) added by the translator presents in condensed form the author's derivation of Einstein's law of gravitation. L. P.

II. GEOLOGY AND MINERALOGY.

1. *Gravity Anomalies and their Geological Interpretation**.—This article is in part a condensation of a more detailed paper by the same author entitled "Die mediterranen Kettengebirge in ihrer Beziehung zum Gleichgewichtszustande der Erdrinde." (Abh. Sächs. Akad. d. Wiss., Bd. **38,** 2. Leipzig, 1020.) The article opens with some general explanations of the formulas for theoretical gravity and of the methods for reducing gravity observations for topography. This opening section contains two or three statements not strictly correct, but these concern matters not generally understood except by specialists in gravity work or in the theory of the figure of the Earth, and do not essentially affect the conclusions reached.

The Bouguer anomaly is used throughout the article as a measure of the compensation. A single Bouguer anomaly measures, of course, merely the net effect of the compensation and of the distant topography and affords no clue to the mass of the compensation nor to its situation. Thus no allowance is made by this method for the effect of nearness to the continental shelf, but for nearly all of Europe this effect is practically negligible. The advantages of using Bouguer anomalies are the ease with which they are computed and the fact that they imply no particular depth or distribution of compensation, and that, when gravity stations are sufficiently dense, they lend themselves, according to Prof. Kossmat, to geological interpretation better than the anomalies computed by the isostatic method.

The article summarizes the results of Prof. Kossmat's examination of known gravity anomalies in Europe, Asia, Africa and North America. For the last-named the war has evidently prevented him from receiving the more recent publications on the subject. He maintains that mountain chains are not caused by a swelling of the crust in their vicinity but by the folding under tangential pressure of certain weaker portions of the crust. Such a chain is not compensated by itself but only in connection with the neighboring piedmont regions. The additional matter imposed upon a given area by the folding may be partly compensated by the sinking of that area under the additional load. This sinking the author conceives as partly elastic rather than entirely flotational, the substratum being bent under the load. The result is that the compensation is regional rather than local. In regard to the evidence on this subject offered by the 124 stations in the United States, the number treated in U. S. Coast and Geodetic Survey Special Publication No. 12, which evidently

---

* Die Beziehungen zwischen Schweranomalien und Bau der Erdrinde, by Franz Kossmat. Geologische Rundschau, vol. **12,** pp. 165-189. 1921.

was the latest publication available to him, Prof. Kossmat is noncommittal. In accepting the existence of large tangential forces he does not accept Wegener's ideas as to the crustal movements produced by them. At the close of the article there is a useful bibliography.

Geologists have been rather slow to utilize the evidence available from gravity observations in regard to the distribution of density in the Earth's crust, evidence which began accumulating when Bouguer from 1736 to 1740 made pendulum observations in what is now Ecuador. One reason for the neglect of this accumulating geodetic evidence has doubtless been the difficulty of finding an unequivocal interpretation, but as gravity stations and stations where the deflection of the plumb line is known become more numerous and more densely distributed over a given area, the practical range of our interpretations of this evidence in terms of density, if not the range of purely speculative mathematical possibilities, becomes more and more restricted and the evidence of more real service to the geologist. Articles like the present are a welcome sign that geologists are beginning to realize that geodesy has evidence of value to them and that compensation for every topographic feature exists in some degree and must be explained by the adopted hypotheses of dynamic geology. Both geologists and geodesists will find the article profitable reading even though they may not accept all of the author's conclusions. W. D. LAMBERT.

2. *Publications of the United States Geological Survey,* GEORGE OTIS SMITH, Director.—Recent publications of the U. S. Geological Survey are noted below: (See earlier, **3**, 97-98, Jan., 1922.)

ANNUAL REPORT:—Forty-second Report of the Director for the year ending June 30, 1921. Pp. 108, 1 plate.—This publication gives in detail the work carried through by the Survey during the year noted. The Director dwells in particular upon the economy attained through a higher degree of efficiency. The end sought for is one greatly to be desired in all departments of the Government, but, unfortunately not often attained. In the case of the Survey the efficiency striven for is much limited by conditions which have already existed too long. These include inadequate office quarters, restriction in the selection of personnel, small salaries and reduced appropriations for printing. The total funds available for 1920-21 were $405,575. The authorized expenditures were distributed as follows: For economic geology of metalliferous deposits, $50,000; of non-metalliferous deposits, $23,575; of oil, gas, coal, $110,000. Scientific researches not directly economic were allotted $117,000; while administration, salaries, etc., received $105,000. Of the total sum available for geologic work, $122,000 was used for field expenses (including search for potash); of this 75 per cent was expended west of the one-hundreth meridian.

Other publications are:

Professional Papers, No. 123.—A Superpower system for the region between Boston and Washington; by W. S. Murray and others. Pp. 261, 11 pls., 61 text figures. This is the report of a special investigation of the possible economy of fuel, labor, and materials resulting from the use in the industrial region named of a comprehensive system for the generation and distribution of electricity to transportation lines and industries. The investigation was made by a staff of engineers under the administrative supervision of the Geological Survey The annual net saving, after fixed charges are deducted, if the energy required in this region in 1930 were supplied by a co-ordinated power system, as described, is estimated at $429,000,000; the annual return on the investment would be 33 per cent. Of the 36,000 miles of railroad in this region it is estimated that 19,000 miles can be profitably electrified, so as to yield by 1930 an annual saving of $81,000,000 as compared with the cost of operation by steam. The coal saved annually under the superpower system would amount to 50,000,000 tons. The system contemplates interconnection of existing plants and systems and construction of new steam-electric and hydroelectric plants at the most favorable locations. This ''superpower zone'' embraces one-fourth of the population of the United States, with a corresponding importance in railroads, industrial plants, etc.

No. 129. Parts C to I.

Topographic Atlas:—Forty-three sheets.

Geologic Folio, No. 213. New Athens-Okawville, Illinois; by E. W. Shaw. 12 pages of folio text, 4 maps, 6 text figures.

Bulletins:—Several parts, separately issued, of Nos. 722, 725, 726, 730, 735. Part B of No. 735 by L. F. Noble describes the colemanite of Clark County, Nevada. This occurs in fairly extensive deposits of economic importance.

Water Supply Paper:—No. 500, C. Some characteristics of Run-off in the Rocky Mountain Region; by Robert Follansbee. 17 pages, 10 text figures, and in

Mineral Resources.—Numerous advance chapters.

3. *Die Eruptivgesteine des Kristianiagebietes IV. Das Fengebiet in Telemark, Norwegen;* by W. C. Brögger. Videnskap. Skrifter. I. Mat.-naturw. Klasse 1920, no. 9. 408 pages, with 2 geologic maps, 30 plates, and 46 text figures. Christiania, 1921.—It is nearly a quarter of a century since the third volume of the epoch-making series ''Die Eruptivgesteine des Kristianiagebietes'' appeared. During this interval detailed mapping of the region has been in progress, and a vast amount of material

has been accumulated—about 15,000 hand specimens, 6,000 thin sections, and 300 chemical analyses. The results of this work were to have been embodied in volume IV, but the discovery of a remarkable series of alkali rocks in the Fen district by Professor Brögger's colleague, Professor V. M. Goldschmidt, in 1918 made it imperative to study this district at once, because it differs so strongly from the Christiania district. It is the results of this study, this interim investigation as it were, that are presented in this superb monograph. It need hardly be said that it represents a very notable achievement, but coming as it does at the time of Professor Brögger's seventieth birthday, the remarkableness of the achievement is enhanced many fold.

The outstanding feature of the Fen area is the occurrence of large intrusive masses of limestone and dolomite in association with ijolitic rocks that range from highly leucocratic to highly melanocratic.

The Fen area, lying 115 km. southwest of Christiania, is 4.2 square kilometers in extent, and is surrounded on all sides by Pre-Cambrian granite. A little less than half of the area consists of intrusive limestone, termed sövite. The predominant rocks consist of a series of plutonic pyroxene-nephelite rocks. In composition they range from hypermelanocratic members—jacupirangite—through members in which pyroxene predominates (melanocratic rocks here named melteigite), through members in which nephelite predominates (the leucocratic rock ijolite), finally to the hyperleucocratic end member of the series—urtite. All these rocks carry more or less primary calcite. In connection with the systematic description of this series, the occurrence of all ijolitic rocks the world over is reviewed and critically discussed, and melteigite is shown to occur in various alkalic provinces.

At Fen melteigite predominates. The melteigite magma exerted a truly remarkable and profound contact metasomatism on the Pre-Cambrian granite, the result of this action being to transform the bordering zone into a wide band of aegirite syenite, or fenite. Fenite has also been formed by the assimilation of the granite by the melteigite magma. Chemically and texturally the pyrogenetic fenite often cannot be distinguished from the fenite of metasomatic origin.

Countless dikes of calcite (sövite) and a lesser number of dolomite (rauhaugite) cut the melteigite, ijolite, and fenite. Their occurrence in the fenite of metasomatic origin rules out the possibility that the dikes may in reality be roof-pendants. Professor Brögger is emphatic that the carbonate rocks are truly igneous and leaves us in no doubt as to what he means by a dike, namely that a dike consists of material that was injected as a homogeneous fluid mass during one pulse, filling the fissure and subsequently consolidating there. The dikes are described as streaky (schlierig) and as unusually rich in apatite, containing as much as 8 per cent, fluidally arranged. These fluxional structures would appear to be the strongest evidence in support of the igneous origin of the carbonate dikes. Further evidence is afforded by the complete series of transitional rocks from pure silicate rocks (ijolites) to pure carbonate rocks. Many of these intermediate rocks have excellent "eutectic" structure, which is regarded as sure proof of their igneous origin, but in view of the fact that in recent years many of the so-called eutectic intergrowths have been shown to be due to replacement, this criterion has not the absolute value that the author attaches to it.

From the petrographic resemblance of the central mass of limestone of the Fen area to the sövite dikes, it also is interpreted as of igneous origin. The possible length of the limestone area is 2 km. and its width is 1 km. The intrusive carbonatites and older rocks are cut by alnoïtic dikes, and all are intruded by diabase dikes, but these last injections are not believed to have any genetic relation with the Fen magma and its consanguineous rocks.

Daly's hypothesis for the origin of alkaline rocks is appreciatively considered, but it is believed that at Fen the parent magma was essexitic rather than basaltic. Igneous activity began at Fen by the formation of a volcanic conduit by a gigantic explosion. The essexite magma dissolved at great depth large quantities of limestone, thereby producing the melteigite magma, which by gravity differentiation eventually yielded urtite. After differentiation the carbonate magma swam on top of the heavier silicate magma and finally solidified in the throat of the volcano. Subsequently the volcano has been very deeply eroded, and to this great denudation is ascribed the marked difference between the igneous phenomena revealed at Fen and those in the Christiania region: at Fen the phenomena are those due to deep-seated igneous activity, whereas in the Christiania region they are those produced in the comparatively shallow depths of the earth's crust. ADOLPH KNOPF.

4. *Mineral Resources of the Philippine Islands for 1919 and 1920.* Pp. 70, with 4 plates and 4 text figures. Manila, 1922.—The mineral production of the Philippines has increased from 234,000 pesos in 1907 to 7,611,000 pesos in 1920. In money value gold is much the most important, namely 3,000,000 pesos (1916), 2,620,000 (1919), 2,425,000 (1920.) Coal increased from nearly 400,000 pesos (1918) to over 800,000 (1919) and 1,452,000 (1920). Salt, sulphur, stone and sand, with other products, are also important. Iron ore exists though not yet developed and the existence of a high grade of petroleum is believed to be assured when active work of prospecting can go on.

5. *A List of new Crystal Forms of Minerals;* by HERBERT P. WHITLOCK. Bull. Amer. Museum Nat. History, vol. **46**, pp. 89-278.—Dr. Whitlock in 1910 published a list of new crystal forms in the *School of Mines Quarterly* (**31**, p. 320, **32**, p. 51); this included forms described subsequent to Goldschmidt's Index (1891). The same author has now in this pamphlet of about 190 pages covered the entire period from 1891 to 1920, and his arduous labors will be highly appreciated by all interested in this subject, one that no work on mineralogy, however comprehensive, can expect to cope with. The accepted letter, the Goldschmidt and Miller symbols, locality, and original reference are all given.

6. *Handbook and Descriptive Catalogue of Gems and Precious Stones in the U. S. National Museum;* by GEORGE P. MERRILL, assisted by MARGARET W. MOODEY and EDGAR T. WHERRY. Pp. 225, with 14 plates, 26 text figures. (Bulletin **118**, U. S. National Museum.)—Dr. Merrill's contribution will be welcomed by all interested in precious stones, particularly those of American origin. The collection, even if "poorly balanced," is large and worthy of careful study. The "Isaac Lea Collection" forms a very important part; this originated with the bequest of Mrs. Frances Lea Chamberlain of the collection of her father, Dr. Isaac Lea. This has been made more valuable by the further gift from Dr. L. T. Chamberlain of numerous specimens and (on his decease) a bequest for the increase of this collection.

7. *Virginia Geological Survey;* THOMAS L. WATSON, Director. Bulletin XVII. *The Geology and Coal Resources of Russell County;* by CHESTER K. WENTWORTH, with a chapter on the Forests of Russell County by J. W. O'BYRNE. Pp. X, 179; 28 plates (3 in pocket), 16 figures. Charlottesville, 1922.—Russell County is in the southwestern part of the State and the part here described is a belt, 3 to 5 miles wide, along the northwestern border. Its resources are estimated at 706,000,000 tons of recoverable coal; in 1918 the output was very nearly 2,000,000 tons, having a value of over $5,000,000.

8. *The Topographic and Geological Survey of Pennsylvania;* GEORGE H. ASHLEY, State Geologist.—Bulletins 6, 9, 38-42 have been received (mimeographed). No. 40, by F. B. BECK, is on the white clay deposits at Saylorsburg, Monroe Co.; the others (see **3**, 305, 384) deal with various aspects of the coal situation.

9. *Geology of Drumheller Coal Field, Alberta;* by JOHN A. ALLAN. Pp. 72 with index; 17 plates including a large colored geological map of the Drumheller district in pocket.—This district is the largest producer of coal in Alberta. Within the 75 square miles mapped there are 28 mines and the annual output is over one million tons. The coal seams and associated sedimentary beds belong to the Edmonton formation, the uppermost member of the Upper Cretaceous. The area is 85 miles east-

northeast from Calgary and 185 miles south of Edmonton. It is assumed that in the Red Deer and tributary valleys within the area mapped there is an aggregate of ten feet of workable coal over at least 6,000 acres; this is figured as meaning a reserve of over one hundred million tons.

10. *Potash in a new area of Texas, deposit of polyhalite found at several levels in a well in Reagan County, Texas.*—The discovery of potash in notable amounts in a new area in Texas is announced by the U. S. Geological Survey. This has been brought to light through the analysis by the Survey of drill cuttings collected from the Santa Rita No. 1 well, drilled by the Texon Oil and Land Co., in the southwest corner of Reagan County. Most of the samples contained no potash worth noting, but the samples which were taken from bailings at depths of 1150 to 1325 feet showed from 2.05 to 8.29 p. c. K_2O. The richest of the samples indicates 10.78 per cent of K_2O in the soluble salts when one gram of the dry rock is dissolved in 100 cc. of water.

III. NATURAL HISTORY.

1. *Arctic Alcyonaria and Actinaria; I, II, The Alcyonaria of the Canadian Arctic Expedition,* 1913-1918, *with a revision of some other Canadian genera and species; III. The Actinaria of the Canadian Arctic Expeditions, with notes on interesting species from Hudson Bay and other Canadian localities;* by A. E. VERRILL. Pp. 164, with 31 plates. Ottawa, 1922.—These papers from volume VII of the Report of the Canadian Arctic Expedition, 1913-1918, contain a full systematic revision, with specific descriptions and illustrations, of all the species of these groups known from Arctic North American waters, including some of the more characteristic forms from the Grand Banks. Several new genera and species are included, and the previously perplexing confusion in synonymy is eliminated.

Zoologists will long be indebted to Professor Verrill for bringing together in this monographic form the accumulated results of his studies for more than half a century on these groups.

W. R. C.

2. *Genetics: An Introduction to the Study of Heredity:* by HERBERT EUGENE WALTER. Revised edition; pp. xvi, 354. New York, 1922 (The Macmillan Company).—In the ten years that have passed since the first edition of this widely used text-book was issued discoveries of such profound significance have been made as to necessitate extensive revision and the rewriting of a large portion of the work. Several new chapters have been added and a number of cleverly elucidative diagrams incorporated. The first edition was recognized as one of the most successful elementary treatises of the subject of genetics that have

been written since the discovery of the Mendelian principles. Its usefulness is attested not only by its wide adoption as a textbook in English-speaking countries but also by its translation into other languages.

The present revision will restore the book to its former prestige. In it both the student and the general reader may find the essential facts of the rapidly advancing science of heredity presented in a most orderly, intelligible, and discriminating manner.

W. R. C.

3. *A Naturalist in the Great Lakes Region;* by ELLIOT ROWLAND DOWNING. Pp. xxv, 328, with 452 illustrations. Chicago, 1922 (The University of Chicago Press).—The object of this book is to place in the hands of school children an intelligible and inspiring story of the natural world about them. The first chapter shows them the unfinished world at their feet, with the elements ever at work changing the topography of hill and valley —filling up the ponds and eroding the mountains. They next read about the world in the making and the story told by the rocks and by the boulders in the fields as to the changes which have taken place on the surface of the earth in its past history. Then the living world is surveyed and the adjustment among the different groups of organisms is pointed out. This is followed by visits to the dunes, the ponds, the swamps, forest, prairie, ravine, brook, and river. In each of these pleasant and instructive excursions the reader makes the personal acquaintance of the more interesting plant and animal inhabitants of the regions and learns the reasons why each has become settled in its particular environment. Although the modern name for this method of studying nature may be ecology, it is, nevertheless, good old-fashioned natural history.

The book is most attractively bound in flexible covers and will go easily into a coat pocket, and it should be carried afield not only by the pupil in nature study courses, but also by grown-ups whenever they are fortunate enough to have an hour to spend with nature.

W. R. C.

4. *La Constitution des plantes vasculaires révélée par leur Ontogénie;* by GUSTAVE CHAUVEAUD. Pp. xiii, 155, with 54 text-figures. Paris, 1921 (Payot & Cie.).—In this interesting pamphlet the author explains and defends his theory of the "phyllorhiza," according to which the fundamental unit of the vascular plants is neither the stem nor the leaf but a composite organ composed of a leaf-like part united to a root-like part. In certain aquatic pteridophytes these units are clearly shown by young embryos; the first phyllorhiza gives rise to a second by means of a vegetative point arising laterally, the second gives rise to a third, and so on. At first the successive phyllorhizas remain distinct but, as development goes on, they become more

crowded and, where they are joined together, a stem gradually makes its appearance upon which the leaves seem to arise secondarily. Although the described conditions are clear in these lower aquatic types, the development in spermatophytes and especially in those of terrestrial habit is so condensed that the phyllorhizas can be demonstrated only with difficulty. In support of his theory Chauveaud secures evidence from the gross morphology of the plants discussed and also from their minute anatomy.

A. W. E.

5. *The Vegetation of New Zealand* (Engler und Drude's "Vegetation der Erde," vol. **14**); by L. Cockayne. Pp. xxii, 364, with 65 plates, 13 text-figures and 2 maps. Leipzig, 1921 (Wilhelm Engelmann).—Botanical investigations in New Zealand date back to 1769 and the unique characteristics of the flora of this island have been made known through a long series of works by many authors. Most of these investigations, however, have been along taxonomic lines and it is only within the last twenty years that serious attention has been given to the study of vegetation—of plants considered *en masse* rather than as individuals or species. With studies along this line is inseparably linked the name of Cockayne, and the present volume (in English) embodies a clear and comprehensive summary of the work carried on by this author and his colleagues since about 1900, together with that contained in the scattered contributions of earlier writers. The greater part of the book is devoted to the "Vegetation of primitive New Zealand," but there are also sections on the physical geography and climate, the flora and its distribution, and the history of the flora. G. E. NICHOLS.

6. *Les Mouvements des Végétaux.*—Du réveil et du sommiel des plantes; by René Dutrochet. Pp. vii, 121, with 21 text-figures. Paris, 1921 (Gautier-Villars et Cie., Éditeurs).—Dutrochet's essays on plant movements, which are here reprinted, were published in 1837 and exerted a profound influence on the development of plant physiology. The author was able to demonstrate the fact that many of these movements could be explained from a mechanical point of view and emphasized the important part played by osmotic phenomena in bringing them about. The present volume is the first botanical number of a series entitled, "Les Maitres de la Pensée Scientifique." A. W. E.

7. *Die Pflanzenwelt Afrikas, insbesondere seiner tropischen Gebiete: Die dicotyledonen Angiospermen* (Engler & Drude's "Vegetation der Erde," vol. **9**); by A. Engler. Pp. vii, 878, with 338 text-figures. Leipzig, 1921 (Wilhelm Engelmann).—In this second part of the third volume of the Vegetation of Africa (the ninth of the series of plant geographical monographs edited by Engler and Drude) Professor Engler continues the discussion of the families of African plants commenced in Vol-

ume 2. The present volume completes the dicotyledonous Angiosperms, extending from the Euphorbiaceae through the Cornaceae. Engler was assisted in the preparation of this work by several of his friends and students, notably Dr. Pax of Breslau, who is responsible for the exhaustive treatment of the Euphorbiaceae. Other collaborators include Drs. Brehmer, Brandt, Burret, Diehls, Gilg, Harms, Krause, Loesener, Mildbraed, Radlkofer and Ulbrich. The method of treatment follows that of the earlier volumes and is essentially similar to that of the familiar Pflanzenreich. The discussion of the families is followed by a summary of the geographical relations of the African flora with examples of the various floristic elements of which it is composed; and also by an account of the morphology, taxonomy, distribution and origin of the characteristic xerophytes of the country. A. F. HILL.

8. *Précis de Physiologie Végétale;* by L. MAQUENNE. Pp. 175, with 4 text-figures. Paris, 1922 (Payot & Cie.).—Professor Maquenne's work gives in condensed form the essentials of plant physiology. It represents a resumé of a course of lectures given for many years at the Natural History Museum in Paris. The first chapter deals with certain physical and chemical phenomena which have an immediate bearing on the plant's activities. In the second chapter germination is discussed; in the third, fourth and fifth, the anabolic processes of the plant; in the sixth, the respiratory processes; and in the seventh and eighth, the movements of water and other substances in the plant, together with the changes associated with maturity. The ninth and last chapter discusses the more important chemical substances found in plants. A. W. E.

9. *The North American Slime-moulds:* A descriptive list of all species of Myxomycetes hitherto reported from the continent of North America with notes on some extra-limital species; new and revised edition; by THOMAS H. MACBRIDE. Pp. xvii, 299, with 23 plates. New York, 1922 (The Macmillan Company).—The first edition of this valuable manual was published in 1899 and contained 231 pages and 18 plates. The increase in size is largely due to the addition of 53 species to the flora of North America, including 12 proposed as new. The extra-limital species described number 13 and occur in various parts of the world. The most important change in the systematic portion of the work is the recognition of both orders and families, these groups being designated by the usual suffixes. In the first edition the orders had the family suffix while the families had the tribal suffix. The first 18 plates in the new edition are in large part redrawn from those in the first edition, while the additional plates illustrate the species since accredited to our flora. A comparison of the two editions demonstrates the continued activity of

North American students of the slime-moulds and the important results achieved during the last twenty-five years. A. W. E.

10. *Soil Conditions and Plant Growth;* by E. J. Russell. Pp. xii, 405, with 32 text-figures. Fourth edition. London, 1921 (Longmans, Green & Co.).—Originally published as one of a series of monographs on biochemistry, this book in its present form appears as the first of the "Rothamsted monographs on agricultural science." Presenting as it does a comprehensive survey of the physical, biological and chemical conditions of the soil as related to plant growth, a survey which three thorough revisions have kept well abreast with advances in scientific knowledge in this complex field, its value to students both in this and in related fields has been recognized from the outset. The fourth edition, more than half as large again as the first, retains the general character of the earlier editions, dealing broadly with the whole subject. G. E. NICHOLS.

11. *A Handbook of the British Lichens;* by Annie Lorrain Smith. Pp. 158, with 90 text figures. London, 1921 (British Museum).—This Handbook is based on the author's recent Monograph of the British Lichens, a much more extensive work in two volumes published by the British Museum. After a brief introduction in which the morphology of lichens is described, together with notes on their physiology, ecology, economic uses and phylogeny, the author gives full descriptions of the families and genera of British Lichens, and makes it possible to determine the species by means of keys. Characteristic species of the more important genera are illustrated. Since many of the British species occur also in North America the Handbook ought to prove serviceable to students of the lichens on both sides of the Atlantic.

A. W. E.

IV. Miscellaneous Scientific Intelligence.

1. *The Outline of Science: A plain story simply told;* edited by J. Arthur Thompson. Four volumes, with 40 colored plates and 800 other illustrations. New York and London, 1922 (G. P. Putnam's Sons).—With the high degree of specialization that has taken place in recent years among the workers in the various fields of science there are now but very few who have been able to keep in touch with the marvelous discoveries of recent years and with the modern points of view in all these branches. Consequently there are but few whose knowledge of science is so far-reaching as to give them a broad view of the interrelations of the entire field; and only those could hope to succeed in presenting to the general reader a comprehensive story of science. The editor of these volumes stands pre-eminent in this class.

The first volume, which is the only one of the series which has yet appeared, gives bright promise of the phenomenal success of the whole. It consists of eight chapters, covering 296 pages, with more than two hundred illustrations and ten colored plates.

The book begins with a survey of the universe, with a simply-stated but thrilling "romance of the heavens." Then follows the story of evolution, with an account of the evolution of the earth, the hypothetical origin of life, the beginnings of life, and its evolution through the ages. The reader is next shown the marvelous adaptations of organisms to their environment, the endless struggle for existence, followed by the ascent of man. Now comes an analysis of the evolutionary changes taking place in man and other organisms at the present day and the wonderful progress which may result from man's intelligent propagation of desirable types selected from the multitude of new forms which nature is constantly producing. The dawn of mind is next taken up for discussion and the reader is led from the simple reaction systems of the lower forms of life to the eventual development of intelligence and reason.

With the completion of the story of evolutionary biology the reader's attention is directed to that most fascinating and speculative subject, the foundations of the universe. In this final chapter of the book the atom is analyzed in terms that any one may understand, the electron is pictured, and the inferences as to the relation of matter and energy are pointed out.

At the end of each article is a short list of the books in which the reader can follow the subject to which the chapter has been so auspicious an introduction.

It will be readily admitted that the aim of the book "to give the reader a clear and concise view of the essentials of present-day science" will be fully realized if the remaining volumes are of the character of the first W. R. C.

2. *Publications of the Smithsonian Institution, Washington, D. C.;* CHARLES D. WALCOTT, Secretary.—The *Annual Report* for 1920 has been recently received. This is a volume of over 700 pages, containing the Secretary's report already noticed (vol. **1**, pp. 95, 96); also the General Appendix (pp. 145-690) embracing twenty-seven papers of wide interest all illustrated by excellent plates.

Explorations and Field Work in 1921. Pp. 128.—The paper (pp. 1-22) by the Secretary, giving a Summary of his continued work in the Canadian Rockies for 1921, opens this pamphlet and aside from its scientific value will charm the reader by the reproductions of the beautiful photographs taken by Dr. and Mrs. Walcott in the region studied to the northwest of the Lake Louise Station.

Other papers, by various authors in different regions, deal with paleontological, astrophysical, botanical, entomological and archeological field work. The admirable character of the illustrations leaves nothing to be desired.

3. *Banking, Principles and Practice;* by RAY B. WESTERFIELD.—An important and comprehensive work in five volumes on the historical, legal, practical and theoretical aspects of banking has recently been published by the Ronald Press Company (New York City). The author, R. B. Westerfield, is assistant professor of political economy at Yale University and secretary-treasurer of the American Economic Association. Prof. Westerfield writes authoritatively from long experience and exhaustive study, and although the work is thoroughly up-to-date, embracing the most recent developments, a conservative approach to the issues in discussion has been preserved throughout. The exposition of the subject matter is admirably clear, and the various phases of banking are presented with as much conciseness as their numerous ramifications allow. The author has apparently spared no pains or caution in making the work completely reliable, so that it constitutes a valuable and accurate symposium for reference study. The careful and orderly arrangement of chapter headings and subjects is well adapted to convenience and handy use.

The first volume (pp. 207) deals with the fundamental principles of money, credit and banking; the second (pp. 208-507) with the banking system of the United States, including full discussion, historical and descriptive, of the Federal Reserve and the Federal Farm Loan systems; the third (pp. 511-809) with domestic banking, covering cash and deposit operations, bank management, administration of departments, and other important branches of the subject. The fourth volume (pp. 810-1080) continues the discussion of domestic banking with complete information concerning earning assets, and the fifth (pp. 1081-1370) gives all the details of the foreign division, comprising foreign exchange, the handling of foreign operations, collections, letters of credit, and miscellaneous departments.

The book admirably fills the needs of more than one class of people; First, the student who wishes to know what banking is and how it is done; second, the employe who desires to perfect himself in his subject and secure promotion; third, the banker of experience who will use the book for reference and latest methods; fourth, the teacher who could find no better text book in so wide a field; fifth, every inquiring mind.

"Banking, Principles and Practice" provides a compendium of practical information which unites in a single work the many phases of an entire subject. As such, it fills a definite need and does so in a comprehensive and authoritative manner.

DEAN B. LYMAN.

4. *Civic Science in the Home.* Pp. 416. *Civic Science in the*

Community. Pp. 430; by George W. Hunter and Walter G. Whitman. New York, 1921 (Amer. Book Company).—These books cannot be criticized for narrow specialism. They compass the whole wide domain of General Science, and attempt to relate this science to citizenship. The books are intended for public elementary school use and their scope is defined by their authors in the following statement: "In short, Civic Science plans to lead the child in a manner which is both logical and psychological from the simple factors which make up his environment as a living thing to the complex combinations and interactions which have arisen through what we call civilization."

Consequently the chapters range from flies, foods, and pests to street lighting, automobiles, plumbing, eugenics and euthenics. The task of organizing such eclectic material into pedagogical units is, of course, a difficult one. The authors have depended on the problem setting or project method to accomplish such unification. They have also made very free use of the blank score card as a teaching device. Thus we have score cards for the "home," "the natural resources of my environment," "water in my home," "foods in my home," "removal of wastes from my home," etc.

The volumes are attractively printed, crowded with pictures and diagrams and references and, therefore, constitute a useful source book for the teacher. The proper teaching of elementary school science unfortunately depends to a very slight degree upon textbooks; but, even without a good teacher, these books will awaken a popular interest in science and an appreciation of its everyday importance, thus anticipating in a way the "Science Service" of the American Association for the Advancement of Science. ARNOLD GESELL.

5. *Memoirs of the Queensland Museum, vol. VII, parts II and III;* edited by the Director, Heber A. Longman.—Part II (pp. 65-80, with 4 plates) contains an account by the Director of a new genus of fossil marsupials, *Euryzygoma.* This was obtained from the Post-Tertiary deposits in the Darling Downs. It is described as a remarkably bizarre monster of the Nototherium group (*Euryzygoma dunense*) with a skull, the width of which exceeds the length by 46 mm.

Part III (pp. 81-240, plates VIII to XII) contains an article by T. D. A. Cockerell of Colorado on Australian bees, with a catalogue by Henry Hacker; also the second of the papers on Queensland fishes by A. R. McCulloch; a new Nyctimene by H. A. Longman and on Coleoptera, mostly from Queensland, by A. M. Lea.

6. *United States Life Tables,* 1890, 1901, 1910 *and* 1901-1910; prepared by James W. Glover. Pp. 496, quarto. Washington, 1921. (Bureau of the Census, Samuel L. Rogers, Director.)—

This volume, in addition to the full explanatory text, mathematical theory, computations, graphs and original statistics, gives also tables of United States life annuities, life tables for foreign countries and mortality tables of life insurance companies. The scope of the work is, therefore, as wide as the subject itself; Mr. Glover, who has had charge of it, is not only the expert special agent of the Census Bureau but also professor of mathematics and insurance in the University of Michigan.

The tables show the rates of mortality and expectation of life for all classes of people residing in the country. It is interesting to note that the two decades from 1890 to 1910 show an improvement in mortality conditions for men and women under 50 years, while above that age conditions were stationary. Further women rank much higher than men, persons living in the country higher than those residing in cities, whites than negroes, and for most ages the native born than those of foreign birth.

The work is divided into eight parts, the first five being designed for the general public, the remainder for the specialist. Part I (pp. 23-49) carefully read will give the average reader all the information ordinarily required, and enable him to consult the many tables with intelligence.

7. *Public Opinion;* by WALTER LIPPMANN. Pp. x, 427. New York, 1922 (Harcourt, Brace & Howe).—Mr. Lippmann's book falls into two parts, nearly equal in size. The first part is mainly a study in psychology, as is indicated by its headings: The world outside and the pictures in our heads, approaches to the world outside, stereotypes, interests. The author, who was graduated from Harvard in 1910, has kept alive the interests developed under William James and others there, and applies his analysis to the conditions, both individual and social, underlying the formation of public opinion. In the latter part of the book he follows his subject into the field of politics, taking as his main topics: The making of a common will, The image of democracy, Newspapers, Organized intelligence.

The author has observed the action of the modern political system, both from the outside as journalist, and from the inside as a worker in practical politics, and, during the latter part of the war, in the service of the government. He illustrates his meaning with concrete examples from recent history, and so does much to help the reader over the hard places in doctrine. The book is interesting. It is, furthermore, important. The author makes a determined effort to see things as they are, not as they have been supposed to be. If he has not the experience of political sages like Morley and Bryce he has a freedom from tradition, a freshness of imagination, and a vigor of attack which make his analysis of present conditions well worth attention. He does not offer a panacea for the ills of the time, but in his concluding chapters he discusses in a sober and practical way some measures of reform. His proposal, in brief, looks to a system in which experts, trained and organized for the purpose, shall be set to ascertain facts of public interest, and so provide at least a firm basis for public opinion. CLIVE DAY.

8. *Publications of the Carnegie Foundation for the Advancement of Teaching* (522 Fifth Avenue, New York City).—The following publications of the Carnegie Institution have been recently issued. (See earlier, vol. **3**, pp. 157, 307.) BULLETIN XVI. *Education in the Maritime Provinces of Canada.* Pp. vii, 50, with a map (frontispiece).—Dr. W. S. Learned of the Carnegie Foundation and Dr. KENNETH C. M. SILLS of Bowdoin College have prepared this study of the present provincial situation in higher education in Nova Scotia and New Brunswick, discussing also the elementary and secondary school conditions. The conclusion reached is the desirability of the union of six small universities in the Canadian provinces of Nova Scotia and New Brunswick to make one strong university at Halifax. The institutions concerned are King's College at Windsor, N. S., Dalhousie University at Halifax, Acadia University at Wolfville, N. S., Mt. Allison University at Sackville, N. B., St. Francis Xavier's University at Antigonish, N. S., and the University of New Brunswick at Fredericton, N. B. It is proposed to raise $4,500,000 to accomplish the purpose proposed.

The plan suggested is an adaptation of English collegiate organization. Each college would maintain its own student residence, class-rooms, chapel, etc., where most of the freshman and sophomore work would be conducted, while advanced courses, all honor courses, and the expensive laboratory sciences would be taught in a central university controlled by a joint board and supported in part by the provinces. This arrangement would make possible the equipment of a first-class university, while sacrificing few or none of the advantages of the small colleges. It would permit the denominational college with small endowment to command the most extensive university privileges and at the same time retain and strengthen its denominational character. An attractive feature of the scheme from an American point of view is the method suggested for the better organization of large bodies of students—an acute problem in American colleges.

Other publications are:

No. 215-A. History of Domestic and Foreign Commerce of the United States; by E. R. JOHNSON, T. W. VAN METRE, G. G. HUEBNER, and D. S. HANCHETT, with an introductory note by H. W. FARNAM. Pp. xxiv, 761, 10 maps. A second photographic edition ($3.00).

No. 309. Gaseous Exchange and Physiological Requirements for Level and Grade Walking; by HENRY MONMOUTH SMITH. Pp. viii, 310; 1 plate, 42 figs. ($6.00).

No. 316. Development and Activities of the Roots of Crop Plants: A Study in Crop Ecology; by J. E. WEAVER, F. C. JEAN and J. W. CRIST. Pp. vi, 116, 14 pls., 42 figs. ($2.00).

No. 320. Genetic Studies of Rabbits and Rats; by W. E. Castle. Pp. 55, 2 pls., 7 figs. ($1.00).

9. *American Association for the Advancement of Science.*—The seventy-fifth meeting of the Association was held in Salt Lake City on June 22 to 24, under the auspices of the Pacific Division, of which Dr. Barton W. Evermann is president.

10. *Observatory Publications.*—The University of Cincinnati, Jermain G. Porter Director, has recently issued No. 19 of its Publications. This gives a Catalogue of 4683 Stars for the Epoch 1900, observed by Eliott Smith and prepared for publication by the director. It presents the positions of all stars determined with the meridian circle from January, 1907, to December, 1921. The proper motions of the greater part of the stars were computed in No. 18; other stars are those of the Boss preliminary general catalogue. Computations have been made by the Director assisted by Dr. Yowell. It is announced that the next meridian work published by the Observatory will be reduced to 1925.

The observatory of Krakow has issued an eight-page publication giving the minimos of Algol and RW Tauri in 1922, reduced to the meridian of Greenwich.

The Annual Report of the U. S. Naval Observatory at Washington has also been received.

The National University of La Plata has issued part 2 of volume VI, by Numa Tapica, giving micrometric measurements of double and vicinal stars. From the same source comes a determination of the orbit of the planetoid (796) Saria by Hugo A. Martinez.

The Hector Observatory at Wellington, New Zealand, published some time since a reprint (Bulletin 33) on observations of Southern variable stars by C. E. Adams; also a brief method of calculating occultations of stars by the moon by C. J. Westland.

The observatory at Lyons, France, publishes a Bulletin of which No. 4 for April, 1922 (4th year) has been received (H. Georg, Editeur). The annual subscription is only 12 francs.

OBITUARY.

Professor George Simonds, the English botanist, died on May 4 at the age of sixty-nine years.

Arthur Bacot, entomologist to the Lister Institute, died at Cairo on April 12 as the result of infection contracted when prosecuting investigations on the etiology of typhus.

Louis Antoine Ranvier, the veteran French histologist, died recently at the age of eighty-seven years.

Dr. Henry Marion Howe, the distinguished metallurgist, since 1897 professor in Columbia University, died recently at the age of seventy-four years.

CONTENTS.

SCIENTIFIC INTELLIGENCE.

VOL. IV AUGUST, 1922

Established by **BENJAMIN SILLIMAN** in 1818.

THE
AMERICAN
JOURNAL OF SCIENCE.

EDITOR: EDWARD S. DANA.

ASSOCIATE EDITORS

PROFESSORS WILLIAM M. DAVIS AND REGINALD A. DALY,
OF CAMBRIDGE,

PROFESSORS HORACE L. WELLS, CHARLES SCHUCHERT,
HERBERT E. GREGORY, WESLEY R. COE AND
FREDERICK E. BEACH, OF NEW HAVEN,

PROFESSOR EDWARD W. BERRY, OF BALTIMORE,
DRS. FREDERICK L. RANSOME AND WILLIAM BOWIE,
OF WASHINGTON.

FIFTH SERIES

VOL. IV—[WHOLE NUMBER, CCIV].

No. 20—AUGUST, 1922.

NEW HAVEN, CONNECTICUT.

1922.

THE TUTTLE, MOREHOUSE & TAYLOR CO., PRINTERS, 123 TEMPLE STREET.

Published monthly. Six dollars per year, in advance. $6.40 to countries in the Postal Union; $6.25 to Canada. Single numbers 50 cents; No. 271, one dollar.

Entered as second-class matter at the Post Office at New Haven, Conn., under the Act of March 3, 1879.

WILEY BOOKS

By **H. RIES, PH.D.**, and **THOMAS L. WATSON, PH.D.**

Elements of Engineering Geology

More than a condensation and simplification of the authors' larger text '*Engineering Geology*,' since it has involved complete rewriting of many parts of the larger book and the amplification of other parts.

365 pages. 5½ by 8½. 252 figures. Cloth, $3.75.

Engineering Geology

Outlines those fundamental principles which relate to engineering practice including the character of rocks, their use in building, their structure and the geological conditions which affect and control underground waters.

722 pages. 6 by 9. 249 figures, 104 plates. Cloth, $5.00.

By **H. RIES, PH.D.**

Clays: Their Occurrence, Properties and Uses

Describes the occurrence, properties, methods of mining and the manufacturing and uses of a vast variety of clays.

554 pages. 6 by 9. 112 figures, 44 plates. Cloth, $5.00.

Economic Geology

Presents, first, the non-metallic minerals and then the metallic, thus leading the reader from the simpler to the more complex phases of the subject.

856 pages. 6 by 9. 291 figures, 75 plates. Cloth, $5.00.

By **H. RIES, PH.D.**, and **HENRY LEIGHTON, A.B.**

History of the Clay-Working Industry in the United States.

Mentions the important deposits of clay and takes up the developments in manufacturing methods.

270 pages. 6 by 9. Illustrated. Cloth, $2.50.

Send for any or all of these books on Free Examination terms.

JOHN WILEY & SONS, Inc.
432 Fourth Avenue
New York

London
CHAPMAN & HALL, Ltd.

Montreal, Quebec
Renouf Publishing Company

AJS 8.22

THE

AMERICAN JOURNAL OF SCIENCE

[FIFTH SERIES.]

Art. VIII.—*Colloids in Geologic Problems*; by George D. Hubbard.[1]

Introduction.—It has long been recognized that solid matter occurs in more than two states. The terms "crystalline" and "amorphous" exclude quite a large body of materials, some of which are organic and some inorganic. The other condition has been called the colloidal state. Many substances which occur crystalline can be prepared in the colloidal state without any compositional difference. Amorphous substances were in many instances once in colloidal condition. Perhaps all substances can ultimately be prepared in this state whether they are normally crystalline or amorphous.

In the case of some substances, there seems to be no line fixed between the crystalline and the colloidal state. In the same way, there seems to be no line which can be definitely drawn between a true solution and a colloidal solution. In practice we say a substance is in the colloidal state when it will not dialyze or diffuse through certain membranes, as egg skin, bladder, goldbeater's skin, or parchment paper. Molecular dispersions are in true solution; dispersions of much larger aggregates (a hundred, more or less, of molecules in one particle) are in colloidal solution. Such particles are too large to pass through the membrane.

Bancroft[2] says, "Colloid chemistry is the chemistry of grains, drops, bubbles, filaments, and films." Grains of solid particles, drops of fluids, bubbles of gas, filaments very small in two directions, films small only in one direc-

---

[1] The author is deeply indebted at many points in the paper to Dr. Harry N. Holmes of Oberlin College for suggestions and criticism. His General Chemistry and Colloid Manual have been of much help also. This paper was presented to the Geologic Section of the Ohio Academy of Science, April 15, 1922.

[2] Bancroft, W. D., Applied Colloid Chemistry, p. 2 (McGraw-Hill Co.).

tion,—these constitute the field of the student of colloids. The smallest particle visible with the aid of the best compound microscope is about 100 millimicrons in diameter, while the largest molecules approach a diameter of 1 millimicron. Materials in the colloidal state have particles ranging between these limits.[3]

The term "colloid" or "colloidal state" has been expanded to include not only solid gels, but suspensions and emulsions. The former may be solids in liquids, as the very fine sediments in roily water, liquids in liquids, or even solids in solids, as the blue rock salt which is a suspension of finely divided metallic sodium in crystalline halite. In suspensoids the solid particles do not powerfully absorb or hold large quantities of water. In emulsoids, on the other hand, the particles very powerfully hold or absorb large quantities of water, forming gels. Such gels have been made solid, containing as high as 99.87% water.

Gels are substances in the colloidal state which have set or become apparently solid, even though they contain a large percentage of water. The fruit juice (acid), water, and sugar in the jelly cup have set because of a small percentage of pectin. All are essential to the phenomenon. Certain minerals, for example most orthosilicates and some zeolites, on some evaporation after solution in hydrochloric or nitric acid, will set in beautiful gels because of the silicic acid liberated. Sodium silicate or water glass sets in the same way when treated with acetic or some other acid, which makes a salt with the sodium and leaves the silica to gel.

As early as 1861 Thomas Graham[4] knew that dissolved crystalline substances diffused in and out of silica gels, and that reactions occurred between salts in solution in the gels and solutions from outside which diffused in. The famous Liesegang rings were discovered in 1896. Many of these were rings of metallic crystals or crystalline salts, formed in silica gels by reactions between two solutions, one of which was in the gel and the other was gradually diffusing through the gel. The well-developed crystal had time to form because the solutions came in

---

[3] Holmes, H. N., Colloid Chemistry, 1922 (Wiley and Sons).

[4] Hatschek, E., and Simon, A. L. Trans. Inst. Mining and Metallurgy, London, 21, 451-480, 1911-12.

contact so slowly. Bechhold in 1905, Ziegler in 1906, and Hatschek in 1911 continued experiments with rings in gels.

Mineral Genesis through Colloidal State.—Liesegang suggested after his studies on the rings in gels that the banding of agates might be due, in many cases, to the slow diffusion of iron salts through silicic acid gels which had previously been laid in cavities or crevices. He also suggested that this process might explain the formation of large crystals in or on quartz in places where igneous activity had not operated, and where they therefore could not be due to its heat and gases.

In the discussion at the Academy meeting, two points were made. Prof. G. F. Lamb reported orally the finding of good agates in recent clays; the data seem to be wanting as to whether they developed in preexisting cavities or made their own spaces. Agates in the major cavities of buried bones testify to the recency also of agate-making, and as well to the rate of making. Long ages are not necessary. No evidence was presented as to whether or not the agates came through the gel stage, or how the banding originated.

As early as 1884, Clarke tells us, Bourgeois[5] made opal synthetically from gels of SiO_2. Clarke[6] states also that the gelatinous silica formed by the solution of silicates in mineral acids becomes, upon drying, an amorphous mass essentially identical with opal. He also reports that Schafhäutl heated a solution of colloidal silica in a Papin digester and obtained a crystalline deposit of quartz; while de Senarmont heated gelatinous silica with water and carbonic acid gas to temperatures between 200° and 300° C. and obtained a crystalline quartz. Chrustschoff, 1873, obtained quartz from an aqueous solution of colloidal silica by heating to 250° C. for several months. The heat apparently hastened the process, which would have reached the same end in a longer time without so much heat. Silica is dissolved when silicates decompose, and is redeposited by evaporation as opal if still in an acid solution, but when alkalies are present it crystallizes.

When the Simplon tunnel in central Switzerland was put through the Alps, the engineers found a vein of silica

[5] Bourgeois, L., Production of Minerals Artificially, p. 93. French.

[6] Clarke, F. W., Data of Geochemistry, U. S. G. S. Bull. 616, p. 357.

in the gel condition or colloidal state, thus showing that the silica gel is not purely an artificial product. If the ancient scientists who gave the name "quartz" to rock crystal had found this vein and watched it through its transformation to crystalline quartz, they might have had some ground for their theory that it was made of water which had become so thoroughly frozen in a very cold winter that its solid state had become permanent.

The experiments of Liesegang, and of many other colloid chemists who have followed him, suggest a method for the formation of the quartz-gold vein. They have shown that if a gold solution, e.g. $AuCl_3$, is mingled with a silica gel when the latter sets, and then is treated with a reducing agent diffusing through the gel, crystals of gold will form in the gel. Oxalic acid placed on top may serve as this reducing agent. H_2S in water, SO_2, or CO will serve the same purpose. Sodium sulphite, and especially $FeSO_4$, do occur in solutions in nature and would be suitable reducing agents there.

Holmes[7] has shown that a preparation of silicic acid gel made 0.1N with respect to potassium iodide, and then covered with 0.5N mercuric chloride, gives in the gel after a few days bands of red crystalline mercuric iodide. In some cases as many as 40 rather sharply marked bands occurred in a distance of 8 cm. In a similar manner, bands of copper chromate, cuprous oxide, basic lead iodide, basic mercuric chloride, and other substances were formed. Bands of colloidal gold with scattered crystals of gold developed in a preparation of gold chloride and H_2SO_4 with oxalic acid above the gel.

If the silica gel were in one crevice and an intersecting crevice should be conveying one of these reducing solutions, the conditions of the laboratory would be very nearly duplicated. The only difference would be that the solution need not become continually more dilute, but might remain essentially the same in composition for years. In such case there might be no occasion for the banding of the salts, or if bands developed, they would no doubt be evenly spaced. Banding is explained[8] as a result of a reduction in concentration of the solution in the gel just in front of the ring, so that the diffusing

[7] Holmes, H. N., Jour. Amer. Chem. Soc., 40, 1187-1195, 1918.
[8] Holmes, ibid.

solution must needs go beyond the clear space to find sufficient concentration for the development of another band. If the flowing solution remain constant in quantity and condition, would not the bands maintain uniform spacing instead of becoming farther and farther apart as in the laboratory experiment?

The laboratory experiment also throws light on the formation of metallic copper in quartz veins. The experimentor used a silica gel dialyzed with acetic acid (sulphuric would have served the same purpose), and mixed with his gel, before it set, a solution of copper sulphate. The reducing agent was placed on top, and the tiny tetrahedrons of metallic copper began to shine in the gel. If the gel was free from air or any oxidizing agent, the crystals preserved their copper luster, but without due precautions, they oxidized dark to black. Clusters and chains of tetrahedrons formed as the process continued. After many months this process produced a silica gel vein with appreciable quantities of metallic copper disseminated through it. If one wishes to repeat or extend this work, Prof. Holmes[9] has given full directions for preparing silicic acid gels.

In these cases, all that is necessary to make the typical mineralized quartz vein is to allow the gel to crystallize, a change which has already been explained as a laboratory experiment, and which seems perfectly possible as a natural geologic phenomenon.

Limonite seems to furnish an illustration of an ore once in a colloidal state. There are six hydroxides of iron, made by combining one to six molecules of water with the ferric oxide, only one of which, goethite, is known in the crystalline form. This is the hydroxide with one molecule of water to one of Fe_2O_3. Clarke in the "Data of Geochemistry," p. 531, quotes Van Bemmelen as saying that probably no formulas should be given to any of these ferric hydroxides, but rather they should be regarded as polymers of the first, or colloidal, complexes of two or more polymers. Van Bemmelen in a number of papers published between 1888 and 1904 so regards them, and Nicolardot and Spring both consider the several hydroxides polymers of the first. Thus the ferruginous slimes in bogs and around springs, and sometimes in stalactites

---

[9] Holmes, H. N., Silicite Acid Gels, Jour. Phys. Chem., 22, 510-519, 1918.

in caves, as at Mount Tabor or Reame's Cave, Ohio, many of which are precipitated by organic agencies, are truly colloids which may in the course of time be dehydrated and pass over into the crystalline goethite, or even into hematite.

Some bauxite was formed by passing through a colloidal state. Colloidal alumina is soluble in water and has been carried some distance before coagulation has taken place. The coagulation is a result of the meeting with electrolytes in solution, whose charge is different from that of the colloid, and therefore the alumina loses its negative charge; the solution first becomes turbid, then the hydroxide actually flocculates and collects into larger and larger lumps, and finally falls to the bottom. Apparently the continued growth of these lumps by the successive addition of layers of aluminum hydroxide builds up the oolitic and pisolitic bodies of typical bauxite. Some bauxite is certainly not of this origin.

These gel ores of iron and aluminum start by decomposition of silicate rocks in the weather zone. Descending waters carry them down into other rocks, or surface waters carry them away to marshes and bogs where the the precipitating conditions are found, and the ores are dropped. In the cooler, higher latitudes the iron ores are formed, while the alumina and silica remain together[10]; and in the warmer or subtropical climates the laterites or bodies of bauxite are formed. Thus the ore deposit may witness to the character of the climate in force when the deposit was made. The precipitation in other rocks would probably take place above the water table; hence in high and dry regions there would be a long vertical range for deposition, which could take place anywhere between the surface and the water table.

It has been pointed out by Krusch[11] that the manganese oxides may also be laid down as gel ores, and subsequently become crystalline. He makes a point also of the fact that this colloidal ground mass of manganese oxides and hydroxides is capable of adsorbing other substances which may permeate it, e.g., barium and potassium compounds. In this way, he accounts for psilomelane, a manganese mineral containing barium and potassium.

[10] Schlösing, T., Compt. Red., **132**, p. 401, 1901.
[11] Krusch, P., Mining and Scientific Press, **170**, 418, 1913.

F. W. Clarke in his "Data of Geochemistry," p. 533, accepts psilomelane, and some other less known manganese ores as colloidal complexes. In this connection he also mentions lampadite, a cupriferous hydrate of manganese. The copper may be present simply by adsorption.

The silicate nickel ores have always been a confusing group, but an interpretation involving colloidal substances seems to simplify the matter. It will be remembered that these ores are hydrous magnesium nickel silicates. The non-metalliferous foundation seems to have accumulated first as a gel,[12] and subsequently to have adsorbed some nickel compound, perhaps nickel silicate, and a magnesium compound, and thus a mixture of two substances occurs whose proportions may vary greatly within short distances.

Coagulation or Flocculation of Sediments.—It has long been known that even the finest sediments which come out to the sea in the waters of our great rivers fall to the bottom long before they get far into the sea, and that the main body of the ocean is made of comparatively clear water. This speedy precipitation of sediments has also been ascribed to the saltiness of the sea, but the connection had not been worked out until recent studies in colloids and their relations to electrolytes.

An electrolyte is a salt, or in some cases a base or an acid, in water solution through which electric current flows. Salts are generally better electrolytes than acids. The theory is that the electrolyte is ionized, e.g., sodium chloride becomes Na^+ and Cl^- in solution, magnesium chloride becomes Mg^{++} and $2Cl^-$ in solution. The higher the valence of the base part of the salt (the positive ion), the more powerful the electrolyte, as a coagulant of negatively charged suspensions, and the power seems to bear no definite relation to the valence. Aluminum chloride, for example, is hundreds of times more potent than sodium chloride. The charge on the electrolyte and on the colloid must be of opposite sign. The aluminum ion of $Al_2(SO_4)_3$ has a positive charge, and aluminum is trivalent in the sulphate. Since most colloids are negative, aluminum sulphate is one of the most effective flocculators.

---

[12] Krusch, P., loc. cit.

These salts are all three in the sea. The sodium chloride makes up fully three-fourths of all the salts there, while the alum constitutes a very small fraction of one per cent, but because of its greater activity, it may be as efficient as the much more abundant sodium chloride. For our purposes, however, it is not material which does the work. A much more important question is, how long have the seas been salt enough to coagulate the fine clays in colloidal suspension as they come down? We have shale rocks made of such clays of all ages back through the Mesozoic, Paleozoic, and perhaps well into the Proterozoic. Such clays of course would settle out of quiet waters without the assistance of an electrolyte, but such waters certainly would be difficult to find on the continental shelf. Therefore we may safely assume that these shales made of extremely fine clays were largely precipitated by electrolytes, and that the sea was salt enough in those Proterozoic days to effect their coagulation.

Experiments show that one per cent. sodium chloride solution will coagulate clays rather quickly and that one-tenth per-cent. alum solutions will bring them down in a few hours, so we need not assume that the sea had a greater saltiness than, say, 25 per cent. of its present salinity in order to bring down the clays. In this connection it may be interesting to note that the age of the ocean has been calculated on the basis of the NaCl in the water, assuming essentially the same rate of inflow as at present, and only trifling losses as compared with the present salt in the sea. The latter assumption is easily established. The former is probably safe. Dividing the rate by the amount of salt in the sea, Chamberlin and Salisbury arrive at the figure of 370,000,000 years. If anything like one-fourth the present saltiness would be necessary before effective precipitation should take place, then these old shales may be at least 250,000,000 years old, a much larger figure than usually given by geologists for the period since early Proterozoic. On the basis of these figures they may not be more than 300,000,000 years old. Pirsson and Schuchert's geology gives 80-90 instead of 370 million years.

Many colloidal suspensions, like those in the muddy waters of lakes, owe part of their stability to the fact that their particles all carry like charges. Of course, the movements of the waters help to keep the particles up, but in spite of the movements, electrolytes will bring them down, so it seems probable that the electric conditions are as significant in suspensions as is the agitation of the water. If the particles of the colloidal material, and other substances in the solution are similarly charged the tiny pieces of the colloid do not fall.

Even when waters are allowed to stand as still as they can in a laboratory, some of these colloidal suspensions do not clear up in months. It is believed that the particles are so small that their own Brownian motion prevents them from clinging together into flocculent masses large enough to fall through the water. Stokes' formula gives the following relation:—

$$V = 2r^2g \,/\, 9k.(d - d')$$

V is the velocity of fall of spherical particles of radius r; k is the viscosity of the fluid; d′ and d are the densities of the fluid and the particle respectively, and g the acceleration due to gravity. If water and the same kind of particles are used on the same table for experiment, the variables all drop out but r.

Theoretically, then, the rate of fall can not quite be zero, and permanent suspension becomes impossible if the particle is denser than the medium, but practically, since V varies with the square of the radius, we can find particles so small that their fall would be so slow that convection currents and Brownian movement would be ample to keep them up. When two or more coagulate together, their Brownian kicks are proportionately much smaller, and the particle begins to descend. Protecting films of gelatine or other substance which does not mix readily with the medium may surround each suspended particle and prevent its cohering or coalescing with others into masses large enough to fall. Any influence then, Brownian motion, similar electric charge, or protecting films, may help keep the particles small and aid them in staying in suspension.

Colloids as Cements.—It has long been known that nothing soluble occurs in the shales to hold them together, and yet they are extremely resistant to pulling strains. We say their tensile strength is high. The ultra clay in shales and clays has been shown by ceramists to consist largely of hydrated aluminum silicates, such as kaolin and halloysite, also nontronite, iron hydroxides, silicic acid, organic matter, and possibly aluminum hydroxide. These in their finely divided state are all colloidal, and as binders they are stronger when dry than Portland cement. They are the cement of shales and the strength of some limestones. Colloidal silica also serves as a binder in many sandstones. It is known too that the silica cements now in the crystalline state were deposited in some cases in chalcedonic or colloidal condition.

In addition to this colloidal material in the shales it is known that opaline silica when subjected to the processes of metamorphism loses its H_2O and becomes crystalline quartz in a mica schist. Clarke[13] shows that colloidal matter contained in most muds and clays is perfectly capable of binding under the influence of pressure alone, and believes that shales owe most of their coherence to unions of this sort. He states on page 609 that it is possible for colloidal silica and colloidal hydroxides of aluminum and iron to react and form new silicates when the shales are metamorphosed into schists. Thus these finely divided materials play their parts in the make-up of metamorphic products derived from the shales.

This process must be closely akin to the one going on in the process of binding the materials of our stone roads. Grout[14] and Cushman[15] have been carrying on experiments on the cements of roads, and they think their work shows rather conclusively that the binding power of road-making materials is due to substances in the colloidal state, developed by hydrolyzing the oxides, probably of calcium, iron, and aluminum, thus making the body more or less plastic. Subsequently by crystallization and dehydration they become firm, making a solid road.

Adsorption and Mineral Colors.—Very much can be said on the subject of adsorption and colloids which is not geologic, but a number of points certainly belong in this paper at this place. Every surface has an attraction for other substances. This holding-to a surface is called adsorption. Glue on a board or in a beaker adsorbs board or glass, that is, there is a strong attraction

---

[13] Clarke, F. W., Data of Geochemistry, U. S. G. S. Bull. **616**, p. 545.

[14] Grout, F. E., Journ. Am. Chem. Soc., **27**, 1037, 1905.

[15] Cushman, A. S., U. S. Dep. Agr., Bur. Chem., Bull. **85**, p. 92; Trans. Am. Ceramic Soc., **6**, 7, 1904.

between the surface of the one and the particles of the other.

Adsorption, then, probably explains some of the colors of minerals, inasmuch as the particles of the mineral crystal correspond to the surface of the wood or glass, and the coloring is in such minute particles as to be in the colloidal state. Examples of such intimate relationships are found in the carbon and iron oxide which give the smoky tint to cairngorm, and the carbon which is believed to be responsible for the color of amethyst. Rose quartz owes its color to the adsorption of colloidal titanium on its particles as they come together to build up the crystal, and chrysoprase is said to be colored much in the same way by nickel oxide. Feldspars have long been believed to owe their color to traces of iron oxide which seems to be adsorbed by the molecules of the feldspar.

The beautiful blue color of some halite has been shown to be due to metallic colloidal sodium, and probably the bluish tint of sylvite may be traced to the same cause. The colors of barite are thought by Patten to be due to various oxides. He has shown that it adsorbs salts of nickel, cobalt, chromium, iron and manganese. Calcite is practically never a colloid, but it shows rather high adsorptive powers for certain colloids. The amber calcite has been shown to be due to organic matter, and the amber fluorite is probably due to hydrocarbons. Ruby spinel seems to owe its beautiful tints to adsorbed chromium oxide, and cerussite in blues and greens to colloidal hydrous copper carbonate. More than likely, though this is not demonstrated, the soft tints of the zinc salts, calamine, and smithsonite, from Laurium, Greece, are due to the adsorption also of copper carbonates. The colors of many gems may probably be due to adsorption of some finely divided substance which becomes so intimately mixed with the gem materials, yet which occurs in such minute quantities, as almost to defy detection. This problem has only recently been taken up, and we may, as the work goes on, find much more in it than has yet been shown.

Colloids and the Flotation Process.[16] While the flota-

---

[16] Moses, F. G., Colloids and Flotation, U. S. Bur. Mines, Tech. Paper 200 furnishes many data for this section.

tion process now practiced in many of our ore concentration plants is not really a geologic problem, it is so closely connected with geologic materials that I venture to call attention to it here.

In the last few years, many of our large concentration plants have installed elaborate facilities for flotation of ores. By the use of this process, the heavy sulphides are separated from the gangue minerals in what might be called a reverse gravity method, because the heavy ores come to the top and are from there removed, while the lighter materials go to the bottom of the medium. But gravity has nothing to do with the process. If galena be wetted with water, and a drop of oil be put upon it, the oil displaces the water. Galena adsorbs oil much more strongly than it does water. On the other hand, if oil be spread over a quartz or calcite crystal and a drop of water be put upon it, the oil is at once displaced by the water. In other words, water is adsorbed much better by these common gangue minerals than is the oil.

For flotation the mineral is finely ground, usually in a wet condition, fine enough to pass through a 48-mesh sieve. A very small amount of pine, or some other, oil with air is beaten into the water which already contains the pulp of ore and gangue. The beating must not go far enough to make an emulsion or bring the oil into a colloidal state. The oily froth is made up of films of colloidal thinness, but is not emulsified. In this mixture the fine particles of sulphides adsorb the oil because it wets their surfaces, float to the top by means of their little coats, disperse themselves in the froth, and are scraped off the flotation tank. Then the froth is beaten out and the ore is free from most of the gangue which has, because wet by water, gone to the bottom of the flotation tank. More than 60,000,000 tons of sulphide ores are thus treated in the United States every year and carried much more cheaply to a higher concentration than was obtained by the old methods.

In the following ways, then, the subject of colloids touches the flotation process. The oil coat held by adsorption on the sulphides is so thin that the oil is really in colloidal state; in like manner, films of water of colloidal thinness wet or are adsorbed to the gangues. In a few cases colloidal kaolins and other clay substances are present, which interfere with the flotation, by adsorbing the oil and preventing its use by the sulphides. Here too, the trouble increases if the oil is emulsified, for the finer the oil particles are, the more readily do the clay colloids adsorb them. Usually the ore is not ground fine enough so that its slime is at all colloidal. Electrolytes are sometimes used as an aid in flotation, for they help to prevent emulsions, or coagulate them if formed.

Plasticity in Clays.—This subject has been the theme for many interesting papers, and of some heated discussions, but the air seems to be clearing, and Ashley[17] writes that it is pretty generally believed by the students of ceramics that the control of plasticity in clays is a matter of the control of colloids. A number of other writers can also be quoted in support of this position. A French ceramic chemist, T. Schlösing, in 1888, P. Rohland in various papers from 1902-9, A. S. Cushman, quoted above, and F. W. Clarke in the Data of Geochemistry, all agree that the plasticity of clays can be very directly traced to their colloid content. Schlösing shows, according to Ashley, that the amount of colloidal material in the best clays is small, and rarely exceeds one and one-half per cent. As the percentage of material in the colloidal state decreases, so does the plasticity, and a clay with one-third of the amount mentioned is a lean clay. Likewise, if the amount is greatly increased above the one and one-half per-cent, the clay becomes less plastic, and more sticky.

It is well known that the plasticity of clays is destroyed by ignition and that the colloids are also made to change state by the same treatment. On the other hand, many thoroughly ignited clays absorb water quite as well as unignited ones. This makes it clear that the colloidal material is not the cause of the absorption of water, nor is the absorption of water vitally related to plasticity. Series of experiments have been made with lean clays to increase their plasticity, and it has been found that very poor clays can be made plastic enough to be worked successfully by adding small quantities of certain colloids; agar-agar .08% increases the plasticity of different clays as much as 40 and in some cases 60%, and aluminum cream produced the same effects by adding in much larger quantities, e.g. about 3%.

---

[17] Ashley, H. E., Bur. Stand., Tech. Paper 23, 1911.

As was shown on a previous page, colloidal material increases the tensile strength of shales, and it has been shown to do the same for clays. Other colloidal substances have also been used to increase the plasticity. Humus, for example, an organic colloid, produces beneficial results in lean clays. Clays in a cool, moist place improve in plasticity even within a few weeks. It is believed that the development of organic matter in the clay by the growth of bacteria, or even protozoa, is responsible for the improvement, for the protoplasm of these minute organisms is itself a colloid.

If plasticity of clays should be found to be dependent upon the inorganic colloids in them, it might be pertinent to ask if clays and shales laid in the sea would be more plastic than those laid in fresh water, where the finest or colloidal material had difficulty in being precipitated.

Ries[18] has shown that the fineness of the material, the thinness of the plates in the shale, and the colloids, are each in themselves inefficient to fully explain plasticity. His theory suggests that plasticity may be due to cohesion and adhesion factors which depend on the constitution of the molecule, but not on the chemical composition. It might be said that he does not seem to be fully satisfied with his explanation, for he adds that "practical work to improve the plasticity of clays may well follow lines already started, such as the addition of colloids, and weathering, which may mean the addition of colloidal material by bacterial growth."

One can never understand the raw materials and their relations to the finished products in cements, brick and terra-cotta, pottery, porcelain, enamels, and glass, until he has dipped rather seriously into the study of colloids from the geologic side. Weathering is a colloid-producing process, as well as a maker of most of the soils and the salts of the sea. Since macadam, brick, cement, and asphalt roads all start with materials whose vital properties are connected with the colloidal state of matter and the geologic processes that produce these materials, the road industry has real need of a colloid geologist.

Colloids in Soils. Perhaps this topic will take us as far into questions of physiography as the last has into metallurgical and industrial processes, but in the last

---

[18] Ries, H., Geol. Survey, W. Va., vol. 3, pp. 46-54, 1905.

analysis, all three go straight back to geologic processes, and involve geologic problems. Soils result from the normal geologic decay of rocks, primarily of silicate rocks. In their decay, the elements K, Na, Ca, and Mg usually go into true solution in their secondary salts, while silica, aluminum, and iron go chiefly into colloidal solution and constitute the ultra-clay material of clays and shales.

In solutions, the colloidal material can be separated from the crystalline material by the use of the Sharple's centrifugal machine, capable of producing a force seventeen thousand times that of gravity, or by the use of the Pasteur-Chamberland filter. This separation can also be brought about by coagulation by the addition of salts, and by dialysis.

In soils the body is essentially sand and clay, the sand being made of fragments of many kinds of minerals, but mostly of quartz; and the clays mostly of hydrous aluminum silicates, with smaller quantities of aluminum and iron hydroxides. When the salts mentioned above come to the soils they are carried on through, providing the water has free circulation and drainage below: but if there is insufficient rainfall to equal evaporation, then these salts may be left in the soils and be continually carried to the surface by evaporation of the water. The colloidal material, however, will usually be adsorbed and will remain in the soil. Too much of the latter tends to clog a soil and prevent the free and necessary movement of air and water.

This last item becomes particularly troublesome in soils that must be irrigated, for irrigation waters differ from rain waters in carrying both true solution and colloidal solution materials, thus furnishing more material to clog the soil than rain waters. The difficulty is still further increased by the fact that most of the water on irrigated lands is removed by evaporation so that everything of both kinds of solution is left in the soil. The colloids become a nuisance usually much before the salts do when ordinary stream water is used for irrigation. The colloids tend to cement the soil together some little distance below the surface, usually not beyond the reach of the plow, and produce there a "hard pan" layer. This interferes with the movement of the water, either up or down, and of course prevents the roots striking deeply. It can be broken up by deep cultivation, but the soil experts are now of the opinion that treatment with an electrolyte is really better. Aluminum sulphate has been successfully used in a number of cases. It acts much as the salts do in the sea, by coagulation of the colloidal material into little pellets, large enough so that the water and the air can get among them, and thus prevents their operation as cements.

In western United States, where most of our irrigation is carried on, there have been discovered in recent years great quantities of aluminum sulphate, and it is believed that a large use of this salt will greatly extend the life of our irrigated soils.

The subject of colloids in geology is just beginning to attract the attention of men who should be concerned with it. While the chemists have tackled their colloid problems with vigor and enthusiasm the geologists have all but neglected the whole field. There should be many geologists turning their attention seriously to the solution of the great numbers of problems now before us, such as these suggested in this paper, and there should be many more geologists keeping up with the literature that discusses these colloid problems.

Department of Geology and Geography,
Oberlin College, Oberlin, Ohio.

Art. IX.—*Primitive Pecora in the Yale Museum;* by Richard S. Lull.

[Contributions from the Othniel Charles Marsh Publication Fund, Peabody Museum, Yale University, New Haven, Conn.]

The genus *Hypertragulus* was established in 1873 by Professor Cope to include a group of deer-like creatures which in some respects resembled those of the genus *Leptomeryx* very closely. The main distinctions as shown by the dentition are as follows:

Hypertragulus possesses: the superior laniary canine, P^1, separated from both C^1 and P^2 by diastemata, upper molars without mesostyle, and M^3 bearing three ribs on its outer face, all of which are the converse of *Leptomeryx*. The lower dentition differs from that of *Leptomeryx* in the development of a caniniform P_1, a diastema behind P_2, a compressed and elevated P_3 which is shorter than the three-lobed P_4, and in the fact that in M_3 the posterior crescents are opposite each other, subequal in size, and not separated posteriorly by a fissure.

The geological range of *Hypertragulus* is apparently from Middle Oligocene Oreodon beds to Lower Miocene Rosebud. Geographically, the genus is found in the Great Plains region—Colorado to South Dakota, Montana, Canada, and the John Day Basin of Oregon.

The following species have been named, *H. calcaratus* Cope from the Great Plains region being the type of the genus.

H. calcaratus Cope 1873.
H. tricostatus Cope 1873.
H. transversus Cope 1889.
H. hesperius Hay 1902.
H. ordinatus Matthew 1907.
Allomeryx planiceps Sinclair 1905.

To which are added in this paper:

H. minutus, sp. nov.
Leptomeryx obliquidens, sp. nov.
Nanotragulus loomisi, gen. et sp. nov.

Hypertragulus calcaratus Cope.

The original description of the genus is brief, and two species, *H. calcaratus* and *H. tricostatus,* are mentioned without definition, the first adequate description appearing in Paleontological Bulletin No. 16, p. 7, under the genus *Leptauchenia.* In this description Cope mentions several characters which are really of generic value, the real specific distinctions of *H. calcaratus* being apparently as follows:

Molars bear a slight external cingulum which has a small cusp between the two outer crescents, representing either an incipient or vestigial mesostyle. M^3 relatively somewhat smaller in *H. calcaratus,* and the metastyle, while variable, never as pronounced as in the John Day form. In general, the teeth are somewhat smaller than in the John Day jaws, and in one instance where P_3 is preserved, it is markedly smaller. Interrupted cingula are present in all the *Hypertragulus* jaws before me, although omitted from every published figure.

Cope's measurements are:

	mm.
Length of five molars	26
Length of three true molars	17.5
Length of last true molar	8
Width of last true molar	7

This species is smaller than the smallest of the genus yet described (Cope).

Of the Yale material, assuming Cope's figures to be correct, but one specimen agrees exactly with the type in the combined length of the five teeth, and even in this specimen M^3 is only seven-eighths as long. The third molar, however, has been shown to be variable and the degree of wear also affects its dimensions. I find no evidence in the Yale Great Plains material of even subspecific departure from *H. calcaratus.*

Hypertragulus tricostatus Cope.

Cope thought he recognized a second species about the size of *H. calcaratus* but distinguished therefrom by the presence of but three ribs on the outer side of the third molar, the characteristic heel being absent. This molar also lacked the posterior cingulum. *H. tricostatus* is considered a synonym of *H. calcaratus* by Hay, and with this the present writer agrees, for out of twenty-four individuals in the Yale Collection represented by the upper molar teeth, the metastyle of M^3 varies from good development to marked reduction in at least four specimens, but is never entirely absent. The degree of development of the posterior cingulum is also variable to total obsolescence. As *tricostatus* is founded upon a single specimen, it seems to represent merely the extreme of a variational series of which the means were still extant and therefore not a separate species but a varietal tendency. Cope himself says in 1884 (p. 24): "I know but the one species, the *H. calcaratus* Cope," a statement which, as Matthew rightly says, invalidates *H. tricostatus.*

MATERIAL FROM THE JOHN DAY FORMATION.

Hypertragulus hesperius Hay.

Both Cope and Leidy have discussed hypertragulids from the John Day Basin of Oregon, but have referred them either to *H. calcaratus* or to *Leptomeryx evansi* without further attempt at specific differentiation. Scott has also figured John Day material belonging to this genus under the name *H. calcaratus.* Hay, however, in his catalogue, p. 675, gives the new name *H. hesperius* to the John Day hypertragulids, with neither definition, indication of type, nor restriction to any one level. Doctor Matthew informs me (personal communication) that Cat. No. 7918, A. M. N. H., the specimen figured by Cope and later by Scott, is to be regarded as the type. It consists of the skull and jaws and a few fragments of the skeleton. The matrix is "greenish tinged with buff and rather hard" but there is no record of its exact level or locality, save that it is from the John Day. The matrix color, judging from the known distribution of the large amount of John Day material in the Yale Collection, would indicate middle John Day as the horizon of this type.

Cope's description of *H. hesperius* gives no specific characters other than that the size is the same as *H. calcaratus,* sometimes distinctly larger; later (1884, p. 25) he says "I can not distinguish the John Day species from the *H. calcaratus,* although the size is generally distinctly larger." He does, however, use the John Day material for his description of the morphology of the feet of the genus, but this part of his description is generic and not specific.

The type skull is fairly complete, except that it is injured in the pterygoid region, and represents a fully mature animal in which the tooth pattern of M^1 is entirely obliterated. Anteriorly, a portion of the large canine alveolus is present, but no trace of the premaxillaries is preserved. There is no jugal process, but the postorbital process of the frontal forms about half the posterior margin of the orbit. Scott's figure, which was drawn by Mr. R. Weber, is the more accurate of the two except for the restoration of the superior canine *behind* the caniniform P_1, which the author evidently mistook for the true lower canine tooth. Scott further restores the orbit as though it were closed behind, for which there is no evidence.

Allomeryx planiceps Sinclair.

This form agrees with *Hypertragulus* in the absence of the mesostyle on the molars and in the development of the metastyle on M^3. It is distinguished by the closure of the orbit behind by the frontal and jugal processes which overlap but are not completely fused. The bullæ are small and separated from the basi-occipital by an outgrowth of the petrosal. The brain-case is shorter than in *Hypertragulus,* and the interorbital tract and sagittal crest lie in one plane.

Merriam and Sinclair in a later paper (1907) doubt the generic rank of these several characters. The closure of the orbit, however, is an evolutionary advance which is significant, especially as in the known species of *Hypertragulus* the jugal process is undeveloped.

An imperfect skull, No. 10227, Y. P. M., shows *Allomeryx* characters in so far as preserved, especially those noted in the basicranial region. It also possesses an ample brain-case. Unfortunately the postorbital region is not preserved. The Yale skull is from the upper John Day beds.

Hypertragulus ordinatus Matthew.

This species is based on a complete lower jaw (No. 13011, A. M. N. H.) from the lower Rosebud beds on Porcupine Creek, South Dakota. It is larger than the type species of the genus, *H. calcaratus,* and about equal to *H. hesperius.* It may be distinguished from either by the following characters: Closing of diastema between P_2 and P_3, and great reduction of diastema between C_1 and P_1; increased length of diastema between caniniform P_1 and P_2, so that general proportions of jaw are about the same; molar crowns more hypsodont than in *H. hesperius,* about as in *H. calcaratus;* P_1 and P_2 shorter and proportionately higher than in the John Day species but less reduced than in that from the White River. In the upper Rosebud this species is replaced by *Blastomeryx.*

Hypertragulus minutus, sp. nov.

Holotype, Cat. No. 10545, Y. P. M. Upper Oligocene (upper John Day), Oregon. Fragments of upper and lower jaws and teeth.

A very small form, apparently *Hypertragulus.* Distinguishable from *H. hesperius* mainly by its small size. Cingula well developed, but metastyle of M^3 much reduced, not forming the conspicuous "heel" of *hesperius.* Its measurements are, compared with those of *hesperius:*

	H. minutus mm.	*H. hesperius* Yale spm. mm.
Length, M^1 to M^3	14	20
Length, M^3	5.8	8.5
Width, M^3	5	8.5

Leptomeryx obliquidens, sp. nov.

Holotype, Cat. No. 10541, Y. P. M. Oligocene (Protoceras beds), Hermosa, South Dakota. Poorly preserved skull and jaws, with entire series of cheek teeth.

Distinguishing characters.—Large size; superior molars obliquely set; temporal ridges meeting at a wide angle to form the sagittal crest which is sharp and thin throughout its preserved length; bullæ laterally compressed, elongated oval in shape.

This form is distinguished from *L. evansi* of the Oreodon beds, aside from its geological level, by being about one fourth larger, and by the great obliquity of the molars. The bullæ in all specimens of *L. evansi* before me are more inflated. The type is an aged animal, hence in their present state of wear there is little that is distinctive about the teeth. The general shape of the mandible and the position of the mental foramina, of which there are two, are about the same in both species. Cingula are absent and the external basal pillars are feebly developed, as in *evansi.*

Measurements are as follows:

	L. obliquidens Holotype mm.	Ratio	*L. evansi* Cat. No. 10542 Y. P. M. mm.
Length, tooth-row, P^2 to M^3 (left)	48	1.23	39
Length, M^1 to M^3	26	1.24	21
Length, M^3	9	1.20	7.5
Width, M^3	12	1.54	7.7
Width, P^2	5	1.25	4
Length, tooth-row, P_2 to M_3	51.7	1.21	42.5
Length, M_1 to M_3	31	1.26	23.7
Length, M_3	14	1.29	10.8
Width, M_3	7	1.40	5

Nanotragulus loomisi, gen. et sp. nov.

(Fig. 1.)

Holotype, Cat. No. 10330, Y. P. M. Collected by R. S. Lull in 1908 at Castle Butte, Big Muddy River, near Spanish Mines, Wyo. Miocene (lower Harrison). Palate with upper cheek teeth complete, right lower jaw fairly complete, with six teeth, left with series of four teeth. Detached premolar. Imperfect petrosal?

Distinguishing characters: Upper dentition.—Teeth subhypsodont; P^2-M^3 a compact series without diastemata; mesostyle lacking on molars; no trace of molar cingula nor of internal basal pillars; molars simple, of four crescents each; M^3 with four external pillars; metastyle enlarged toward base of tooth. Premolars three only, preserved in situ; P^2 trenchant, single-cusped, two-rooted, slightly grooved on outer face. P^3 also trenchant, of greater antero-posterior diameter than P^2, apparently three-rooted, with postero-internal cingulum but no internal cusp (deuterocone), and with two faint external ridges. P^4 a unique tooth, triangular in section, with outer crescent not fully evolved, flanked by three faint ridges on its outer face; postero-internal cingulum forming a sharp, straight ridge abutting against the well developed deuterocone but distinct therefrom in the unworn tooth. Measurements:

	mm.
Length P^2 to M^3	27
Length, M^1 to M^3	17
Length, M^3	7
Width, M^3, at base of ant. crescent	5

Lower dentition.—P_3-M_3 a continuous series. Probably slight diastema separating P_2 and P_3, but condition of specimen renders this uncertain. Molars simple, with slightly developed cingula on anterior face. No accessory pillars. Posterior column of M_3 as in *Hypertragulus,* with outer and inner lobes opposite and not separated posteriorly by a cleft as in *Leptomeryx.* P_2 a simple, compressed cone, two-rooted, slightly recurved. P_3 high-crowned, but not so much so as in *Hypertragulus,* hardly rising above P_4, with a main anterior cusp and rather prominent heel. P_4 the most complex, laterally compressed, high protoconid, and pronounced heel. Antero-internal cusp well developed. Protoconid flanked on inner side by a second cone which is confluent with it,

FIG. 1

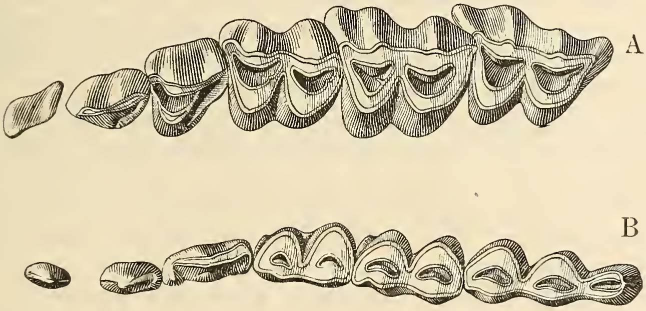


FIG. 1.—*Nanotragulus loomisi,* gen. et sp. nov. Holotype. A, left upper dentition. B, right lower dentition. × a little more than 3.

while a third bears the same relation to the heel. Thus there are three internal buttresses separated by valleys. No traces of cingula on premolars. Measurements:

	mm.
Length, P_2 to M_3	ca. 28*
Length, M_1 to M_3	18.3
Length, M_3	8
Width, M_3	3.5

*Slightly elongated by fracture between P_2 and P_3.

A detached small, slender, two-rooted premolar is present. It probably represents P_2 of the left ramus and is not distinguishable from that already described.

Relationships.—This is the smallest artiodactyl thus far described from the Lower Miocene. In this respect it is suggestive of the Oligocene *Hypisodus,* with which it also agrees in hypsodonty and in the absence of the mesostyle. They differ, however, in the absence of a buttress on the posterior external crescent of $M^{1\cdot2}$ and in the character of the premolar teeth. The inner anterior crescent of M^1 is markedly different.

The form under discussion differs from *Leptomeryx* in the absence of mesostyles, character of heel of posterior lower molar and of the premolars, and in size. With *Hypertragulus* it agrees in the absence of mesostyle and the character of the heel of M_3, but differs again in its much smaller size and the character of its premolars. *Nanotragulus* differs markedly from *Merycodus* in size and geologic level, also morphologically in the absence in the former of the mesostyle, in the convergence of the molar crowns, and in the character of the premolar teeth. They agree mainly in hypsodonty.

From its contemporary, *Stenomylus,* the new genus also differs very markedly in size and in the character of the premolars. The two genera agree, however, in hypsodonty, and in the absence of mesostyle, though the latter is indicated on M^1 of *Stenomylus.* In *Stenomylus,* moreover, the external face is relatively smooth except for parastyle and metastyle. In the lower dentition of *Stenomylus* there is greater simplicity, especially in P_4, which in no way resembles that of *Nanotragulus.* In other words, *Nanotragulus* is deer-like, not camel-like as is *Stenomylus.*

I can not at present place the new genus elsewhere than in the Hypertragulidæ, but it is not clearly derivable from any known Oligocene form except possibly *Hypisodus*.

The generic name *Nanotragulus* refers to its dwarfed size, while the species is named for Professor F. B. Loomis of Amherst College, leader of the joint Amherst-Yale expedition of 1908 during which the type was collected, and the first to recognize its unique character.

References.

Cope, E. D. 1873A. [On *Menotherium lemurinum,* etc.] Proc. Acad. Nat. Sci., Philadelphia, 25, 419-420.

—1873B. Third notice of extinct Vertebrata from the Tertiary of the Plains. Pal. Bull. 16.

—1884. On the structure of the feet in the extinct Artiodactyla of North America. Proc. Amer. Philos. Soc., 22, 21-27.

—1889. The Artiodactyla. Amer. Nat., 23, 111-136.

Leidy, Joseph. 1873. Contributions to the extinct vertebrate fauna of the Western Territories. Rept. U. S. Geol. Survey Terr., 1, 14-358.

Matthew, W. D. 1907. A Lower Miocene fauna from South Dakota. Bull. Amer. Mus. Nat. Hist., vol. 23, 169-219.

Merriam, J. C. and Sinclair, W. J. 1907. Tertiary faunas of the John Day region. Univ. Calif., Bull. Dept. Geology, vol. 5, 171-205.

Scott, W. B. 1899. The selenodont artiodactyls of the Uinta Eocene. Trans. Wagner Free Inst. Sci., Philadelphia, 6, 1-121.

Sinclair, W. J. 1905. New or imperfectly known rodents and ungulates from the John Day series. Univ. Calif., Bull. Dept. Geology, vol. 4, 145-161.

Art. X.—*A Critical Phase in the History of Ammonites;* by C. Diener.

The extinction of ammonites, those masters of the Mesozoic seas, near the close of the Cretaceous period is a fact well known to all students of palæontology. The number of their families and genera is diminishing gradually during the Senonian epoch. Five species only reach into the stage of the Mæstrichtian. Not one passes the fatal border of the Danian.

It is, however, less known, that the existence of ammonites was threatened by a similar crisis at a considerably earlier period of the Mesozoic era. They passed through a very critical phase at the boundary of the Rhætic and Liassic stages. All but one phylum of Triassic ammonites became extinct at the close of the Rhætic epoch. By the survival of this single phylum, which in the Lower Lias gave rise to the development of a new and rich fauna, the ammonites were saved from complete extermination.

E. v. Mojsisovics was the first to notice this remarkable crisis in the history of Triassic ammonites. For fuller details the reader is referred to J. F. Pompeckj, "Ammoniten des Rhæt" (Neues Jahrb. f. Mineral., etc., 1895/II, pp. 1-46) and to some of my own memoirs.

The Upper Triassic deposits of Tethys are divided generally into three subdivisions, the Carnic, Noric and Rhætic stages. E. v. Mojsisovics divided both the Carnic and Noric stages into three substages, thus imparting to the Rhætic stage a taxonomic value inferior to that of the two preceding ones. Many genera belonging to all the known families of Upper Triassic ammonites reach the acme of their development in the Carnic stage. Although a considerable number of older genera are found for the last time at this level, the ammonite fauna of the Noric stage is a continuation and evolution of the Carnic fauna in every branch of life. The last life phase of the Noric stage seems to be the first which is distinguished from the preceding by the apparent extinction of numerous wide-spread and important genera and by the absence of any new elements either of foreign origin or derived from endemic forms. Nevertheless it is doubtful whether a single family of lower Noric ammonites becomes really extinct.

This decay is completed in the Noric epoch. From this stage eleven forms of ammonites only have been enumerated by Pompeckj, all of them of decidedly Triassic affinities. Five belong to the Noric genus *Choristoceras* and its subgenus *Peripleurites,* a phylogerontic descendant of the Ceratitidæ, whose last whorl became gradually uncoiled. *Arcestes,* the true leading genus of the Hallstatt limestone, is still represented by two species. To these are added one species of *Monophyllites* (*Mojsvarites*), of *Megaphyllites,* and a specifically undeterminable representative of *Cladiscites,* all genera of considerable vertical range. A single newcomer is indicated by *Hesperites,* a genus still imperfectly known, which is probably allied to the family of Trachyceratidæ.

It is noteworthy that not a single ancestral representative of Liassic ammonites is recognized in this assemblage. The discovery of one other genus is to be expected beds of Rhætic age. This is *Phylloceras* or, more exactly, with certainty, although it has as yet not been found in *Rhacophyllites,* if this subgeneric designation is extended to all widely umbilicated species of *Phylloceras. Rhacophyllites debilis* Hau. and *R. neojurensis* Quenst. are among the most common leading fossils of the upper Noric substage. In the Lower Lias, *Phylloceras, Rhacophyllites* and *Euphyllites* are remarkable for their richness and variety. The apparent intermittence of *Phylloceras* in the Rhætic is therefore purely accidental. It is in reality the only genus surviving the general extermination of Triassic ammonites.

The importance of the gradual decline of Triassic ammonites during the Rhætic epoch is evident from a comparison with the number of genera in the Carnic and Noric faunæ. Those faunæ do not contain less than 146 genera and subgenera of ammonites, which were reduced to six in the Rhætic stage. Hyatt was certainly right in speaking of a "culmination of ammonites in the Upper Trias after a period of uninterrupted progressive evolution from the early Devonian." Both the Carnic and Noric ammonites were highly varied, including forms with long and short body-chambers, with few and simple clydonitic sutures (*Lobites*) and with a very large number of the most complicated sutural elements (*Pinacoceras*); smooth, globose shells with serial lobes (*Arcestes*) and extremely flattened shapes (*Pompeckjites*); shells exhausting almost every possible combination of sculpture from the most graceful ornamentation (*Acanthinites*) to stout ribs (*Heraclites*) and profusely tuberculated costations (*Trachyceras*).

The close of the Rhætic epoch is marked by the final disappearance of all Triassic types, excepting *Phylloceras.* Primitive and highly specialized forms were equally subjected to this general extermination.

In the eastern Alps the beds of the lowest Lias follow above those containing a Rhætic fauna without any unconformity. There is no trace of a hiatus nor of any diastrophic movement between the two groups. Nevertheless the ammonite fauna of the lowest zone of the Mediterranean Lias is entirely different from that of the Upper Trias. The first impression of this Liassic fauna is the sudden introduction of a large number of types which are only a little less manifold and diversified than those of the Upper Noric, but do not exhibit any phylogenetic affinities with them. We are indebted to F. Waehner for their careful and detailed examination.

There is little doubt that the extinction of the different phyla of Triassic ammonites prepared the way for the evolution of a new and vigorous stock, which originated from the genus *Phylloceras,* the only one which connects the faunæ of the Triassic and Liassic periods. *Phylloceras* is the ancestor of the two leading families of the lowest Lias, the Arietitidæ and Lytoceratidæ. Waehner and Pompeckj have demonstrated their intimate relationship with *Psiloceras,* the most primitive element of the Arietitidæ. Together with *Psiloceras,* more specialized types of the Arietitidæ: *Ægoceras, Schlotheimia, Arietites,* make their appearance in the deepest zone of the Lias. But they are comparatively rare, *Psiloceras* remaining the predominant genus in this and the following life-phase. All these genera are linked together most closely with the ancestral *Psiloceras.*

Of equal moment is the sudden appearance of the Lytoceratidæ in the Lower Lias, where they are represented by the genera *Lytoceras, Ectocentrites* and *Pleuracanthites.* Forms transitional between *Pleuracanthites* and *Psiloceras* have been described by Waehner. Thus *Phyl-*

loceras was destined to give rise to all Lower Triassic ammonites by the intervention of *Psiloceras.*[1]

Thus an aspect quite different from that of the Upper Trias is given to the ammonite fauna of the Lower Lias. Not one of the numerous and diversified genera of world-wide distribution, belonging to the families of Arcestidæ, Cladiscitidæ, Pinacoceratidæ, Haloritidæ, Tropitidæ, Didymitidæ, Ceratitidæ, Tirolitidæ, and Trachyceratidæ is represented in the latter. Their place has been taken by Arietitidæ and Lytoceratidæ. *Phylloceras,* which never played an important part in the fauna of the Upper Trias, was the only survival and was destined to become the ancestor of all Liassic ammonites.

In direct opposition to these facts, Steinmann denied the extermination of Triassic ammonites at the close of the Rhætic epoch. His reconstruction of a phyletic tree, in which *Macrocephalites* is branching off from *Juvavites, Sphæroceras* from *Halorites, Harpoceras* from *Discotropites, Desmoceras* from *Arcestes, Pachydiscus* from *Cladiscites,* need not be discussed here. It means toying with possibilities, the reality of which can never be proved.[2] One of his critical arguments, however, deserves consideration. He believes the palæontological record not to be sufficiently perfect to prove a real decline of the Triassic ammonites during the Rhætic epoch. It is true that cephalopod-bearing strata of Rhætic age have scarcely been discovered up to now outside the north-eastern Alps. But here they are as rich in ammonites as

---

[1] In connecting *Psiloceras* with *Phylloceras* (*Rhacophyllites*) I am following J. F. Pompeckj's view, which has been set forth by this author in his memoirs, "Note sur les *Oxynoticeras* du Sinémurien du Portugal, etc." (Comm. serv. géol. Portugal, VI, 1906-1907, p. 332) and "Zur Rassenpersistenz der Ammoniten" (3. Jahresber. d. niedersächs. Geol. Ver. Hannover, 1910, p. 82). E. v. Mojsisovics prefers to consider a specialised type of *Monophyllites* (*Mojsvarites planorboides* Winkler) as the ancestor of *Psiloceras.* Winkler's description and illustration, on which this suggestion has been based, are not absolutely reliable, and the type-specimen itself has, unfortunately, been lost.

It makes, however, little difference, whether the one or the other view is adopted, *Mojsvarites* itself being closely related to the Phylloceratidæ. According to Pompeckj, one genus only, *Phylloceras,* persists throughout the Triassic and Jurassic periods. In following E. v. Mojsisovics we have to record, simultaneously with the decline of *Monophyllites,* the first appearance of a new and transitional form, connecting this genus with *Psiloceras,* the undoubted ancestor of all Arietitidæ.

[2] Its only advocate is O. Wilckens (Naturwiss. Wochenschrift, N. F., X., No. 45, Jena, 1914, p. 20).

many beds of the Ladinic or Noric stages. Our knowledge of Rhætic ammonites is certainly not more limited than that of Permian ammonites after the discovery of the Artinsk and Sosio fauna. There is, consequently, as much evidence of a decline of the group during the Rhætic, as there is of a decline of the trilobites during the Carboniferous and Permian.

Such are the facts. They show us a great dying-out of ammonites towards the close of the Triassic and a rebirth, as it were, of a new fauna in the early Liassic, giving rise to the great wealth of Jurassic ammonite evolution. In entering into a discussion of the probable causes of this remarkable event in the life history of ammonites, we have to face the grave problem of the repeated extinction of large and flourishing groups of organisms. That this extinction has been partial only, affecting all but one stock of Triassic ammonites, marks the special case of our problem.

If we reflect on the multitude, the variety, and the complexity of the facts to be explained, and the scantiness of our information regarding them, we shall be ready to acknowledge that a full and satisfactory solution of so profound a problem is hardly to be hoped for, and that the most we can do in the present state of our knowledge is to hazard a more or less plausible conjecture.

In discussing the possible causes of the decay and final extermination of Upper Triassic ammonites, it will be best to follow the lines which have been traced by H. F. Osborn in his memoir on the causes of extinction of Mammalia (Amer. Naturalist, XL, 1906, p. 769).

Changes of Geographical Conditions.—The Triassic was on the whole a geocratic (land) period. A transgression of marine Rhætic beds is confined to the coasts of western Europe. It is counterbalanced by a regression of the sea in southern China, Japan, North and South America, where the Rhætic stage is represented by deposits of terrestrial and lacustrine origin only. There is but a small change in the distribution of land and sea during the Lower Lias, which in some regions of the ancient geosynclines is marked by a transgression of a rather limited range. The extinction of Triassic ammonites consequently does not admit of an explanation by changes of geographical conditions.

Changes of Climate.—The importance of this factor has been advocated very strongly by C. Schuchert,[3] who insists on a general lowering of the temperature during the Liassic period, chiefly on the strength of the arguments of Handlirsch. I am happy to agree with this learned author in the opinion that the facts which prove the influence of climatic changes are many and weighty, but I think that the extinction of Triassic ammonites at the close of the Rhætic does not admit of this explanation.

It can hardly be too often repeated that the decay of ammonites, near the close of both the Triassic and Cretaceous periods, was gradual, that in the first instance it clearly began in the Upper Noric and continued throughout the Rhætic. Now, we are well informed about the climatic conditions of Upper Noric time, due to the discovery of rich faunæ of reef-building corals in this substage. Such faunæ are known to us from the Austrian Alps, from Timor, Nevada, Oregon and Alaska. J. Perrin Smith demonstrated the identity of nearly all his Alaskan species with types from the Upper Noric Zlambach beds of the Salzkammergut. The presence of this fauna under the 60th degree of north latitude is contradictory to the suggestion of a lowering of temperature in the Upper Noric seas. It may be equally well to call attention to the wide distribution of several species of ammonites and bivalves (*Pseudomonotis ochotica*) throughout the Pacific Ocean and into the arctic region (New Siberia), which is in favor of a comparatively equable but not of a low temperature.

Nor does the flora of the Rhætic stage exhibit any traces of increasing cold. It is of a remarkable uniformity in North America, England, Sweden, Germany, eastern Greenland, Spitzbergen, Persia, India, Japan, China, New South Wales, New Zealand, South Africa, Argentina, Chile and Honduras, and seems to prove a climate more uniform and milder in the polar regions than that of the present day.

If a period of cooling set in at the close of the Rhætic epoch—and I do not dissent from Professor Schuchert's opinion in this respect—it came too late to influence the extermination of Triassic ammonites, for this had been heralded long before by their gradual decay.

---

[3] Ch. Schuchert, Climates of geologic time, Carnegie Inst. Washington, Publ. No. 192, p. 284.

Lack of Internal Adaptation and Inadaptability.—*Arcestes* is one of the most persistent ammonite genera, ranging from the Anisic into the Rhætic stage, without undergoing any modifications of its characters. Thus its inadaptability can scarcely have been the primary cause of its extinction.

In the family of Ceratitidæ Hyatt signalized the first symptoms of general regression by the appearance of uncoiled and turriliticonic genera in the Noric stage. The development of uncoiled shells, which reaches its climax in the lower and middle Cretaceous, is considered as a sign of degeneration by many palæontologists. To this view I cannot assent. The best instance of this mode of development is *Lytoceras*. It is one of the most conservative types from the Lias up to the Neocomian, when suddenly a large number of uncoiled, straight, hook-shaped and even turriliticonic genera branch off from the old stem. All this stock flourishes for a considerable time. This does not mean degeneration, but adaptation to new and different forms of marine life, from a benthonic swimming to a chiefly creeping or even sessile mode of living. Still less can *Lytoceras* be stigmatized as degenerating, if we take into consideration the fact that it survives all its uncoiled offspring and persists into the Senonian stage. I consequently find in the development of uncoiled shapes in the family Ceratitidæ, which begins with *Choristoceras* in the upper Carnic and reaches its climax in the lower Noric substage, a sign of increased adaptability to new modes of life, not of degeneration.

Peculiarities of Constitution.—It is only touching the fringe of a great subject, if I venture to call attention to Brocchi's hypothesis, that the gradual and successive disappearance of species might be regulated by a constant law, that their death, like that of individuals, might depend on certain peculiarities of constitution. In our special case, as in many others, the extermination of a large and flourishing group of animals can be explained satisfactorily neither by external nor by such internal causes as are accessible to examination. In such cases Brocchi's hypothesis, although dealing with powers and influences of a still hitherto obscure nature, may yet serve its purpose as a first attempt to approach the solution of a hitherto unexplained problem.

University of Vienna.

Art. XI.—*Saccoglottis, Recent and Fossil*; by

Edward W. Berry.

One of the most interesting of the romantic assemblages of fruits and seeds that constitute the sea drift, typically developed in the tropics, is *Saccoglottis amazonica*. Although the plant itself was described by Martius from the lower Amazon, its strange fruits had been known in Europe for over two centuries before their identity became known. They were figured by Clusius in 1605 and mentioned by Sloane in 1696 but it was not until 1889 that their botanical identification was accomplished, the details of this story having been told by both Morris[1] and Guppy.[2]

The latter author deals very fully with this species, whose fruits are widely distributed in the Antillean sea drift, and are occasionally washed ashore in Europe. The fruits possess great buoyancy because of the ligneous pericarp and the numerous large resin cysts which it contains. Although the fruits are such ideal ocean travellers there is no evidence that they have established themselves on any of the Antilles where they are habitually washed ashore, unless the few plants in southern Trinidad have been introduced in this way through the agency of the Orinoco drift.

According to Guppy this species is an inhabitant of the estuarine forests of the great rivers of Brazil, the Guianas, and Venezuela. As far as I know it has never been recorded from Colombia or Central America or anywhere on the Pacific coast. Great interest, therefore, attaches to my finding the fruits in 1919 near Old Panama in the sea drift of Panama Bay. Obviously the parent plant must grow somewhere on the Pacific watershed of Central or Northern South America. Two of these fruits from Panama Bay are shown in the accompanying figures. One with the warty sarcotesta intact and indicative of the fruit not having been in the water a long time, and the other with the outer coat worn away thus exposing the resin cavities and representing the usual form of preservation of these fruits in the Antillean sea drift.

---

[1] Morris, D., Nature, Jan. 31, 1889; Nov. 21, 1895.

[2] Guppy, H. B.; Plants, Seeds and Currents in the West Indies and Azores, pp. 133-137, 1917.

The genus Saccoglottis consists of about ten existing species found in the region from Brazil to Venezuela, and is a member of the restricted family Humiriaceæ of the order Geraniales. The family is usually divided into the three genera Humiria, Vantanea, and Saccoglottis, and all of the known species are dwellers in the wet forests of Brazil, the Guianas, Venezuela and eastern Peru, except for the single species *Saccoglottis* or *Humiria gabonensis* Urban which is sometimes considered the type of a fourth genus—Aubrya.

Fig. 1.

Explanation of Fig. 1.

a. *Saccoglottis tertiaria* Berry. Side view of a prolate form.
b. End view of same showing the 5 seeds.
c. A single seed of same.
d. *Saccoglottis amazonica* Martius from Panama Bay.
e. End view of a worn fruit of this species showing seeds.
f. Same in side view.

The presence of Saccoglottis on the Pacific coast would suggest that the genus was an inhabitant of this general region before the Isthmus of Panama was closed, and the presence of a well marked fossil species, to be described presently, suggests an American origin for the family, and suggests further, that the single west African coastal species reached that continent either by means of an equatorial counter current, or before the continental outlines had assumed their modern form. As I have pointed out on a former occasion, there are a number of facts which suggest that Guppy, in his admirable studies on distribution, has underestimated the possibilities in this direction. Although the main equatorial currents might be expected to carry coastal types with seaworthy fruits from the Old to the New World, I see slight evidence of this ever having taken place, and there is a considerable body of evidence of dispersal in the opposite direction. If the present currents in the equatorial Atlantic preclude effective dispersal from west to east then we are forced to assume that the Tertiary oceanic circulation in this region differed from its present arrangement, and this could readily be brought about by changed continental outlines, even though we are not in a position to predict at the present time just what these outlines were.

One of the most interesting localities that I visited in 1919 was a place called Pisllypampa in the mountains north of Cochabamba, Bolivia. Here on a bleak and treeless pampa at an elevation of 11,800 feet I found a rich tropical flora of Pliocene age preserved in beds of tuff. This flora will be described in full in the Hopkins Studies in Geology. One of the most abundant elements in this Pliocene flora were the fruits of a species of Saccoglottis, which may be described as follows:

Saccoglottis tertiaria Berry, n. sp.

Fruits relatively small, varying from globular to prolate spheroidal in form, sometimes somewhat flattened by pressure during fossilization. Drupaceous in character, the thin outer flesh (sarcotesta or epicarp) being preserved as a carbonaceous incrustation in several specimens. The bulk of the fruit consisting of a woody stone or pericarp. The surface is slightly irregularly mammilated or warty, and thickly impregnated with resinous cysts, whose cavities conspicuously and thickly pit the surface of the woody stone with depressions from 1 to 2 millimeters in diameter. The stone has imbedded in it five large seeds, arranged symmetrically around the central axis, and these appear to break away tardily on drying as in *Saccoglottis amazonica* Martius, since several are found as fossils in a detached state. These seeds are narrowly elliptical in surface outline, about 2 centimeters long and 7 millimeters wide; the inner margins are truncated to a central, nearly straight, gable-like keel; the thickness of the seed, i.e., measured radially with respect to the fruit as a whole, being about 6 millimeters. There is some slight inequality in the development of the individual seeds, but generally all five seeds are nearly equally developed. The total dimensions of the fruit are from 2 to 2.25 centimeters in length and from 1.6 to 1.9 centimeters in diameter. No leaves that could be correlated with these fruits were found in the deposits.

No plant family except the Humiriaceæ has the features shown by these fruits—thin flesh, woody stone with numerous resin cysts, and 5 radially symmetrically arranged large seeds. I am unable to state the nearest living relative of these fruits, being much hampered by the lack of comparative material in the larger herbaria, and this is well illustrated by the number of years that elapsed before the botanists at Kew succeeded in determining the fruits of *Saccoglottis amazonica.* The fossil fruits, as may be seen in the accompanying illustrations, are in a good state of preservation. They are certainly referable to the Humiriaceæ and are strikingly like those of *Saccoglottis amazonica,* but as just stated, I have not seen the fruits of the majority of the Humiriaceæ. I have ventured to refer the fossil to Saccoglottis which it so much resembles, and in any event it affords a striking glimpse into the past history of a family which is otherwise scarcely known in the geological record.

Art. XII.—*A Crossotheca from the Rhode Island Carboniferous;* by Eda M. Round.

The presence of any form of fruiting body in the Pennsylvanian is of interest, especially if it sheds light upon the evolution of seed plants. Among fossils of this class from the Rhode Island coal basin have been found specimens of a new species of Crossotheca named from its diminutive size *nana* and described as follows:

Crossotheca nana, n. sp.—Stirps 5 mm. latus, paniculi laxi racemorum fructuum sustinere videtur. Paniculi for minimum 5-6 cm. longi vel longiores probabiliter; secundariæ divisiones ovatas fusiformas fruges sustinent, unaquaque 3-4 mm. longa, 1-1½ mm. lataque est. Fruges maturiores inclives sunt arcutatim paullum esse, ex raceme axe super quem sustinentur. Fruges longitudinales in partes tres dividuntur. Partes ulteriores noviter divisae sunt et compositae oblongarum antheridium quae separatae vel ex parte conjunctæ centrali parti videtur esse similis fimbriis. (Figs. 1, 2.)

Stem 5 mm. wide, bearing loose panicles of clustered fruits. Panicles at least 5-6 cm. long, probably longer; secondary divisions bearing oval fusiform fruits each 3-4 mm. long by 1-1½ mm. in diameter, in more mature forms inclined to be slightly arcuate, the more convex side being farthest from the axis of the raceme on which they are borne. The fruits appear to be divided longitudinally into three parts. The outer portions, which are again divided, are composed of oblong antheridia which are either separate or partly attached to the central part like fringe.

In seeking for evidences of the presence of *Crossotheca nana* in other parts of the world, sketches by Gutbier of specimens[1] from the Zwickau coal basin of Saxony may be cited. The raceme figured by him (see fig. 3) is suggestive of the general appearance of the Rhode Island fossil when viewed under low magnification. Gutbier, however, makes no reference to his figures but in another text speaks of them as *Sphenopteris allosaurioides,*[2] a name which gives an interesting sidelight upon his interpretation of the fossil and shows that he regarded it as the fertile portion of a fern closely allied to the modern cliff brake.

---

[1] Gutbier, A. von: Abdrücke u. Verstein. Zwickauer, Atlas, Pl. 10, figs. 4-4b, 1836.

[2] Reichenbach, Ludwig: in Gaea von Sachsen (Verst. Uebersachsen) 1843.

FIG. 1.

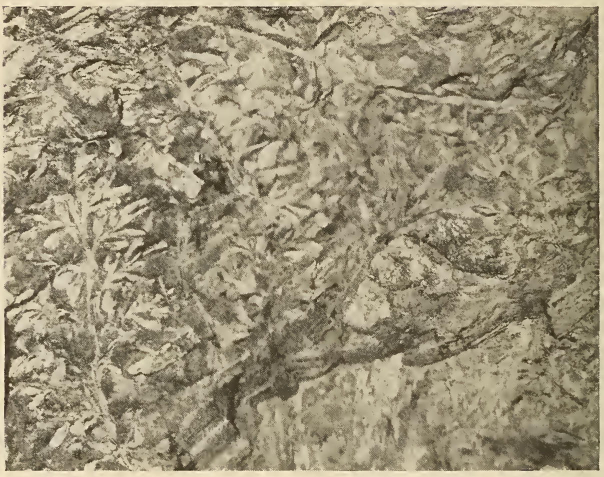


FIG. 1.—*Crossotheca nana* Round, nat. size, Pawtucket, R. I. (No. 1012 Roger Williams Park collection, Prov., R. I.)

FIG. 2.

FIG. 2.—*Crossotheca nana;* detail, × 5.

According to Kidston,[3] Crossotheca fruits are not, as formerly supposed, the exannulate fertile pinnæ of Pteridophytes allied to the Marattiaceae but represent microsporangiate parts of a Pteridosperm, the sterile forms of which are of the Sphenopterid or Pecopterid type.

Fig. 3.

Fig. 3.—Showing specimen as figured by Gutbier.

Three typical Crossotheca species from the European coal flora show noteworthy differences from the American form. *Crossotheca schatzlarensis* Stur[4] consists of a more complex panicle than the Rhode Island specimen, the units of which are divided into four to eight antheridia as contrasted with fifteen to twenty in *Crossotheca nana.* The size of each unit, however, is about the same as that of the Rhode Island form although the proportions are very different, being loose where *Crossotheca nana* is compact. *Sphenopteris* (*Crossotheca*) *Crepini* Zeiller[5] is about the size of the Rhode Island species but more stout in form and simple in details. *Sphenopteris* (*Cros-*

---

[3] Kidston, R.: Phil. Trans. Roy. Soc., vol. **198**B, pp. 413-445, Pls. 25-28, 1908. Les vegetaux houillers recueillis dans le Hainaut belge, p. 41, 1909.

[4] Kidston, R.: Proc. Roy. Phys. Soc., vol. 9, Pl. 21, figs. 1-6, 1888.

[5] Zeiller, R.: Bassin houiller de Valenciennes, Pl. 13, figs. 1-3, 1886.

Crossotheca.	Length of raceme.	Width of raceme.	Stem.	Inflexion, lateral raceme to main stem.	Length of lateral raceme.	Width of lateral raceme.	Length of fruit.	Width of fruit.	Antheridia each side of fruit, numbers	Length of antheridia.	Width of antheridia.	Formation.
	c.m.	cm.			cm.	cm.	mm.	mm.		mm.	mm.	
1. *schatzlarensis** .	8	3	grooved	30°	3 1/2	2	2-3	2	4-9	2	3/4	Middle Coal, Yorkshire, Eng.
2. *Crepini*	7	3	striated	60°	1 1/3	1	4-5	3	7-16	1/2-1	1/3	Westphalian, Valenciennes, France.
3. *Boulayi*†	?	?	finely striated	45°	3	2	12	5-6	28	2-2 1/2	1	Westphalian, Valenciennes, France.
4. *nana*, n. sp. ...	5	2	grooved	45°	1	1/2	3	1-2	15-20	1 1/-2	1/5	Middle Coal ? Rhode Island.

* Cf. *Sorocladus asteroides*, Lesqx., Coal Flore, 2d Geol. Surv. Penn., Pl. 48, figs. 9-9b, 1880.

† Cf. *Sorocladus sagittatus*, Lesqx., ibid., Pl. 48, figs. 10-10b.

sotheca) *Boulayi* Zeiller,[6] however, has about the same proportions as *Crossotheca nana* but is about four times larger. Details of comparison of all these species are shown in the accompanying table.

Specimens of *Crossotheca nana* have been found in the Pawtucket and Portsmouth sections of Rhode Island, an indication that the species was somewhat widespread in the Narragansett Basin during the Carboniferous.

Paleontological Laboratory,
Brown University.

---

[6] Ibid., Pl. 4, fig. 4.

Art. XIII.—*A Fossil Dogwood Flower;* by F. H. Knowlton.

Fossil flowers are of such rare occurrence in this country that when one comes to light it seems to merit an early description. In working up some material from the Fort Union formation (Eocene) in the Glenrock coal field, Converse County, Wyoming, I found the specimen here described, which is so obviously a dogwood "flower" that there is no hesitation in referring it to Cornus. It may be named *Cornus speciosissima* and described as follows:

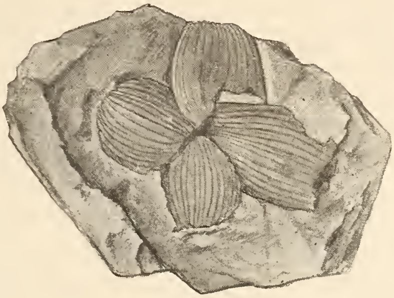
Involucral bracts 4, closely sessile, elliptical or elliptical-obovate in shape, rather obtuse at the apex where the tip is thickened. The bracts appear to have been rather thick and have the veins strong and all converging in the thickened tip. The length of the bracts is 18 or 20 millimeters and their greatest width 12 or 13 millimeters. The spread of the perfect "flower" must have been nearly 4 centimeters.

Although no evidence of the peduncle can now be detected it is clearly the under side of the whorl of involucral bracts that is exposed. At the base of the best preserved one of the four bracts the surface is seen to be finely striate and somewhat wrinkled, and showing through are five or six dark circles which undoubtedly represent a part of the cluster of flowers on the upper side. This completes the evidence necessary for its reference to Cornus.

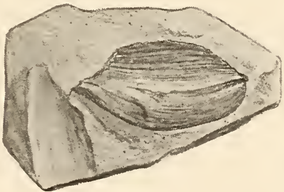
Cornus has some forty or fifty living species widely distributed over the three continents of the northern hemisphere, with a single species crossing the equator and reaching Peru. The genus is sharply separated into several groups which have sometimes been given separate generic rank, but it seems to me that they are all best retained under Cornus. In one group which embraces the majority of the species the flowers are cymose and not involucrate, while in another group the flowers are capitate with an involucre of large usually white bracts.

Cornus speciosissima belongs, of course, to the involucrate group and as nearly as can be made out seems to be most like *Cornus canadensis* Linné, the dwarf cornel or bunch-berry, which ranges from Newfoundland to

Alaska and south to New Jersey, Ohio, Colorado, and California. This species is herbaceous above and woody at the base, with a whorl of leaves at the top, and long-stalked flowers. The fossil species under discussion is slightly larger than *C. canadensis,* has the bracts more nearly elliptical than obovate, and seemingly thicker in texture. No leaves of Cornus were found in direct association with this specimen, but the collection was a small one and so such leaves might have escaped observation.



1



2

Figure 1.—*Cornus speciosissima,* new species, showing the four involucral tracts.

Figure 2.—Bract showing thickened tip.

There are, however, two well-defined species in the Fort Union, based on leaves, namely *Cornus newberryi* Hollick and *Cornus fosteri* Ward. Judging from the size and texture of the leaves of these forms they were shrubby species and not of the herbaceous type of *Cornus canadensis.* Without being in any way positive about it, it seems probable that *Cornus speciosissima* was borne on a plant of the shrubby type, and not by one of the herbaceous type, although its flowers do resemble that of *C. canadensis.*

Over twenty fossil species of Cornus have been described from North America, all based on leaves. These range in age from Middle Cretaceous to Pleistocene. In the Old World over forty fossil species have been named, two of which—both from the Miocene of Switzerland—are founded on the involucral bracts. Of these, *Cornus büchii* Heer[1] has the bracts oblong in shape but not conspicuously thickened at the tip, and *C. apiculata* Heer,[2] with a long, slender evidently hardened point. Both these species are based on small detached bracts, and while *C. speciosissima* agrees closest in shape with *C. büchii,* they are distinct. *Cornus apiculata* is wholly unlike *C. speciosissima.*

The exact locality whence *Cornus speciosissima* came is the west bank of Cole Creek, about 1 mile east of Big Muddy, Converse County, Wyo. (Sec. 36, T. 33 N., R. 77 W.). Collected by John B. Reeside, Jr., September 5, 1913. The types are preserved in the United States National Museum, Nos. 36616, 36617.

U. S. Geological Survey,
Washington, D. C.

---

[1] Flora fossilis helvetiæ, vol. 2, p. 27, pl. CV, figs. 6, 7, 1859.

[2] Idem, p. 28, pl. CV, figs. 10, 11.

Art. XIV.—*Intrusive Rocks of the Portsmouth Basin, Maine and New Hampshire;* by Alfred Wandke, Foxcroft House, Cambridge, Mass.

Introduction.

Location.—The portion of the Portsmouth Basin to be treated in this paper includes 500 square miles of territory that lies partly in the southwestern corner of Maine, and partly in the southeastern corner of New Hampshire. The area under consideration is easily accessible by rail being served by the Eastern and Western Divisions of the Boston and Maine Railroad. The Atlantic Shore Street Railway passes through much of the country not touched by the steam road and thus but little remains that is not easy of access.

The portion of this area in Maine, except for the immediate vicinity of the shore where a thriving business is done entertaining summer visitors, is sparsely settled; that in New Hampshire, traversed by several rivers upon which manufacturing industries have been established, although not densely populated, contains a number of prosperous communities.

Field Work.—This paper is based upon field work done during the years 1915, 1916 and 1917. During this time members of the United States Geological Survey were conducting an investigation of the geology of southwestern Maine and conferences with Dr. L. Laforge of the Survey aided greatly in deciphering the obscure geology.

Previous Work.—Except for the work of Jackson[1] of the Maine Survey in 1839, and of Hitchcock[2] of the New Hampshire Survey in 1868, but little had been done in this field. At various intervals since the publication of the reconnaissances of these two men, notes mentioning the area have appeared in several publications: the clays of South Berwick, Maine, which contain Pleistocene fossils, have been cited in papers dealing with the elevation of the coast of Maine; Kemp[3] in 1890 described some of the dikes at Kennebunkport and Bald Head Cliffs,

---

[1] Geology of Maine, Augusta, Maine, 1839.

[2] Geology of New Hampshire, Concord, New Hampshire, 1878.

[3] Amer. Geologist, vol. 5, 1890.

Maine, and mentioned similar occurrences at Portsmouth, New Hampshire; G. P. Merrill[4] noted the Durham granite in his "Building Stones"; Dale[5] briefly referred to the Berwick "black granite"; Powers[6] in 1914 had occasion to visit Bald Head Cliffs while collecting material for his paper on the inclusions in dikes. Recently the U. S. Geological Survey began a systematic study of this region and two papers[7] relating to the geology have appeared.

Acknowledgments.—In connection with this paper acknowledgments are due to Professor R. A. Daly of Harvard University under whose guidance the area was studied; to Professors John E. Wolff and Charles Palache, both of Harvard, for helpful aid in the microscopic investigation; to Dr. L. Laforge and Dr. Frank Katz of the U. S. Geological Survey for suggestions regarding the characteristics of the formations.

TOPOGRAPHY.

The Portsmouth Basin lies within the tilted and dissected Cretaceous peneplain of the Northern Appalachian Geological Province. The portion of this peneplain near the shore, spoken of as the coastal lowland, to which the area under consideration properly belongs, is a land surface of low relief and slight diversity. It rises gently toward the interior and its few hills, either monadnocks or morainal material left by the Pleistocene glaciers, rarely attain an elevation of more than 300 feet above sea level. Its valleys, except for those of the short coastal streams, are relatively broad and shallow depressions whose courses, determined largely during post-Cretaceous time, were but slightly affected by the glaciers of the Pleistocene period. The shore line is marked by a succession of bold rocky headlands between which are marshes fronted by excellent sand beaches. Wherever rivers enter the ocean they generally afford good harbors, this being one result of a recent drowning of the shore.

---

[4] G. P. Merrill, Stones for Building, 1897.

[5] T. N. Dale, U. S. Geol. Survey, Bull. 313, 1907.

[6] S. Powers, Jour. of Geol., vol. 23, 1915.

[7] U. S. Geol. Survey, Prof. Paper 108, 1917.

AREAL GEOLOGY.

General Statement.—The Portsmouth Basin resembles in many respects the other fragmentary geological basins which have been recognized in the as yet imperfectly known area of the Northern Appalachians. The rocks consist of fine-grained steeply inclined sediments supposed to be of Upper Carboniferous age, of both intrusive and effusive igneous rocks, and of some thoroughly metamorphosed rocks of doubtful origin and unknown age which have been classified as gneisses and schists. The sediments and the metamorphic rocks have a general strike of N 45° E, but local departures from this general direction are numerous; the dikes of the region follow a northeasterly trend; and the batholiths are elongated in the same direction. The dip of the stratification of the sediments and of the schistosity of the metamorphics is, on the whole, to the northwest, but frequent departures from this direction indicate, perhaps, local folds and crumplings. The gneisses and schists occur both to the northwest and to the southeast of the sediments of Upper Carboniferous age, and since the highly metamorphosed rocks almost close in on the sediments to the southwest, a basin-like arrangement results.

Sedimentary Rocks.

General Statement.—Hitchcock[8] in his survey made no attempt to separate the rocks of the Portsmouth Basin into groups or formations, as is indicated by the following quotation: "This name (Merrimack Group) was informally applied by my father to the mica schists, slates, and quartzites contained in the Merrimack River, in Massachusetts. They skirt the Exeter sienites in New Hampshire, lying in troughs in an anticlinal. They probably belong to the earliest Silurian." On purely lithologic grounds it seems possible to separate this Merrimack group of Hitchcock's into two groups. The first contains three formations which have been called the Gonic schist[a], the Berwick gneiss[b], and the Rye gneiss[c]; the second con-

---

[8] Geology of New Hampshire, Concord, New Hampshire, p. 27, 1878.

[a] Correlated by Katz, as a part of the Eliot formation but lithologically different.

[b] Is the same as the Berwick gneiss of Katz.

[c] Is the Algonkian complex of Katz.

sists of two formations, the Kittery quartzite[d] and the Eliot phyllite[e]. No definite age has been assigned to the first group nor can correlations be made between the different members; the second group, it seems, can be traced to Worcester, Massachusetts, where fossil-bearing rocks,[9] Upper Carboniferous in age, have been found. The writer, however, has been able to trace the Kittery formation only as far as Lowell, Mass. From there on to Worcester, Mass., a distance of 30 miles, glacial material makes it difficult to follow the strata. The rocks at Worcester from which the fossils have been reported are lithologically unlike those of the Portsmouth Basin. In the hand specimen the typical Kittery quartzite is almost identical in appearance with the Isleboro[10] formation of Rockland, Maine, perhaps of Cambrian age. It would seem, therefore, that until fossils are found within the Kittery formation its age must remain a matter of inference. The Kittery and Eliot formations are however provisionally dated as Carboniferous, following the lead of the U. S. Geological Survey.

Metamorphic Rocks of Unknown Age.

General Statement.—This classification includes the Gonic schist and the Berwick gneiss which form the northwestern boundary of the basin, and the Rye gneiss on the southeastern side. Limits have been assigned to the extent of these formations with the understanding that they are not to be regarded as fixed.

Gonic Schist.—The Gonic schist has been named from the typical exposures occurring in the falls of the Cocheco River at Gonic, New Hampshire. The rock is a biotite-garnet schist evidently produced by dynamic and contact metamorphism of argillaceous and arenaceous sediments. Cutting across the schistosity of the formation, although occasionally paralleling the same, are a great many stringers of coarse pegmatite and veins of quartz. It is entirely probable that these stringers and veins are genetically related to the intrusive pegmatitic

---

[d] The same as the Katz's Kittery quartzite.

[e] Is the Eliot slate of Katz.

[9] David White, Jour. Wash. Acad. Sci., p. 115, 1914.

[10] U. S. Geol. Survey, Folio 158, 1908.

granite which outcrops less than 2000 feet distant from the exposures of Gonic schist. The formation has, in general, a gentle northwesterly dip, but departures from the normal dip and strike are abundant. The thickness of the formation is unknown.

Berwick Gneiss.—This formation is typically developed at the falls of the Salmon Falls River in Berwick, Maine. Dynamic and static metamorphism have entirely obscured the original texture and composition of the rocks which now consist of thin bands of mica schist alternating with well banded paragneiss. The formation appears to have been derived from an argillaceous sandstone or a graywacke. Because of metamorphism some of the bands are now characterized by glaucophane. Associated with the amphibole are feldspar, quartz, biotite, chlorite, pyrite, and titanite. Quartz veins varying in width from mere stringers up to masses two feet in thickness frequently cut the formation. Although some of the veins are developed parallel to the foliation of the gneiss, the general tendency is for them to occur in cross-cutting relationships. The thickness could not be determined. Departures from the general northwesterly dip of the foliation, which in rather limited areas may undergo wide variations, suggest that the formation is compressed into several tight folds which have been overturned to the southeast. Little can be said of the position of this formation in relation to its neighbors.

Rye Gneiss.—The Rye gneiss has been so called from the typical exposures that occur along the Rye coast of New Hampshire. The most northerly outcrops of rock belonging to this formation are found on Gerrish's Island, Kittery, Maine. From this locality the rocks have been traced south and southwest into Portsmouth, Rye, North Hampton and Hampton, New Hampshire. At Hampton Falls the country becomes drift-covered and for a space of six miles westward across the towns of Kensington and East Kensington no outcrops are to be seen. In the town of Kingston gneisses outcrop at Rock Rimmon Hill.

At the type-locality the gneiss is well banded, consisting of alternations of light feldspathic layers, which become pegmatitic with dark-fine biotite-rich bands that are schistose. On Gerrish's Island the rock is fine-grained, the banding characteristic of the typical gneiss being absent. As narrow stringers of feldspathic material penetrate the rock it loses its sedimentary habit. The feldspathic stringers may increase in size until they attain a width of fifteen feet. The entire occurrence is suggestive of the feldspathization described by Wherry[11] in the pre-Cambrian highlands of eastern Pennsylvania. On Newcastle Island the process of feldspathization is well marked, and the gneisses become distinctly granitized.

A number of dikes cut the gneisses, but in not a single instance in the good exposures along the coast has the metamorphism so characteristic of the gneisses affected a dike. Since some of these dikes are earlier than the batholiths (to be described later) the period of granitization and feldspathization must be earlier than the period of batholitic intrusion.

Grouped with these gneisses are some rocks which suggest altered basic volcanic flows. These have not been studied in detail.

Sedimentary Rocks Upper Carboniferous in Age.

General Statement.—The Upper Carboniferous rocks form a single group consisting of two formations. The Kittery quartzite is the older of these and the Eliot phyllite the younger. Boundary lines between the two cannot be drawn with any great degree of accuracy, and the lack of exposures and the prevalent glacial drift prevent a close correlation. The two formations appear to be conformable.

Kittery Quartzite.—The typical Kittery quartzite is found just north of the bridge of the York Harbor and Beach Railroad that crosses Spruce Creek in the town of Kittery, Maine. At this locality the formation consists of a series of thin beds of red phyllite that alternate with thicker strata of a dense fine-grained grayish green or bluish quartzite. Variations from the normal are, however, abundant, the differences being due in part to primary causes during the time of deposition and in part to secondary changes during and after the period of fold-

---

[11] Paper read before the Geol. Soc. of America, 1916.

ing. The thickness cannot be accurately stated. In a section from Godfrey's Cove northwest to the contact of the sediments with the granites, a distance of eight miles, the rocks dip almost invariably steeply to the northwest, and although several folds seem to be indicated, the covering of glacial drift obscures the structure. Along the coast where outcrops are more numerous a duplication of lithologically similar rocks appears at such intervals as to suggest that the formation has a thickness of about 2000 feet.

The lower limit of the Kittery could not be established: in the southeastern part of the area the formation is seemingly a faulted contact with the Rye gneiss; in the northwestern part it appears to stand in a faulted relationship to the Berwick gneiss. Multitudes of dikes cut this formation.

Eliot Phyllite.—This phyllite is typically developed in the town of Eliot, Maine. It is, as a rule, gray in color but red, brown, black, and buff phases are common. Slight variations in texture and composition are observed and in the formation calcareous and carbonaceous phyllites, true slates, and a light yellow to brown gray crumpled and easily eroded argillite have been included. Quartz veins and dikes are frequently seen cutting the formation. Because of the lack of exposures it becomes difficult to establish a standard section, and hence the thickness can at best merely be estimated. South of Eliot where exposures are most numerous the thickness would seem not to exceed 2500 feet. Since the passage from quartzite to phyllite is effected by transitional beds which gradually change from quartzite with thin beds of phyllite to homogeneous phyllite or shale, and because the prevalent dips are such as to carry the quartzite constantly beneath the shale or phyllite, it seems certain that the Eliot and Kittery formations are conformable and that the Eliot is the younger.

IGNEOUS ROCKS.

General Statement.—The igneous rocks of the area include a great many dikes, several subjacent bodies, a few effusives, and some mixed gneisses. The mixed gneisses are pre-Carboniferous in age and occur in the

Rye formation. The effusives, or at least rocks resembling metamorphosed effusives, occur in a narrow belt at Portsmouth, New Hampshire. No attempt was made to study them. The discussion will center upon the dikes and subjacent bodies which for the most part cut the Upper Carboniferous rocks.

Dikes.

The dikes, because of their number, their wide range in composition, and the manner and order of their intrusion form a group of rocks well deserving of more detailed study. Although every outcrop carries one or more of them, the best display of dikes occurs along the coastal section from Perkin's Cove to Brave Boat Harbor. In these eleven miles there are several hundred, perhaps a thousand, dikes and they vary in width from stringers hardly thicker than the blade of a case knife up to 200 feet. Multiple and composite examples abound. In several instances three or more dikes of the same or of contrasted compositions may occupy a single fissure. In composition they range from an olivine-bearing lamprophyre through diabase, diorite, and granite porphyry to paisanite and aplite. Some abound in inclusions, which being fragments either brought up from depth or torn from the adjacent walls, occur in various stages of assimilation. In short, the dikes of the area form a remarkable display and illustrate most of the phenomena associated with intrusions of this type. All of the observed dikes are later than both the period of folding and the period of granitization which produced the Rye gneisses, and for the most part appear younger than the quartz veins and the metamorphism which characterize the outcrops from Perkin's Cove to Brave Boat Harbor. In a broad way they may be separated into two groups,[12] (a) those earlier, and (b), those later than the stocks and batholiths. On the basis of composition each of these groups may be subdivided and such a sub-division is helpful in gaining a clearer conception of the changes in the magma from which the dikes were derived.

---

[12] A similar grouping was made by C. H. Clapp for the dike rocks of Essex County, Mass., U. S. Geol. Surv., Bull. 704, p. 107, 1921.

First Group.

Although this group has been divided into three subgroups,—diabases, diorites, and granite porphyries, no hard and fast line of division can be drawn, since the diabases grade into the diorites and the diorites show transition phases which suggest the granite porphyries.

Diabases.—For the most part the diabase dikes are the oldest of the region. In the batholiths other diabasic dikes are seen which indicate a second period of diabase intrusion as a late phase of igneous activity. This region illustrates therefore the initiation of a period of intrusion by a great development of diabase dikes and the recurrence of similar rocks at the close of the irruptive period.

Diorites.—As the rocks in the preceding class grow lighter in color they grade into the diorites. The lighter colored members of the group have a banded appearance due to the development of innumerable segregations of quartz and feldspar in subparallel lines that follow the contacts. The development of quartz in these rocks is worthy of note for it may indicate that the magma of which they are offshoots began to approach a quartz diorite in composition.

Granite Porphyries.—Under this heading have been placed all of the light-colored typically porphyritic dike rocks of which the phenocrysts are invariably quartz and feldspar. Some of these are characterized by resorbed quartz phenocrysts, by pyrrhotite instead of pyrite, and by a groundmass which consists almost entirely of myrmekite. The myrmekite may well have resulted from the escape of volatile components as has been suggested by Sederholm.[13]

Second Group.

General Statement.—This group consists of two subgroups of diaschistic dikes,—the one contains the paisanites, tinguaites, and camptonites; the other the aplites and the late diabases. The first sub-group is generally associated with rocks that belong to the alkaline clan; the second with those which belong to the subalkaline clan.

---

[13] Bulletin de la Commission Geologique de Finland, No. 48, p. 81, 1916.

First Sub-group.

Tinguaites.—The tinguaite dikes vary from a deep blue to a light gray in color. The feldspar is anorthoclase. The aegerite needles which dominate the groundmass give the rock its characteristic color.

Camptonites.—The camptonites are poorly exposed, but wherever found they are characteristically developed. They are full of inclusions and contain large porphyritic crystals of glistening poikilitic hornblende. The hornblende is full of feldspar and apatite.

Paisanite.—A single example of this type of dike was found near the crest of a hill just north of "Scotland," York, Maine. The minerals present are quartz, albite, microcline, microperthite, aegerite, riebeckite, arfvedsonite, zoisite, and an undetermined titaniferous mineral, brown in color and platy in habit. Both zoisite and the feldspars are poikilitically intergrown..

Second Sub-group.

Aplites.—The aplites, present in each of the subjacent intrusives, are composed essentially of feldspar and quartz, the darker minerals being sparingly developed. Their composition and texture present no unusual features.

Diabases.—The diabases of the second generation differ but little from those of the earlier period. They are found cross cutting all of the other types of rock.

Stocks and Batholiths.

General Statement.—Large intrusive bodies occupy a considerable part of the Portsmouth Basin. They are of especial interest because of their contrasted compositions, their contact actions, and their method of emplacement. For purposes of easy reference these bodies have been named the Rochester biotite granite; Durham quartz diorite; Hampton granodiorite; Agamenticus complex, which consists of biotite granite, gabbro, syenite, and alkaline granite; Cape Neddick gabbro; York Harbor biotite granite; and the Brave Boat Harbor biotite granite.

The New England province seems to have been affected by two periods[14] of batholithic intrusion. The first is usually dated as Devonian (?) and is characterized by granites, granodiorites, and quartz diorites; the second, or Carboniferous, is characterized by alkaline granites of which the Quincy granite is the typical example. It is probable that the subjacent rocks of the Portsmouth Basin fall into these two groups. In (1) may be placed the Rochester granite; in (2), the Durham, Hampton, Agamenticus, Cape Neddick, and York Harbor occurrences. The granite at Brave Boat Harbor is much more sheared than are the other nearby intrusives. It is doubtfully classified as a Carboniferous intrusive.

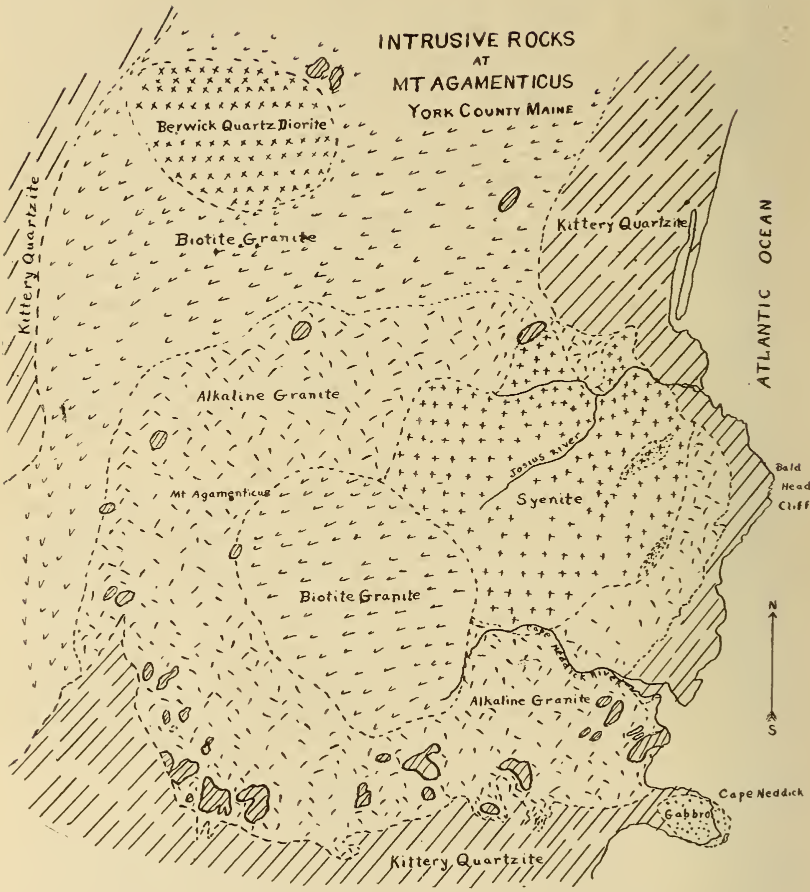
Rochester Biotite-Granite.—This body has no unusual features of mineralogical composition. Outcrops are not numerous, the best exposures occurring in a few small quarries. The rock cuts the Gonic schist and may be a pre-Carboniferous intrusive. Pegmatite veins cut the granite and as a rule carry quartz, perthitic feldspar, and muscovite.

Durham Quartz-Diorite.—The Durham quartz diorite batholith is an elongated body that extends from two miles southwest of Exeter, N. H., to within one fourth mile of Rollingsford, N. H. It occupies about one third of the Dover quadrangle, has an extreme length of twenty miles, and a maximum width of four and one half miles. Outcrops showing the crosscutting relationships of the body are abundant and the boundaries as shown on the map will need but slight revision. The elongation corresponds to the dominant strike of the invaded sediments. In places inclusions of the Kittery formation occur in various stages of assimilation.

Although the composition has been indicated as quartz diorite this term merely covers the dominant phase. A distinct gradation from a basic margin to an acidic interior is one of the features of this body. In a section taken across the batholith in a southeasterly direction through the town of Durham, the following variations in composition have been noted: a marginal phase of gabbro, quartz norite, quartz gabbro, quartz augite gabbro; an intermediate phase of quartz augite diorite,

---

[14] B. K. Emerson, Geology of Massachusetts and Rhode Island, U. S. Geol. Survey, Bull. 597, p. 172, 1917.


INTRUSIVE ROCKS
AT
MT AGAMENTICUS
YORK COUNTY MAINE
Berwick Quartz Diorite
Biotite Granite
Kittery Quartzite
Kittery Quartzite
ATLANTIC OCEAN
Alkaline Granite
Josias River
Syenite
Mt Agamenticus
Bald Head Cliffs
Biotite Granite
N
S
Cape Neddick River
Alkaline Granite
Cape Neddick
Gabbro
Kittery Quartzite

quartz diorite, quartz biotite diorite; and a central phase of granodiorite, granite, and granite aplite.

Volumetric composition of two phases of the Durham quartz diorite:

	I	II
Plagioclase (Ab_3An_7—Ab_6An_4)	63.15	....
Microperthite to oligoclase	....	56.06
Quartz	10.03	17.10
Biotite	16.21	15.92
Pyroxene	8.91	....
Amphibole	1.68	10.10
Apatite	....	.01
Totals	99.98	99.19

I. Quartz diorite 300 feet from the contact.
II. Granite from the central portion.

Other bodies related to the quartz diorite.—Two other bodies within the area resemble the Durham batholith, not only in composition, but also in a similar gradation from basic margins to a more acidic central phase. One of these, a small stock, occurs about two miles east of North Berwick; the other, also stock-like in habit, occurs at the intersection of the North Hampton, Exeter and Newington boundaries.

Cape Neddick Gabbro.—The Cape Neddick gabbro forms a small oval stock measuring about one-half by three-fourths of a mile. It is well exposed and shows particularly fine contact phenomena as well as variations in composition. This stock shows four phases: (a) the contact phase, a medium to fine-grained rock rich in olivine, myrmekite, and apatite, and contains abundant inclusions of the invaded quartzites; (b) a dark coarse-grained phase (phenocrysts may show a diameter up to 2 cm.) having about equal amounts of the light and dark minerals which are poikilitically intergrown and characterized furthermore by a vertical banding parallel to the contacts; (c) a very dark, almost black phase, medium to coarse in grain, containing olivine embedded in large poikilitic crystals of hornblende, biotite, and titaniferous pyroxene; and (d) a light colored central phase composed largely of plagioclase feldspar accompanied by small amounts of quartz and orthoclase.

Volumetric composition of the four phases of the Cape Neddick gabbro:

	I	II	III	IV
Olivine	17.89	1.50	6.76	....
Plagioclase	45.50	45.60	51.85	87.10
Alkaline feldspar	1.17	....	....	.16
Pyroxene	23.53	25.00	8.23	9.43
Hornblende	....	10.01	21.42	.68
Biotite	3.77	3.26	4.76	1.21
Hypersthene	2.33	....	....	....
Magnetite	3.62	13.82	6.79	1.55
Apatite	2.97	....	....	....
Totals	100.78	99.19	99.81	100.13

I. Contact phase of the gabbro.
II. Pyroxene-rich phase.
III. Hornblende-rich phase.
IV. Central feldspathic phase.

Agamenticus Complex.

This complex, so-called to signify that it consists of more than one kind of rock, is situated in York County, Maine, and has been named from Mount Agamenticus upon whose slopes three of the dominant rock types are to be found.

Biotite Granite.—This rock forms the dominant phase of the batholith. The texture and composition vary from place to place, but on the whole the rock is light colored, has a slightly cataclastic structure, and a porphyritic habit. Near the Jewett station, York, Maine, a narrow vein carrying pyrite and molybdenum was found. This vein is the only evidence of ore mineralization seen in the entire area.

Alkaline Granite.—This rock forms an irregular, roughly U-shaped body, the limb of the U enclosing biotite granite and the syenite stock. The typical granite is characterized by euhedral and anhedral perthitic feldspar, allotriomorphic to poikilitic arfvedsonite and aegerite-augite. Quartz-rich phases, aplitic tendencies and peculiar orbicular fine-grained contact phases are some of the departures from the normal. Although the usual amphibole is arfvedsonite, riebeckite is common; aegerite and aegerite-augite are the usual pyroxenes; orthite is seen in almost every section.

Syenite.—The syenite forms an irregular stock-like mass measuring three and one-half by four miles. The field habit of the rock is varied, all gradations being seen from a fine-grained grayish-green quartz-free syenite to a coarsely pegmatitic rock consisting essentially of perthitic feldspar, quartz, and arfvedsonite. The olivine, fayalite, occurs rather abundantly in the contact phases; in some of the central phases, arfvedsonite, riebeckite, orthite, aegerite, and zircon become locally abundant.

Contacts of this rock against the alkaline granite are rather poor so that age relations cannot be established with certainty. Along the northwestern margin of the syenite this rock appears to dike the alkaline granite. The syenite, usually a quartz syenite (nordmarkite) in composition, is in turn cut by the lenticular masses of rather coarse-grained pegmatic quartz syenite, thus indicating an additional concentration of volatile components in the later stages of this intrusive.

Volumetric composition of two phases of the Agamenticus complex:

	I	II
Alkaline feldspar	87.90	76.02
Fayalite	3.76	....
Aegerite augite	3.35	2.61
Quartz	2.43	17.46
Arfvedsonite	.49	3.55
Biotite	.61	....
Magnetite	.73	....
Allanite	....	.19
Zircon	....	.09
Totals	99.27	99.92

I. Border phase of the syenite.
II. Typical alkaline granite from Mt. Agamenticus.

Berwick Quartz Diorite.—Apparently later than the main biotite granite is the small stock of quartz diorite situated about two miles east of Berwick. The contact phase is essentially a gabbro, but the central mass is a typical quartz diorite. This body may possibly be correlated with the Cape Neddick gabbro.

Other Granitic Bodies.—In addition to the above mentioned occurrences of granite there are other small bodies such as those along the South side of York Harbor and along the northeastern side of Brave Boat Harbor. The Brave Boat Harbor granite is highly cataclastic. Neither body presents unusual characteristics.

Emplacement of the Intrusives.

Elongation.—The map shows that each of the larger intrusive bodies is distinctly elongated in a northeasterly direction, which corresponds in a general way to the dominant direction of folding for this region. In this respect they conform to one of the characteristics of batholiths as postulated by Daly,[15] that they should be elongated in the direction of the orogenic axes.

Method of Emplacement.—The contacts of each of the large intrusive bodies have been traced as carefully as the exposures would admit. The mapping has shown that they are distinctly cross-cutting. Contact breccias are decidedly common and within each of the intrusive bodies are "islands" of the invaded sediments whose strike and dip corresponds with that of the nearby country rock. These inliers are unquestionably roof pendants. The map on an earlier page will better show the relationships. The question of the isolation of the roof pendants becomes vital in considering the emplacement of the intrusives. Without going into the details as to how this emplacement was effected, the following table is offered in support of the method that seems to have played an important part:

Specific Gravities.[16]

Temp. in Centigrade	Solid				Molten		
	20	1000	1100	1200	1000	1100	1200
Sediment	2.71	2.67	2.66	2.65	....	....	....
Gabbro	2.92	2.85	2.84	2.83	2.67	2.66	2.65
Quartz diorite.	2.81	2.77	2.76	2.75	2.58	2.57	2.56
Alkaline granite	2.67	2.63	2.62	2.61	2.38	2.37	2.36

The tabulated specific gravities indicate that a fragment of sedimentary rock similar to the Kittery quartzite in composition would tend to sink in a magma having

---

[15] Igneous Rocks and Their Origin, 1914.

[16] Day, Sosman and Hostetter, this Journal, vol. 37, 1914.

the composition of a quartz diorite or an alkaline granite if the magma in question were molten at a temperature even less than 1000° C. The stoping hypothesis[17] may thus account for a large measure of the final emplacement,

Although assimilation in place may have removed a part of the invaded sediments, and although block-faulting or differential lateral movement may account for a part of the width of these batholiths, nevertheless, the areas of contact breccias, the roof pendants, and the relative specific gravities of molten rock and engulfed fragments all seem to indicate that the intrusives of the Portsmouth Basin in their later stages have been emplaced to a large degree by magmatic stoping.

Slightly different in its method of emplacement is the Cape Neddick gabbro. Excellent exposures of this body are to be had, the northwestern contact being particularly illuminating. Here the waves have cut a marine bench about 100 feet wide and at low tide the rocks can be studied in detail. Basic and granitic dikes cut the Kittery quartzite which forms the country rock. Close to the intrusive the dikes and sediments are mixed by contact brecciation and contact metamorphism has almost obliterated the original lithologic differences. A short distance from the contact the sediments are seen to be crumpled, simple folds, overturned folds and overthrust faults all being present on a miniature scale. The crumpling gives way 75 feet distant from the contact to gentle folding and this in turn grades into the characteristic steep dip and NE-SW strike of the sediments. The intrusive was apparently emplaced in part by bodily forcing its containing walls apart and crumpling and mashing them. As shown by the peculiar quartz-rich contact phases a part of this shattered rock was assimilated; a part seems also to have been removed by being floated away. This latter condition is well illustrated by frozen-in isolated blocks of quartzite weighing several tons now removed a short distance from the contact. The figures dealing with specific gravities indicate that these blocks may have sunk in gabbroid magma, there to be slowly digested and assimilated at depth.

---

[17] For a detailed presentation of this hypothesis, see R. A. Daly, Igneous Rocks and Their Origin, p. 194, 1914.

DIFFERENTIATION.

The stocks and batholiths of the Portsmouth Basin, although not remarkable for an assemblage of rare rock types, nevertheless exhibit contrasted mineralogical compositions. In the descriptions of the igneous bodies it was mentioned that the composition of the Durham quartz diorite varied from a basic marginal phase to an acidic central one; that the Agamenticus complex seems to show a march of progress from calcic to alkalic types; that the dikes in their cross-cutting relationships indicate a change in composition of the parent magma from a basic to an acidic type. The foregoing statements appear to be the field facts; their bearing upon the problem of rock origin seems worthy of consideration.

Of the two contrasting types of rock—the calcic and the alkalic—the former appear to have been developed by the simpler processes. The quartz-rich calcic contact phases of the Durham quartz diorite seem quite clearly the result of the assimilation of Kittery quartzite by the gabbroid magma. The study of a number of selected specimens in which fragments of a quartzite were seen in various stages of alteration seems to prove this point. The abundance of apatite, indicating the presence of plenty of mineralizer, would, moreover, appear to show that the assimilation was aided by the action of the rock's volatile components. But the gradation from a gabbroid margin to a granitic center seems hardly the result of assimilation as no granite was seen in the marginal phase. The formation of granite might in part result from a process of fractional crystallization under gravitative control as the laboratory work of Bowen[18] indicates may take place experimentally. But such a simple setting is hardly the entire story. In studying by means of thin sections several suites of specimens taken across the Durham body, two facts stand out rather clearly: (1) the gradual disappearance of pyroxene and the development of hornblende and biotite, both minerals that all experimental work indicates can only be formed in the wet way; (2) the partial disappearance of calcic feldspar and the development of sodic and potassic feldspar, the latter again, judging

---

[18] Jour. Geology, vol. 23, No. 8, suppl., 1915.

from experimental evidence, only to be produced in the wet way. Thus to the theory of fractional crystallization under gravitative control a necessary addition would seem to be the influence of mineralizing solutions in furthering changes in composition. It is entirely probable that for a given locality either of these agencies may have been chiefly responsible for a given rock type. In the case of the Durham body, since it shows marked contact effects, it would seem necessary to assign an important role to the action of the volatile components in producing the granite.

The alkaline rocks offer a more complex problem. In this case a biotite granite is succeeded by alkaline granite which in turn is apparently followed by alkaline rocks carrying less and less quartz but rich (10-13%) in such elements as soda and potash. Here and there in these alkaline rocks are found coarse pegmatitic phases in which the crystals of feldspar measure up to 10 centimeters in length and the alkaline hornblende 5 to 6 centimeters. The development of soda—and potash—rich minerals and the presence of pegmatitic phases are both interpreted as indicating that mineralizers were active agents in producing these peculiar rock types. There are, however, other factors, which must be reckoned with. The experimental work of Bowen indicates that fractional crystallization under gravitative control may largely influence the process of differentiation. The contacts of the subjacent bodies against the sedimentaries certainly indicate that magmatic stoping was one of the means of emplacement. The figures dealing with specific gravities appear to show that much of the stoped material would sink. With stoping a factor of emplacement, then the assimilation of the stoped blocks would seem necessary since the contact actions show that the process actually takes place. Such stoped and assimilated material ought to make itself felt as the process of differentiation continues. Both of these aforementioned processes have evidently exerted a control upon the differentiates, but to the writer it seems that their effects were furthered by volatile components which not only aided assimilation but also were active in producing the upward transfer of the alkaline constituents so necessary in producing the alkaline rock types.

CORRELATION OF THE INTRUSIVES.

Alkaline rocks were at one time regarded as rare in New England, but little by little new localities for the occurrence of these types are being reported. The subjoined table notes some of the localities in New England from which alkaline rocks have been reported and also shows the approximate ages of the intrusives.

Locality.	*Types of Intrusives.*	*Age.*
Mt. Ascutney,[19] Vermont.	Biotite granite, nordmarkite, pulaskite, diorite, essexite, gabbro, paisanite.	Post Carboniferous and pre-Cretaceous.
Cuttingsville,[20] Vermont.	Essexite and nepheline syenites.	Age unknown.
Litchfield,[21] Maine.	Syenites and nepheline syenites.	Age unknown.
Belknap Mountain,[22] New Hampshire.	Syenite and aplite.	No age given.
Tripyramid Mountain,[23] New Hampshire.	Monsonite and syenite.	No age given.
Blue Hills,[24] Massachusetts.	Alkali-granite.	Upper Carboniferous.
Copper Mine Hill,[25] Rhode Island.	Quartz diorite and biotite granite.	Middle Devonian.
	Riebeckite-aegerite granite.	Middle Pennsylvanian.
Essex County,[26] Massachusetts.	Diorite, calci-alkaline granite, grano-diorite, gabbro diorite.	Post-Ordovician and pre-Silurian?
	Alkaline syenites, Cape Ann and Peabody granites, Andover alkaline granite.	Mississippian or Pennsylvanian.
Portsmouth Basin, Maine and New Hampshire.	Biotite granite.	Pre-Carboniferous.
	Quartz diorite, biotite granite, gabbro, grano-diorite, alkaline granite, alkaline syenite, gabbro?	Post Upper Carboniferous.

Foxgrove House, Cambridge, Mass.

---

[19] R. A. Daly, U. S. Geol. Survey, Bull. 209, 1903.
[20] J. W. Eggleston, this Journal, vol. 45, 1918.
[21] R. A. Daly, Bull. Geol. Soc. Amer., vol. 29, p. 463, 1918.
[22] L. V. Pirsson, this Journal, vol. 22, 1906.
[23] L. V. Pirsson and W. N. Rice, this Journal, vol. 31, 1911.
[24] C. H. Warren and S. Powers, Bull. Geol. Soc. of Amer., vol. 25, p. 463.
[25] C. H. Warren and S. Powers, ibid. pp. 452 and 463.
[26] C. H. Clapp, U. S. Geol. Survey, Bull. 704, 1921.

Art. XV.—*On the Babingtonite from the Contact Metamorphic Deposits of the Yakuki Mine, Province Iwaki, Japan;* by Manjirô Watanabé.

Mode of occurrence.

The Yakuki mine is located near the eastern margin of the Abukuma mountainland,[1] in the Province of Iwaki, in northeastern Japan. It has been worked for chalcopyrite in the skarn[2] masses, which were formed in the contact aureole between granodiorite and the Paleozoic clay slate and limestone. The minerals, constituting the ore deposits, are chiefly hedenbergite and garnet with some chalcopyrite. Magnetite and sphalerite are also found in notable amounts in some portions. The babingtonite, to be described, occurs in veins and irregular aggregates, mainly in the hedenbergite masses in the western part of the mine. In some specimens, these masses of babingtonite, cut by garnet, are brecciated into small fragments. Some of these fragments are surrounded by thin layers of babingtonite, on which minute crystals of garnet are planted. Thus, it is clearly seen that these two minerals were repeatedly deposited one after the other.

These fragments in the brecciated zone are usually cemented by quartz or calcite. In the latter case, the crystals of babingtonite, planted on the fragments, are easily isolated by dissolving the carbonate in acid.

In other cases, the babingtonite appears in minute veinlets, which cut the hedenbergite, magnetite and ilvaite.[3] Such veinlets often thin out in one direction. The wider portion is filled with garnet, and the narrower portion is made of garnet and babingtonite, the former mineral appearing implanted on the walls. In still narrower parts, babingtonite occurs with quartz, and the veinlet terminates as a pure aggregate of quartz.

---

[1] B. Kotô: The Archean formation of the Abukuma Plateau, Jour. Coll. Sci. Imp. Univ. Tokyô, vol. 5, Pt. 3, 1893.

[2] This term was originally a Scandinavian miner's word, which means rubbish. However, it was applied by V. M. Goldschmidt to a certain type of contact metamorphic rock, which consists essentially of coarse-grained aggregates of pyroxene and garnet, and is now widely used with this meaning.

[3] This mineral is found in very small amount, and is not accurately determined. It is black in color, and is generally opaque, but transmits light in very thin portions, where the pleochroism is marked. It is easily attacked by hydrochloric acid. It is most probably ilvaite.

When the babingtonite vein traverses magnetite or ilvaite, it assumes a shape of a regular vein, but as it cuts hedenbergite, babingtonite often replaces a part of hedenbergite on both sides of the fissure, and still preserves the original texture.

In short, the formation of the babingtonite in the Yakuki mine seems to have commenced at a certain stage of the formation of skarn masses, and to have continued after the brecciation of the skarn and lasted to some stages of fissure, filling deposition of quartz and calcite. Throughout the whole duration, the mineral is most intimately associated with garnet.

Crystallography.

The isolated crystals were picked out from the specimens, in which the mineral is embedded in calcite, and were measured by means of a Czapski two-circle goniometer.[4] Most of these crystals are very small, rarely exceeding 2 or 3 millimeters in dimension. Besides, the

TABLE I.

	Calculated[5]		Measured (mean)	
Faces	ϕ	ρ	ϕ	ρ
c 001	124° 24′	4° 36′	125° 50′	4° 49′
b 010	0 00	90 00	0 00	90 00
a 100	67 48	90 00	67 57	90 00
h 110	24 42	90 00	24 12	90 00
g $2\bar{1}0$	115 24	90 00	115 25	90 00
k $1\bar{1}0$	143 38	90 00	143 37	90 00
o $0\overline{11}$	4 07	42 48	4 06	42 38
s $0\bar{1}1$	176 15	45 29	177 33	43 33
d 101	73 49	32 39	74 02	32 42
n $\bar{1}01$	–119 12	28 55	–120 17	29 04
p 111	28 11	52 29	28 40	52 55
**j* $\bar{1}02$	–127 07	14 39	–127 30	15 15
**l* $\bar{2}01$	–115 26	49 59	–115 50	49 25
**q* $\bar{1}11$	–34 17	40 25	–33 45	41 25
**z* $0\bar{2}3$	174 31	34 48	175 02	34 29

---

[4] This study was done through the courtesy of Professor A. F. Rogers of Stanford University, Calif., to whom the writer offers his sincere thanks.

[5] The calculations of the co-ordinate angles were made mainly according to the formulæ given by A. J. Moses and A. F. Rogers (School of Mines Quarterly, vol. 24, No. 1, 1902), and partly by the method, proposed by H. E. Boeke (Die Anwendung der stereographischen Projektion bei kristallographischen Untersuchungen, 1911, pp. 41-46).

crystal faces are often striated and curved, and the appearance of double and multiple images makes it doubtful which is to be measured. In spite of such difficulties in measuring, the mean values obtained by measurement closely agree with the calculated ones.

The observed forms and their co-ordinate angles are shown in Table I.

The four forms marked with an asterisk are new to this mineral. The crystal orientation and elements, used for notation and calculation, are those of Dauber,[6] the advantage of which has been stated by Palache and Fraprie.[7] It is necessary, therefore, to change the symbols of forms, when these results are compared with the descriptions, which are found in the treatises of Dana and Hintze, or with those of Goldschmidt.

The calculated and measured angles of the forms in the vertical zone agree closely; but with regard to the terminal faces, the deviation of the measured values from the calculated ones is often great. This is partly due to the general disadvantage of a theodolite goniometer that the possible error by measurement of the meridional angle ϕ increases as the polar distance ρ diminishes. To compensate this deficiency, the interfacial angles between the faces belonging to the zone (*bc*) were measured by using the theodolite goniometer as a one-circle one. The results of these measurements fairly well coincide with the calculated values as shown in Table II.

TABLE II.

	Calculated.	Measured. (mean).
bc	92° 36′	92° 29′
bc′	87° 24	87 32
bs	44 40	44 08
cs	42 44	43 07
co	45 13	45 22
bo	47 23	47 25

---

[6] The crystal elements of babingtonite, given by Dauber (Pogg. Ann., 94, 402, 1855) are as follows:
$a : b : c = 1.635 : 1 : 0.8955$; $\alpha = 86° 09'$, $\beta = 93° 48'$, $\gamma = 112° 22'$. $ab = 67° 48'$, $ac = 87° 28'$, $bc = 92° 36'$.
These values were obtained by him from the results of measurements on more than eighty crystals of babingtonite from Arendal.

[7] Palache and Fraprie, Proc. Amer. Acad., 38, 382, 1902. Some misprints occur in their table of corresponding forms for the different positions.

The crystal habits and the zonal relations of the faces are illustrated in the accompanying figures.[8]

Among the observed forms, both *b* and *k* are generally well developed and give a prismatic habit to most crystals, although some platy crystals are produced by the predominance of *b*. These two forms are usually characterized by vertical striations, caused by their mutual oscillatory combination. The forms *a*, *h* and *g* all appear as narrow faces, which truncate the acute edges between *b* and *k*. Among the terminal faces, *c* is best developed in size, though it is striated parallel to the axia *a*, owing to the oscillatory combination of *c* and *d*. All other forms are represented as either narrow or minute faces.

Physical Properties.

The mineral is black in color and has a brilliant vitreous luster. Crystals are commonly opaque, but in thin sections transmit light and gives deep color. The pleochroism is very marked, the axial colors being as follows:

X ....deep emerald-green,
Y ....purple-brown,
Z ....deep brown.

In this particular point, the mineral is distinguished from other triclinic members of the pyroxene group, which have the similar crystal forms. The absorption is strong in the order of X > Y > Z, and the dispersion is marked. Hence, it is difficult to accurately determine the extinction position. As the averages of repeated measurements on several sections, the extinction angle on *b*(010) is given as about 37° from the vertical axis *c*, and that on *c*(001) is about -5° or -6° from the axis *a*.

---

[8] In drawing these figures, a gnomonic projection of the crystal on the plane normal to the prism zone was first made (fig. 1). Each edge in the plans on this plane (figs. 2b and 3b) is normal to the zone line, which connects the poles of the faces intersecting at that edge. Next, to make the elevations on the plane of *b*(010) (figs. 2c. and 3c), the intersection of this plane with the plane of projection and its angle point were found on the projection. In this particular case, they are shown as the line LL′ and the point B respectively. Each edge in the elevations is normal to the line connecting this point B and the intersection between the line LL′ and the zone line, which passes the poles of the two faces intersecting at that edge. Likewise, the line LL′ and its other angle, point B′, determine the directions of the edges of elevations on the plane of *b*′ (010) (figs. 2a and 3a). (See Boeke: Die gnomonische Projektion, 1913, pp. 40-44.)

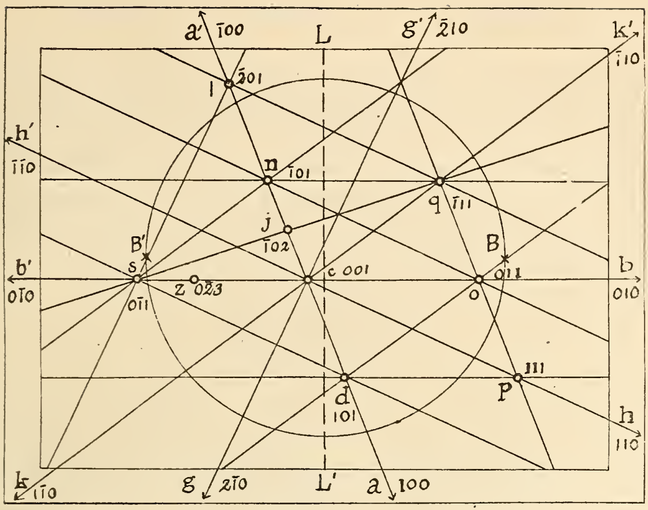


Fig. 1.

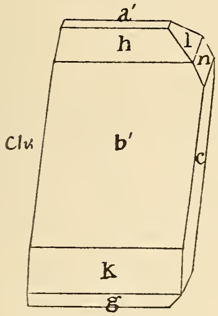


Fig. 2a.

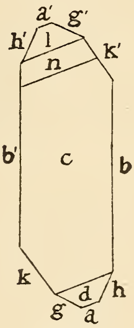


Fig. 2b.

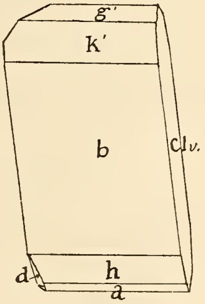


Fig. 2c.

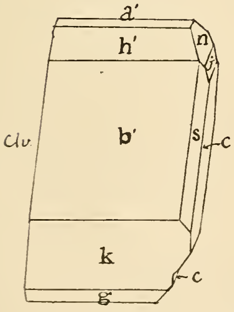


Fig. 3a.

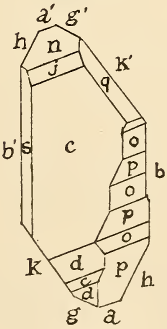


Fig. 3b.

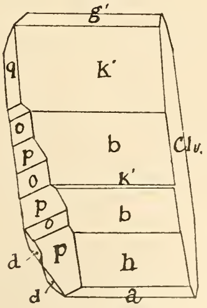


Fig. 3c.

FIG. 1.—Gnomonic projection of the babingtonite from the Yakuki mine, Japan.

FIGS. 2 and 3.—The orthographic drawings of the babingtonite from the Yakuki mine.

FIGS. 2a and 3a.—Elevations on the plane of $(0\bar{1}0)$.

FIGS. 2b and 3b.—Plans on the plane vertical to the prism zone.

FIGS. 2c and 3c.—Elevations on the plane of (010).

The indices of refraction were measured by Becke's method by means of the standard solutions, which were available through the courtesy of Prof. A. F. Rogers. The minimum value is between 1.710 and 1.720, and the maximum a little greater than 1.740. The intermediate principal index lies between 1.720 and 1.730.[9] Thus the three principal indices are approximately:

$$\alpha = 1.715 \pm 0.005$$
$$\beta = 1.725 \pm 0.005$$
$$\gamma = 1.740 + 0.00x$$

Optically biaxial and positive. Cleavage is perfect parallel to $c(001)$, and less perfect parallel to $a(100)$ and $b(010)$. The hardness is almost equal to that of orthoclase, or about 6. Before the blowpipe, the thin edges easily fuse to magnetic globules. The substance is not affected by common acids.

Tôhoku Imperial University, Sendai, Japan.

---

[9] Determined by S. Tsuboi's method, Jour. Geol. Soc. Tokyô, vol. 25, p. 38, 1918.

Art. XVI.—*A Tillite-like Conglomerate in the "Eocambrian" Sparagmite of Southern Norway;* by Olaf Holtedahl.

The so-called Sparagmite formation, which covers a very large area of southeastern Norway (see fig. 1), is in several respects a sedimentary series of considerable interest. We meet here with thick beds of coarse-grained clastic rocks, very rich in fresh feldspar, alternating with thinner zones of clayey material and limestones. Of these the Biri limestone is of most importance and best known.

No fossils have as yet been found in these rocks and therefore there are somewhat divergent opinions as to their exact age. We know that the sparagmites are older than the Lower Cambrian Holmia shale, and as there is a good transition from the highest sandstone into the Holmia shale, Brögger, Münster, and more recently J. Kiær have regarded the sparagmites as closely attached to the Cambrian. Brögger introduced for them the term "Eokambrium," thus indicating that the strata are of the oldest Cambrian, while Kiær classifies them as true Lower Cambrian. The Swedish geologist Törnebohm, on the contrary, referred the sparagmites to the Algonkian.

Non-Scandinavian authors have also discussed the age of the Sparagmite series or parts of it. Walther, in his paper "Ueber algonkische Sedimente,"[1] has emphasized the great petrological likeness to the Torridonian of Scotland, while Rothpletz,[2] by assuming an overthrust that quite certainly does not exist, held that the Biri limestone is younger instead of older than the Holmia shale. From this viewpoint of Rothpletz, Grabau, in his "Comparison of American and European Lower Ordovicic Formations,"[3] has discussed the possibility of the Biri limestone being a continuation of the Durness limestone of northern Scotland.

The main objects of the present article are: (1) to point out the occurrence in the sparagmites of conglomerates of a tillite-like character, and (2) to give a sum-

---

[1] J. Walthier, Zs. deutsch. Geol. Ges., 61, 283-305, 1909.

[2] A. Rothpletz, Sitzber. Bayr. Akad. Wiss., 1-66, 1910.

[3] A. W. Grabau, Bull. Geol. Soc. America, 27, 555-622, 1916

mary review of the stratigraphic sequence of the series, from which the chronologic position of the conglomerates may be seen. A great many Scandinavian geologists have contributed to the clearing up of these features, as Kjerulf, Schiötz, Törnebohm, Münster, Björlykke, Goldschmidt, Werenskiöld, and others. The writer has studied the problem of the Sparagmites in the field during the summers of 1919 and 1920.

Fig. 1.—Sparagmite area of Southern Norway dotted. M = Mjösen.

The greater and especially the northern and central parts of the region covered by sparagmite rocks have been very decidedly deformed by the Caledonian orogeny, and the rocks are highly metamorphosed. The stratigraphic sequence given below is based especially on the conditions met with in the most southern belt, particularly in the region around the northern part of the great lake Mjösen. Even here, intense folding and thrusts have taken place, making the deciphering of the geologic history a rather complicated matter.

The oldest members of the Sparagmite division are known from the more northern district only. Here, as for instance between the Gudbrandsdal and Oesterdal, about 75 km. north of Mjösen, the oldest sparagmite is a somewhat metamorphosed rock, having a conglomerate at the very base, and is seen to rest on the somewhat undulating surface of pre-Cambrian gneiss. In the southern part of the area the oldest zone, the *gray or older sparagmite,* several hundred meters in thickness, is a dark gray, generally coarse sandstone rich in grains of feldspar, with some layers of dark arenaceous shale. Then follows a relatively thin zone with *red and greenish shale* and thin beds of limestone. The earlier time of strong denudation and rapid sedimentation of the detritals derived from granites and gneisses, of which the thick sparagmite zone tells, changed later into one with only slow deposition in a playa-like basin of water.

Denudation again became active, indeed to a quite remarkable extent, for above the last-mentioned zone there is a very coarse conglomerate, in places 100-200 meters thick, the *Biri conglomerate,* consisting of bowlders very often of large size, up to 1 meter in length. The bowlders, made up of granite, gneiss, quartzite, diabase, and limestone, are well rounded and distinctly water-worn. A river transport of such coarse material certainly presupposes a relatively steep grade of the land.

Through an intermediate zone of gray sparagmite and shale, the sequence passes into the *Biri limestone,* the thickness of which in places is as much as 100-150 meters. This zone in part consists of a compact gray (generally more or less magnesian), often arenaceous limestone, the main constituent being, however, a black argillaceous limestone. In the compact variety there are at Lake Mjösen intraformational conglomerates, with angular pieces of limestone lying at very different angles, thus indicating very shallow waters. There are also oolitic and at one locality stromatolitic limestones, which appear to have been chemically precipitated. In spite of much seeking for fossils, none were found.

Over the limestones then follows an accumulation of huge masses of coarse clastics, the *younger, or red, spar-*

agmite, a pink, coarse, very often conglomeratic, thick-bedded sparagmite, 300-400 meters thick, and in places much more. As to the conditions under which this and the other beds of sparagmites have been formed, the large amount of fresh feldspar necessarily presupposes, as has been pointed out by Walther and by several Norwegian geologists, a weathering of granitic rock in a very dry climate. That we are not dealing with wind-blown desert sands is evident from the coarse and angular character of the mineral grains, as well as from the absence of dune stratification. There was here a very short and very rapid detrital transport by torrential waters, from encircling mountains into an intermontane basin, under semi-arid conditions. The thickness of the beds, *e. g.*, the red sparagmite, the coarseness of the material, and the high content of feldspar grains seemingly indicate a far shorter length of transport and a much more rapid accumulation than do the ordinary red sandstones of later formations.

The red sparagmite is often seen to have conglomerate zones with well rounded, water-worn bowlders of moderate size. This passes upward into a more peculiar conglomerate to which I should like to draw special attention. It has a dark reddish brown color, with no visible bedding at all and with fragments of all sizes embedded in a fine-grained matrix. The smaller fragments are generally quite angular and often the larger bowlders, some of which are more than 0.5 meter in diameter, are only partially rounded. The greater part of the fragments consist of granites, gneisses, sandstones, and quartzites. In addition, there are limestones, as in the western district where this conglomerate is found at Lake Mjösen, while in an eastern area, north of Trysil near the Swedish frontier, occur porphyries of types known from the pre-Cambrian still farther east. The limestone bowlders mentioned are quite like those previously spoken of as occurring in the Sparagmite division.

The conglomerate just described[4] has all of the general characteristics of a tillite, and it is difficult to think of any other method of transportation for material of this kind than a glacial one. As yet, however, no undoubted glacial

---

[4] An illustration of a specimen of the conglomerate is given in a paper by the present author, ''Om Trysilsandstenen og sparagmifavdelingen,'' Norsk. Geol. Tidsskrift, 6, 38, 1920.

striæ have been observed, but since the sparagmites have suffered much from the Caledonian deformation, the finding of striæ is very difficult. In fact, when the bowlders are freed from the matrix, their surface is generally seen to be slickensided and tectonically striated. This conglomerate is exactly like the brown tillites of Finmarken, recently mentioned by me in this Journal.[5]

As there is no break in the sequence below the conglomerate just described, it can not have been deposited by a glacier on the dry land; and if we assume a glacial origin, the material must be thought of as having been deposited by floating ice, or, better, as morainic material in front of a submerged glacier.

Above the tillite-like conglomerate, the thickness of which at Lake Mjösen appears to be at least 10 meters (perhaps considerably thicker), though somewhat less in the eastern district, follows a relatively thin zone of red and green shale, sometimes with sandstone beds, and this in turn is overlaid by the so-called "Quartz sandstone." As the name indicates, this formation is a normal sandstone, consisting essentially of quartz with the mineral grains smaller, more even-sized and rounded than in the sparagmites; zones of sparagmite-like rock, however, are also met with here. The color of the quartz sandstone is mostly from bluish to yellowish gray, and the material indicates a longer transport, with better sorting and rounding of the grains. In the southwestern part of the sparagmite area this sandstone is very thick, certainly upward of 100 meters. It gradually passes into sandy shale, which in turn passes into greenish shale holding the Holmia fauna which has recently been revised and described by Kiær.[6] The stratigraphic succession is illustrated in generalized form in fig. 2.

If we next consider the distribution of the different formations above described, it becomes evident, as has been made especially clear by the author's recent studies along the eastern border of the sparagmite area, that the quartz sandstone in the southern part of the area has a much wider distribution than the older feldspar-bearing zones. Ten kilometers west of the Engerdalen valley the

---

[5] O. Holtedahl, this Journal (4), 47, 104, 1919.

[6] J. Kiær, The Lower Cambrian Holmia Fauna at Tömten in Norway, Vidensk. selsk. Skr., 1916, No. 10.

sequence is in the main as described above, for here a thick mass of red sparagmite is exposed as the oldest zone, while in the valley itself the lower part of the "quartz sandstone" is developed as a true, and in part a very coarse, sparagmite (the "gray sparagmite" of O. E. Schiötz), resting directly on pre-Cambrian granite. Here denudation must have taken place while the red sparagmite was being deposited nearby to the west. On the other hand, the red sparagmite of the eastern localities mentioned, that is, in an area that must be very close to the eastern boundary line of this formation, is not in any respect different from that farther west. In other words, it does not seem likely that the present boundary line of the red sparagmite was the original one, because then we should expect distinctly coarser rocks at the eastern localities which were nearer to the highlands. Moreover, along the western boundary of the sparagmites the red sparagmite (and its metamorphic equivalents) are seen suddenly to disappear in this direction. If we remember, furthermore, that in the Mjösen district, near the southern boundary of the sparagmite area, bowlders of limestone, which no doubt belong to the lower part of the sparagmites, occur in the tillite-like conglomerate at the top of red sparagmite, we must conclude that there have been decided marginal uplifts in younger Sparagmite time,

Fig. 2.

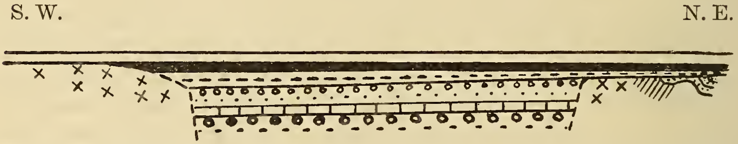


Fig. 2.—Generalized stratigraphic succession of the southern sparagmite area and adjacent districts before the Caledonian deformation (Ordovician and Silurian divisions not introduced). Complete sequence in middle part of the section:

Upper and Middle Cambrian (alum shale).
Lower Cambrian Holmia shale (in black).
Quartz sandstone.
Red sparagmite with tillite-like conglomerate on top.
Biri limestone.
Gray sparagmite.

To the left, pre-Cambrian gneiss and granite. To the right, pre-Cambrian granite, porphyry, and Trysil sandstone with sheets of diabase.

causing a peripheral denudation through the sparagmites down to the granite and porphyry. With an especially marked marginal uplift, glaciers and a laying down of conglomerates without stratification may have come into existence. It seems natural to assume that this uplift represents not merely a gentle flexure, but a decided faulting.

When the deposition of the quartz sandstone began, the land to the east of the red sparagmite was well base-levelled, while toward the southwest there were still rising heights. And as was shown in the paleogeography map of Lower Cambrian time published by the writer in 1920[7] there was still land in this direction at the time of the Holmia shale.

That marginal upheavals or central sinkings have repeatedly taken place in the area here considered, and in the time of the sparagmites, preceding the deposition of the oldest known fossiliferous sediments, is evident from the general geologic occurrences. Such thick accumulations of coarse materials, with their distinct petrological characters, can only have been transported over very short distances. That this upheaval has been not a gentle warping but, rather, an important dislocation of the crust is, in my opinion, further indicated by the large bowlders found above the older sparagmite. A conglomerate like this one, following the deposition of sparagmitic sandstones and arenaceous shales, can scarcely have been brought about alone through climatic changes; it must be due to a decided uplift of the adjacent land.

Even though there must have been quite remarkable *vertical* crust movements during Sparagmite time, we know of no *folding* causing distinct unconformities. On the other hand, a distinctly folded sedimentary series, not far from the sparagmites, is found in the Trysil sandstone, which is the direct western continuation of the Dala sandstone of the Swedish geologists and a representative of the Jotnian formation of the pre-Cambrian of Fennoscandia. The Trysil-Dala sandstones and the Sparagmite have previously been generally considered to belong to one great stratigraphic group, but to me this appears to be a wrong correlation; the former clearly

---

[7] O. Holtedahl, this Journal (4), 49, 3.

belong to the pre-Cambrian, while the latter are closely attached to the Holmia shale of the Lower Cambrian. The folding of the Jotnian sandstone, however, has not been decided; indeed, over the Swedish frontier it is sometimes almost without folding. On the other hand, considerable crust movements did occur in Sparagmite time. In fact, we appear to have here the final dying out of the pre-Cambrian diastrophic movements, the more local vertical movements following the regional and much older tangential ones. In some ways it may be said that the sparagmites are of a time transitional between the true Proterozoic and the Paleozoic, even if stratigraphically they are best classed with the Paleozoic.

It is only natural that sediments like the sparagmites should give rise to divergent opinions as to their age relations. In similar fashion, the well-known tillites of China and Australia, which occur below fossiliferous Cambrian, have been classified both as Cambrian and pre-Cambrian. Such a struggle is often a struggle of words only. The main thing is that we should have a sound idea as to the relative stratigraphic position of these ancient tillites and of their relation to the times of orogeny. Their age relations will then in the course of geologic endeavor be satisfactorily determined. That the tillite-like conglomerate described in this paper is of an age similar to that of the eastern tillites just mentioned seems at any rate to be a rather probable conclusion.

Table of pre-Ordovician formations in the southern sparagmite area of southern Norway.

(Also compare with Fig. 2.)

Paradoxides shale. Middle Cambrian.	Invasion of sea in south and west of sparagmite area.
Holmia shale. Lower Cambrian.	Final pre-Ordovician denudation and base-levelling of land south and west of sparagmite area. Invasion of sea into sparagmite region and further east.
Quartz sandstone. 100 + m.	Very strong denudation of land southwest of sparagmite area; thinning out of sandstones toward northeast.
Upper red and green shale. Thin Eocambrian.	Slow denudation and final peneplanation of land east of area of red sparagmite.

Tillite-like conglomerate. At least 10 m.	Marginal upheaval (or central sinking) and very strong denudation of surrounding land, possibly by glaciers.
Red, coarse, younger sparagmite, often conglomeratic. 300-400 m.	Strong weathering and denudation of marginal lands, periodic flood transport of detrital material into central area.
Biri limestone. About 100 m.	Quiet conditions; deposition of calcareous material.
Biri coarse conglomerate. 100-200 m.	Exceedingly strong denudation of surrounding land, probably caused by important marginal uplift.
Lower red and green shale, with beds of thin limestone.	Slow sedimentation of argillaceous and calcareous material.
Gray, older sparagmite. Several hundred meters.	Strong weathering and denudation of marginal lands, periodic flood transport of detrital material into central area.

Older sparagmite rocks known in more northern part of sparagmite area.

Total maximum of Eocambrian sparagmites more than 2000 m. Probably a lacustrine deposit on a low land bordering the sea.

Erosion interval and unconformity.

Intrusion of diabases into, and folding of, Jotnian Trysil sandstone.

Trysil sandstone.

Porphyry, granites, gneisses.

OBITUARY.

Dr. ALFRED GOLDSBOROUGH MAYOR, for many years a Director of the Carnegie Institution of Washington, died at the Tortugas, Key West, Florida, June 24, at the age of fifty-four years. He was the son of Professor Alfred M. Mayer, the eminent physicist of Lehigh University and later of the Stevens Institute of Technology; the results of many of Professor Mayer's researches, particularly in acoustics, have been published in this Journal.

Dr. Mayor's early training was in the field of mechanical engineering and, at the conclusion of his studies in this subject, he received the degree of M.E. from Stevens Institute in 1889. After graduation he became assistant in physics first at Clark University and then at the University of Kansas. But after three years of this work, he found his interest in the mathematical sciences was overshadowed by his intense love of natural history, and he therefore returned to the east and became associated with Alexander Agassiz at Harvard. He served as Mr. Agassiz's assistant and was given charge of the collection of radiates in the Museum of Comparative Zoology. He retained this position for eight years, accompanying Mr. Agassiz on several expeditions to the tropical seas and acquiring that knowledge of marine life and the methods for its investigation which fitted him so well for the special line of work which occupied his more mature years and in which his reputation as a naturalist has been made. While at Harvard he completed the requirements for the degree of Sc.D., the degree being conferred in 1897.

In 1900 Dr. Mayor became curator-in-chief of the museum of the Brooklyn Institute as well as curator of natural sciences. Four years later he was appointed director of the department of marine zoology of the Carnegie Institution, in which position he has contributed his most important services to biology. He has also served as lecturer in biology at Princeton University since 1913.

The region where the Gulf Stream impinges on the southern coast of Florida has long been known as one of the richest regions of the world in the variety and abundance of its marine life. In 1902, under the auspices of the Brooklyn Institute, Mayor led an expedition to this locality, with which he was already familiar, and hit upon the brilliant idea of utilizing the government reservations of the Tortugas islands as a marine biological laboratory. This plan was eventually supported by the Carnegie Institution and through the enthusiasm and self-sacrificing leadership of Dr. Mayor as director matured into the permanent marine station which has ever since been available to the zoologists of the world. At this laboratory many of the most prominent zoologists have gained their first acquaintance with tropical marine life and their studies here inaugurated have yielded results of far-reaching importance.

Mayor's direct contributions to Zoology consist of numerous papers mainly on coelenterates, which he studied intensively both anatomically and physiologically, His most extensive publication, in three quarto volumes, is a superbly illustrated monograph on the medusæ of the world. To secure material for this work he accompanied Mr. Alexander Agassiz for many years in explorations of the tropical seas of both the Atlantic and Pacific Oceans. He was later the leader of expeditions to the coral reefs of Samoa, Fiji and other islands of the tropical Pacific.

Mayor has also made contributions of importance on the evolution of snails, the coloration of insects, the nature of the nervous impulse, the formation of coral reefs, the rate of growth of corals, the palolo worm, and studies on the physical nature of death. He had a brilliant mind, a friendly, modest and unselfish personality, and a restless energy in his work; he naturally became a member of many learned societies and an officer of several.

W. R. C.

CONTENTS.

SCIENTIFIC INTELLIGENCE.

VOL. IV SEPTEMBER, 1922

Established by **BENJAMIN SILLIMAN** in 1818.

THE
AMERICAN
JOURNAL OF SCIENCE.

EDITOR: EDWARD S. DANA.

ASSOCIATE EDITORS
PROFESSORS WILLIAM M. DAVIS AND REGINALD A. DALY,
OF CAMBRIDGE,

PROFESSORS HORACE L. WELLS, CHARLES SCHUCHERT,
HERBERT E. GREGORY, WESLEY R. COE AND
FREDERICK E. BEACH, OF NEW HAVEN,

PROFESSOR EDWARD W. BERRY, OF BALTIMORE,
DRS. FREDERICK L. RANSOME AND WILLIAM BOWIE,
OF WASHINGTON.

FIFTH SERIES

VOL. IV—[WHOLE NUMBER, CCIV].

No. 21—SEPTEMBER, 1922.

NEW HAVEN, CONNECTICUT.
1922.

THE TUTTLE, MOREHOUSE & TAYLOR CO., PRINTERS, 123 TEMPLE STREET.

Published monthly. Six dollars per year, in advance. $6.40 to countries in the Postal Union; $6.25 to Canada. Single numbers 50 cents; No. 271, one dollar.
Entered as second-class matter at the Post Office at New Haven, Conn., under the Act of March 3, 1879.

These Are Wiley Books

READY OCTOBER 1st.

Elements of Optical Minerals

An Introduction to Microscopic Petrography.

By **N. H. WINCHELL** and **A. N. WINCHELL.** Second Edition. Entirely Rewritten and Much Enlarged by **ALEXANDER N. WINCHELL**, Doct. Univ. of Paris, Professor of Mineralogy and Petrology, University of Wisconsin.

PART I.—PRINCIPLES AND METHODS.

The treatment given in this first Part of the second edition, taking up Principles and Methods, is adapted to the microscopic study of Minerals, **both in thin sections and in powdered form immersed in liquids,** the latter method permitting an accurate quantitative measurement of the index of refraction.

(Now going through the press—ready October 1st.)

The Famous 'Dana' Mineralogies

Textbook of Mineralogy

With an Extended Treatise on Crystallography and Physical Mineralogy. Third Edition, Revised and Enlarged by **WILLIAM E. FORD.**

720 pages, 6 by 9, 1050 figures, $5.00

Manual of Mineralogy

Thirteenth Edition, entirely Revised and Rewritten by **WILLIAM E. FORD.**

460 pages, 6 by 9, 357 figures, 10 plates. Cloth, $3.00. Flexible binding, $3.50.

System of Mineralogy

(Descriptive Mineralogy.) Sixth Edition, with Appendices I and II, completing the work to 1909.

1323 pages, 6¾ by 10, over 1400 figures; half leather, $15.00.

(Third Appendix to "System," completing the work to 1915, by **WILLIAM E. FORD**, issued in separate form, 87 pages, 6¾ by 10, cloth, $2.00.)

Minerals and How to Study Them

A Book for Beginners in Mineralogy.

380 pages, 5 by 7, 319 figures, $2.00.

Send for these books on our liberal Free Examination terms—TODAY.

JOHN WILEY & SONS, Inc.

432 Fourth Avenue
New York

London
CHAPMAN & HALL, Ltd.

Montreal, Quebec
Renouf Publishing Company

AJS 9.22

THE
AMERICAN JOURNAL OF SCIENCE
[FIFTH SERIES.]

Art. XVII.—*The Determination of the Space Group of a Cubic Crystal;* by Ralph W. G. Wyckoff.

Introduction.

The theory of space groups presumably defines all of the ways in which elements of symmetry may be distributed in space so that their aggregates will possess crystallographic symmetry.[1] A knowledge of the space group to which a particular crystal should be assigned thus describes completely its characteristics of symmetry, and forms thereby one of the principal goals of descriptive crystallography. On the basis of direct experimental evidence it has hitherto been impossible to carry crystallographic description so far; only in a few isolated cases could the appropriate space groups be inferred.[2] Use of the diffraction effects resulting from the action of X-rays upon crystals offers, however, the opportunity in many cases of determining experimentally the space group corresponding to a crystal.

The crystal symmetry which is deduced by the use of X-ray methods of study is the symmetry of the arrangement of the atoms of which the crystal is composed. The identification of this *internal* symmetry with the *external* crystal symmetry, obtained from studies of face-development and the like, requires an assumption equivalent to one that states that the external symmetry of a crystal is consistent with the arrangement of its constituent atoms. Not only does it appear natural to relate them thus but the generally satisfactory agreement between the external symmetries and the symmetries of the crystal models of those crystals whose structures have thus far been studied with X-rays points to the correctness of this assumption.

---

[1] A. Schoenflies, Krystallsysteme und Krystallstructur, Leipzig, 1891.

[2] For instance, C. Viola, Z. Kryst., 28, 225, 1897; L. Sohncke and E. Federov have made similar assignments.

The probable space groups corresponding to a few crystals have already been determined by showing that the structures assigned to them by the X-ray studies can be deduced from certain particular space groups.[3] It is the intention of the present paper, however, to show, by taking the cubic crystals as the simplest examples, how the space groups of many crystals can be uniquely determined in advance of a complete elucidation of their structures and to state criteria which serve to distinguish between the various cubic space groups where such a distinction is possible. Not only is such a knowledge of the space group of a crystal an ultimate aim of formal crystallography but it may be of great value in the problem of crystal structure study itself.

In the crystals whose structures have been determined all, or nearly all, of the atoms of which they are composed have been found to occupy positions within the unit cells whose coördinate values are limited and defined by symmetry considerations (the corners, center, centers of the edges and of the faces of a unit cube are such positions). Such very special structures can usually be deduced from more than one space group. Most cubic crystals, however, have one or more of their constituent atoms in positions so general that the symmetry requirements permit their x, y and z coördinates to have any values. Physical data concerning the mechanism of the scattering of X-rays by atoms are not yet sufficient for the complete determination of the structure of any crystal having one or more atoms in these general positions. A knowledge of the space group to which such a crystal should be assigned serves to determine the manner of arrangement of its atoms in many cases, even though the distances between some of these atoms cannot now be established with accuracy.

X-ray criteria for distinguishing between the different space groups are most simply and satisfactorily deduced for those crystals having some atoms of appreciable scattering power in general positions. For this reason and also because a knowledge of the space group of such crystals is valuable to the crystal analyst, the discussion which follows will be limited to cubic crystals having one or more atoms in general positions. Similar criteria

---

[3] A. Johnsen, Physikal. Z., 16, 269, 1915.

have been established for other than cubic crystals, although their application to specific instances is not so straightforward. Some discrimination among the special cases where one or more of the coördinates of position are defined by considerations of symmetry can likewise be made.

Means of distinguishing between cubic space groups as an aid to studies of crystal structure by reflection spectrum observations of the relative spacings against the (100), (110) and (111) faces have already been given.[4] For a variety of reasons, however, this method is of little certain value in actual practice.

A study of the Laue photographs taken in a single direction through a crystal distinguishes as far as possible between the various space groups. Because of the much larger mass of data with which they deal, space group determinations based upon Laue photographic studies are not open to the same measure of uncertainty as those derived from reflection spectrum measurements.

It will be seen from the criteria to be discussed that many of the space groups give diffraction effects which are different from those given by any other space group and thus a method is established for deducing completely and uniquely the (internal) symmetry of a crystal without recourse to methods of studying external symmetry, such as those of face-development and etch-figure formation.

These space group criteria have already been used upon a number of crystals of rather complicated chemical compositions. Of these, studies of nickel nitrate hexammonate[5] and of sodium hydrogen acetate[6] have either been published or are in the course of publication; the determination of the symmetry and structure of zinc bromate hexahydrate, published elsewhere in this Journal,[7] has been written primarily to serve as an illustration of the application of these criteria.

Methods of Distinguishing between the Cubic Space Groups.

The general characteristics of the diffraction effects to

---

[4] P. Niggli, Geometrische Krystallographie des Discontinuums, p. 492, Leipzig, 1919.

[5] Ralph W. G. Wyckoff, Jour. Am. Chem. Soc., June, 1922.

[6] Ralph W. G. Wyckoff, see the third article in this number of this Journal.

[7] See the following article in this number.

be obtained from atoms arranged according to the general positions of any one of the space groups can be readily calculated with the aid of the customary intensity expression:

$$I \propto f\left(\frac{d_{hkl}}{n}\right)[A^2+B^2], \text{ where}$$

$$A=\sum_{m}[\sigma_m \cos 2\pi n(hx_m+ky_m+lz_m)], \qquad [1]$$

and B is a similar sine term. In this expression[8] I is the intensity and n is the order of reflection from a plane whose Miller indices are (hkl); x_m, y_m, z_m are the coördinate positions of each of the m atoms (within the unit) over which the summation is to be extended and σ_m is the scattering power of the atom m. The value of

$$f\left(\frac{d_{hkl}}{n}\right)$$

where d_{hkl} is the spacing of the plane (hkl), need not be evaluated for the present purposes. If these diffraction effects are calculated for each of the space groups it is found that for some of them reflections from certain classes of planes in some orders will be entirely absent. Such a complete absence of definite classes of planes, different for different space groups, makes it possible to distinguish between these groups.

As an example of the mode of procedure a common space group, T_h^6, the sixth group having paramorphic hemihedral (pyritohedral) symmetry, will be considered in detail. The coördinates of the most generally placed equivalent points within a unit cube for this space group are

$$\begin{array}{l}
xyz;\ x+\tfrac{1}{2},\ \tfrac{1}{2}-y,\ \bar{z};\ \bar{x}, y+\tfrac{1}{2},\ \tfrac{1}{2}-z;\ \tfrac{1}{2}-x,\ \bar{y},\ z+\tfrac{1}{2}; \\
zxy;\ \bar{z},\ x+\tfrac{1}{2},\ \tfrac{1}{2}-y;\ \tfrac{1}{2}-z,\ \bar{x},\ y+\tfrac{1}{2};\ z+\tfrac{1}{2},\ \tfrac{1}{2}-x,\ \bar{y}; \\
yzx;\ \tfrac{1}{2}-y,\ \bar{z},\ x+\tfrac{1}{2};\ y+\tfrac{1}{2},\ \tfrac{1}{2}-z,\ \bar{x};\ \bar{y},\ z+\tfrac{1}{2},\ \tfrac{1}{2}-x; \\
\bar{x}\bar{y}\bar{z};\ \tfrac{1}{2}-x,\ y+\tfrac{1}{2},\ z;\ x,\ \tfrac{1}{2}-y,\ z+\tfrac{1}{2};\ x+\tfrac{1}{2},\ y,\ \tfrac{1}{2}-z; \\
\bar{z}\bar{x}\bar{y};\ z,\ \tfrac{1}{2}-x,\ y+\tfrac{1}{2};\ z+\tfrac{1}{2},\ x,\ \tfrac{1}{2}-y;\ \tfrac{1}{2}-z,\ x+\tfrac{1}{2},\ y; \\
\bar{y}\bar{z}\bar{x};\ y+\tfrac{1}{2},\ z,\ \tfrac{1}{2}-x;\ \tfrac{1}{2}-y,\ z+\tfrac{1}{2},\ x;\ y,\ \tfrac{1}{2}-z,\ x+\tfrac{1}{2}.
\end{array}$$

Taking for the present purposes the scattering power (σ) of atoms in these general positions as unity and divid-

---

[8] Ralph W. G. Wyckoff, this Journal, 50, 317, 1920.

ing all reflecting planes into three classes having indices that are (1) two even and one odd, (2) two odd and one even and (3) all odd, the A and B terms of expression [1] are found to be as follows for the first order region of the spectrum (which can be distinguished in Laue photographic data from cubic crystals without any uncertainty):

(1) When the indices are two even and one odd, and *p, q,* and *r* are any integers: B = 0, and

$$\begin{array}{llll}
A=2\cos & 2\pi[2px+2qy+(2r+1)z] & +2\cos & 2\pi[-2px+2qy-(2r+1)z+\frac{1}{2}] \\
+2 & \text{``}\ [2pz+2qx+(2r+1)y] & +2 & \text{``}\ [-2pz+2qx-(2r+1)y+\frac{1}{2}] \\
+2 & \text{``}\ [2py+2qz+(2r+1)x] & +2 & \text{``}\ [-2py+2qz-(2r+1)x+\frac{1}{2}] \\
+2 & \text{``}\ [2px-2qy-(2r+1)z] & +2 & \text{``}\ [-2px-2qy+(2r+1)z+\frac{1}{2}] \\
+2 & \text{``}\ [2pz-2qx-(2r+1)y] & +2 & \text{``}\ [-2pz-2qx+(2r+1)y+\frac{1}{2}] \\
+2 & \text{``}\ [2py-2qz-(2r+1)x] & +2 & \text{``}\ [-2py-2qz+(2r+1)x+\frac{1}{2}]
\end{array}$$

(2) When the indices are two odd and one even: B = 0 and

$$\begin{array}{llll}
A=2\cos & 2\pi[2px+(2q+1)y+(2r+1)z] & +2\cos & 2\pi[2px-(2q+1)y-(2r+1)z+\frac{1}{2}] \\
+2 & \text{``}\ [2pz+(2q+1)x+(2r+1)y] & +2 & \text{``}\ [2pz-(2q+1)x-(2r+1)y+\frac{1}{2}] \\
+2 & \text{``}\ [2py+(2q+1)z+(2r+1)x] & +2 & \text{``}\ [2py-(2q+1)z-(2r+1)x+\frac{1}{2}] \\
+2 & \text{``}\ [-2px+(2q+1)y-(2r+1)z] & +2 & \text{``}\ [-2px-(2q+1)y+(2r+1)z+\frac{1}{2}] \\
+2 & \text{``}\ [-2pz+(2q+1)x-(2r+1)y] & +2 & \text{``}\ [-2pz-(2q+1)x+(2r+1)y-\frac{1}{2}] \\
+2 & \text{``}\ [-2py+(2q+1)z-(2r+1)x] & +2 & \text{``}\ [-2py-(2q+1)z+(2r+1)x+\frac{1}{4}]
\end{array}$$

(3) When the indices are all odd: B = 0, and

$$\begin{array}{llll}
A=2\cos & 2\pi[(2p+1)x+(2q+1)y+(2r+1)z] & +2\cos & 2\pi[-(2p+1)x+(2q+1)y-(2r+1)z] \\
+2 & \text{``}\ [(2p+1)z+(2q+1)x+(2r+1)y] & +2 & \text{``}\ [-(2p+1)z+(2q+1)x-(2r+1)y] \\
+2 & \text{``}\ [(2p+1)y+(2q+1)z+(2r+1)x] & +2 & \text{``}\ [-(2p+1)y+(2q+1)z-(2r+1)x] \\
+2 & \text{``}\ [(2p+1)x-(2q+1)y-(2r+1)z] & +2 & \text{``}\ [-(2p+1)x-(2q+1)y+(2r+1)z] \\
+2 & \text{``}\ [(2p+1)z-(2q+1)x-(2r+1)y] & +2 & \text{``}\ [-(2p+1)z-(2q+1)x+(2r+1)y] \\
+2 & \text{``}\ [(2p+1)y-(2q+1)z-(2r+1)x] & +2 & \text{``}\ [-(2p+1)y-(2q+1)z+(2r+1)x]
\end{array}$$

It is thus seen that in general all three groups will appear in the first order region of the spectrum. The following procedure will, however, serve to determine whether there may not be classes of planes within these groups which will show a different behavior.

$$\cos 2\pi(\alpha) = -\cos 2\pi(\beta), \text{ when } \alpha=(\pm\beta\pm\tfrac{1}{2})$$

Consequently any and all values of *p, q,* and *r* which will make A = 0 for the region $n = 1$ can be found by equating the *revolutions* of the first term of A, $[2px+2qy+(2r+1)z]$, to the revolutions of each of the other terms of A plus ½ (and any integer *s*) and solving the resultant expressions for any possible integral values of p, q, and r. Thus,

$$2px+2qy+(2r+1)z=\pm[2pz+2qx+(2r+1)y+\tfrac{1}{2}+s],$$

$$2px+2qy+(2r+1)z=\pm[2py+2qz+(2r+1)x+\tfrac{1}{2}+s],$$

etc.

$$2px+2qy+(2r+1)z=\pm[2px-2qy-(2r+1)z+\tfrac{1}{2}+s],$$

etc.

It is readily shown that all of the solutions to any of these equations are comprehended by making $p=0$ and letting q and r have any values. A similar set of equations can be set up for the second and for each succeeding term of A and values of p, q and r which will make $A=0$ can be selected from those solutions which are common to all of these sets of equations. Because of the simplicity of these expressions this detailed procedure can be materially shortened in actual practice.

If the B term were not invariably equal to zero, a similar procedure would have to be followed and solutions common to it and to the A term chosen. Since

$$\sin 2\pi(\alpha) = -\sin 2\pi(\beta)$$

both when $\alpha=-\beta$ and when $\alpha=(\beta\pm\frac{1}{2})$, two sets of expressions somewhat different from those of the A terms must be established.

The carrying out of this procedure for each of the three groups of planes shows that

(1) When the indices are two even and one odd, $A=0$ if $2p=h$, $2q=k=0$, $(2r+1)=l$;

(2) When the indices are two odd and one even, $A=0$ if $2p=h=0$, $(2q+1)=k$, $(2r+1)=l$;

(3) When the indices are all odd, A is never equal to zero. This absence in the first order of planes of the class $h0l$, where h is even, and of the class $0kl$, where both k and l are odd, will then be a universal characteristic of the defraction effects from all crystals having the symmetry of the space group T_h^6. Since a further study of all of the space groups shows that there is no other one for which these classes of planes and no others are absent, a unique method is thus provided for determining from a study of its Laue photographs whether or not a crystal has the symmetry of the space group T_h^6.

By extending the typical treatment applied here to each of the cubic space groups, a series of criteria can be established for distinguishing in so far as is possible between them. Since in tetartohedral and paramorphic hemihedral (pyritohedral) crystals the plane *hkl* belongs to a different form from *khl* (for instance 041 is distinct from 401) the Laue photographs to which these crystals give rise will possess less symmetry than photographs of those belonging to one of the other classes of cubic symmetry. On the basis of an observed hemihedry or holohedry in the symmetry of the Laue photographs, crystals of the classes T or T^h can always be distinguished from crystals of the classes T^d,O or O^h.

Crystals corresponding to space groups based upon Γ_c, the simple cubic lattice, will in general like T_h^6 give reflections in the first order from planes of all three groups; those based upon the face-centered lattice, Γ_c', will give first (or any odd numbered) order reflections only from planes all of whose indices are odd; and those developed from the body-centered lattice, Γ_c'', will reflect in the first (or any odd numbered) order only planes having two indices that are odd and one even. Upon the observed symmetry of the corresponding Laue photographs and the nature of the underlying lattice, the cubic space groups can be given the following preliminary arrangement:

Γ_c: all kinds of planes in all orders,
  Hemihedral Laue Photographs:
    $T^1, T^4, T_h^1, T_h^2, T_h^6$;
  Holohedral Laue Photographs:
    $T_d^1, T_d^4, O^1, O^2, O^6, O^7, O_h^1, O_h^2, O_h^3, O_h^4$.

Γ_c': only all odd planes in odd orders,
  Hemihedral Laue Photographs:
    T^2, T_h^3, T_h^4;
  Holohedral Laue Photographs:
    $T_d^2, T_d^5, O^3, O^4, O_h^5, O_h^6, O_h^7, O_h^8$.

Γ_c'': only two odd and one even planes in odd orders,
  Hemihedral Laue Photographs:
    T^3, T^5, T_h^5, T_h^7;
  Holohedral Laue Photographs:
    $T_d^3, T_d^6, O^5, O^8, O_h^9, O_h^{10}$.

Distinctions between most of the space groups of any one of these divisions are possible in the first order region of the spectrum (see page 183). By calculating the A and B terms of the intensity expression [1] for the second-order region for various space groups, using the same procedure previously employed, a few more distinctions between space groups can also be made. A final classification of all of the cubic space groups on the basis of the diffraction effects produced by corresponding crystals can be written as follows. In this table indistinguishable space groups are placed together on one line.

Γ_c:	T^1, T_h^1;	uncertain	T_h^2;	
	T^4;		T_h^6;	
	T_d^1, O^1,	O_h^1;	T_d^4, O_h^3;	
	O^2;	uncertain	O_h^2;	
	O^6, O^7;		O_h^4.	
Γ_c':	T^2, T_h^3;	second order region		
	T_h^4;			
	T_d^2, O^3,	second order region,	O_h^5;	second order
	O^4,	uncertain,	O_h^7;	region
	T_d^5, O_h^6;	second order region		
	O_h^8.			
Γ_c'':	T^3, T^5, T_h^5;			
	T_h^7;			
	T_d^3, O^5;	second order region,	O_h^9;	
	O^8;	uncertain,		
	T_d^6;			
	O_h^{10}.			

Except where definitely stated as lying in the second-order region, the distinguishing characteristics are to be understood as being first-order effects. If it is assumed, as may or may not be the case, that studies of face development as commonly carried out upon crystals invariably indicate the symmetry of the arrangement of their atoms, then it will be seen that means are at hand for distinguishing between all of the various space groups except the two pairs T^3 and T^5 and O^6 and O^7. Those distinctions which involve the absence of planes of a single form (the {100} planes) can, however, be used if at all with only the greatest caution because it may readily happen that the scattering powers and relative positions of different atoms in a crystal will be such as to make the reflections from planes of this form so weak as not to be observed under the ordinary conditions of experimentation. Distinctions of this sort have consequently been designated as uncertain in the preceding classification.

The characteristics serving to distinguish between each of the space groups can be stated as follows:

Space Groups based upon a *Simple Cubic Lattice,* in general all three kinds of planes appearing in all orders:

Hemihedral Photographs:

T^1 and T_h^1: No classes of planes absent;

T^4: Planes of the form {100} absent in odd orders;

T_h^2: Planes of the form {*0kl*}, where *k* and *l* are one even and the other odd, are absent in odd orders;

T_h^6: Planes of the form {*h0l*}, where *h* is even and *l* is odd, and of the form {*0kl*}, where *k* and *l* are both odd, are absent in the odd orders.

Holohedral Photographs:

T_d^1, O^1, and O_h^1: No classes of planes absent.

T_d^4 and O_h^3: Planes of the form {*hkl*}, where $h = \pm k$ and either *h* is even and *l* is odd or both *h* and *l* are odd, are absent in odd orders;

O^2: Planes of the form {100} are absent in odd orders;

O^6 and O^7: Planes of the form {100} are absent in all but the fourth, eighth, etc., orders;

O_h^2: Planes of the form {*0kl*}, where *k* is even and *l* is odd, and of the form {*hhl*}, where either *h* is even and *l* odd or both *h* and *l* are odd, are absent in odd orders.

O_h^4: Planes of the form {*0kl*}, where *k* is even and *l* is odd, are absent in the odd orders.

Space Groups based upon a *Face Centered Cubic Lattice,* in general planes having all odd indices appearing in odd orders:

Hemihedral Photographs:

T^2, T_h^3, and T_h^4: No classes of all odd planes are absent in the first order. Second order reflections are absent from T_h^4 for planes of the forms $\{0hl\}$ and $\{h0l\}$, where h is even and l is odd.

Holohedral Photographs:

T_d^2, O^3, O^4, O_h^5, and O_h^7: No classes of all odd planes are absent in odd orders. From O^4 only fourth, eighth, etc., orders from planes of the form {100} are present. Second order reflections from O_h^7 are absent for planes of the form $\{0kl\}$ where k is even and l is odd;

T_d^5, O_h^6, and O_h^8: Planes with all odd indices are present in odd orders except those of the form $\{hkl\}$, where $h = \pm k$. Second order reflections from O_h^8 of planes of the form $\{0kl\}$, where k is even and l odd, are absent.

Space Groups based upon a *Body Centered Cubic Lattice,* in general planes having two odd and one even indices appearing in odd orders:

Hemihedral Photographs:

T^3, T^5, and T_h^5: No classes of two odd and one even planes are absent;

T_h^7: Planes of the form $\{0kl\}$, where k and l are both odd, are absent from odd orders.

Holohedal Photographs:

T_d^3, O^5, O^8 and O_h^9: No classes of two odd and one even planes are absent in the first order. Reflections in the second order from planes of the form {100} are absent for O^8.

T_d^6: Planes of the forms $\{hll\}$ where $\frac{1}{2}h$ is even and l odd are absent in odd orders. In the second order, planes of the forms $\{hhl\}$, where either h is even and l odd, or both h and l are odd, are absent.

O_h^{10}: Planes of the form $\{0kl\}$, where k and l are odd, and of the form $\{hll\}$, where $\frac{1}{2}h$ is even and l is odd, are absent in the first order. Reflections in the second order are absent for planes of the forms $\{hhl\}$ where either h is even and l odd or both h and l are odd.

It will be observed that a number of space groups give rise to diffraction effects which are different from those resulting from any other space group. These unique space groups are $T_h^2, T_h^6, O_h^2, O_h^4, T_h^4, O_h^7, O_h^8, T_h^7, T_d^6, O_h^{10}$; and, less certainly because they depend upon the presence or absence of planes of the single form 100; T^4, O^2, O^6 and O^7, O^4, O^8. The symmetry of a crystal corresponding to any one of these space groups can consequently be determined with complete certainty without any reference to face development, etch-figure symmetry or any other of the customary methods of crystallography. A possible experimental method is thus furnished for finding out what relations exist between the symmetry assigned to a crystal by studies of its external appearance and the symmetry of the arrangement of its atoms.

The experimental establishment of the space group of a particular crystal is simple and can be carried out by the procedure common in crystal structure determination of taking one or more Laue photographs about some convenient orientation, determining the indices of the various diffraction spots by the usual methods of projection and finding the wave-lengths of the X-rays producing these spots with the aid of a measurement of the dimensions of the unit cell through a reflection spectrum measurement from some convenient crystal face.[9] Then if the voltage applied to the X-ray tube in producing the photographs is known, the range of the spectrum in which there will be only first-order reflections can immediately be told. It happens that in all cases where it is necessary to go to the second-order region to distinguish between space groups, first-order reflections from the planes involved are also missing. No ambiguity is therefore introduced concerning the order of reflection of diffraction spots lying in the region of strong second-order effects. Reflections from faces of the form {100} are as a rule more readily obtained by reflection spectrum measurements than from Laue photographs. It is desirable to reëmphasize that, for the reasons already given, only the appearance and not the absence of {100} reflections can necessarily furnish conclusive evidence upon which to base assignments to particular space groups.

In certain of the cases where the diffraction data are

[9] Ralph W. G. Wyckoff, this Journal, 50, 317, 1920.

insufficient, a knowledge of the numbers of chemical molecules to be associated with the unit cube, such as arises immediately from the density and the dimension of the unit, can be of service. For instance suppose that the diffraction data from a certain crystal assigned it to the two indistinguishable space groups T^3 and T^5, and suppose that the determination of the number of chemical molecules within the unit cube requires but two chemically like atoms within the unit cell, then since only T^3 contains as a special case two equivalent positions, the crystal may be assigned to it, rather than to T^5. In view of the present lack of definite knowledge as to what it is that conditions chemical equivalence in the crystalline state, such information must obviously be used with great caution.

There naturally arises a question of whether even with atoms in the most general equivalent positions coördinate values may not exist such that the diffraction results may simulate those corresponding to some space group other than the one to which it really belongs. Any such coördinates for a space group can readily be found by practically the same procedure which has already been employed in determining the reflection characteristics of planes in different orders. In this process, however, the sets of equations are to be solved for x, y and z rather than for h, k and l.

The space group T_h^6 will again serve as an illustration. The previously established set of equations, [2], must now be solved for x, y and z which can have any values between zero and unity, including the former, instead of for integral values of p, q and r. For the present purpose care must of course be taken to avoid such values of x, y and z as yield special cases with fewer than the maximum number of equivalent positions within the unit cell. By solving these sets of expressions in a manner analogous to that previously used it can be shown for instance that when $x = u$, $y = 0$ and $z = 0$, or when $x = \frac{1}{2}$, $y = \frac{1}{2}$ and $z = 0$, only all odd planes are to be found in the first order region. When attempting to ascertain the space group to which a crystal should be assigned, it is important to take into consideration the possibility of atoms occupying exactly or nearly such positions as these. It must likewise be borne in mind that atoms in special positions may not give diffraction effects in certain orders; so that in cases where most of the heavy atoms are in such positions, the characteristic effects upon which a choice of space groups is made may some of them be relatively weak. Especially in view of this possibility of atoms occupying in some instances coördinate positions which may alter the qualitative character of the resulting diffraction effects, it is necessary to emphasize the fact that though these criteria are not ambiguous when used properly they cannot be applied blindly.

Summary.

Criteria, which are valid for crystals which have any atoms of appreciable scattering power in general positions, are established for determining from studies of Laue photographs the space group to which a cubic crystal should be assigned. This knowledge is of value to the crystal analyst because it is thus possible to tell how the atoms in many chemically complicated crystals are arranged, even though existing methods are not sufficient to locate these atoms with accuracy, and because an assignment of a crystal to a particular space group defines completely the positions of all of its elements of symmetry. Many of the space groups give diffraction effects which are different from those given by any other groups and hence a method is provided, in the cases of crystals assignable to any of these unique space groups, of defining completely crystal symmetry without making use of the older methods such as face development and the like.

Geophysical Laboratory,
April, 1922.

ART. XVIII.—*The Symmetry and Crystal Structure of Zinc Bromate Hexahydrate*, $Zn(BrO_3)_2.6H_2O$; by RALPH W. G. WYCKOFF.[1]

[Contribution from the Gates Chemical Laboratory of the California Institute of Technology, No. 16.]

Introduction.

This paper has the two-fold purpose of adding confirmation to the previously assigned structure of nickel nitrate hexammonate[2] by the study of an analogous compound and, more especially, it is intended to be an illustration of the application of those criteria for distinguishing between the cubic space groups which are described in the preceding article.[3]

Excellent crystals of $Zn(BrO_3)_2.6H_2O$, mostly octahedral in habit, are formed from solutions both by slow cooling and by slow evaporation. The crystals that grow from a cooling solution usually exhibit a slight anomalous double refraction with sectoring.[4] The Laue photographs to which these crystals give rise do not, however, show any anomalous effects. Completely isotropic specimens are obtained by gradual evaporation.

$Zn(BrO_3)_2.6H_2O$ is one of a group of isomorphous crystals to which belong the chlorates of nickel, cobalt and probably copper, and the bromates of nickel, cobalt and magnesium.[5]

The Structure of Zinc Bromate Hexahydrate.

A reflection photograph from the octahedral face combined with an estimation of the density of the salt indicates that four chemical molecules are to be associated with the unit cube.[6] The length of the side of this unit was found to be 10.31 A.U. (10.31×10^{-8}cm.).

Laue photographs were prepared through both octahe-

---

[1] Member of the Staff of the Geophysical Laboratory of the Carnegie Institution of Washington.

[2] Ralph W. G. Wyckoff, Jour. Am. Chem. Soc., June, 1922.

[3] See page 175 of this Journal.

[4] Marbach, Poggendorffs Ann. d. Phys., 99, 465, 1856.

[5] P. Groth, Chemische Krystallographie, II, p. 112, Leipzig, 1908.

[6] Ralph W. G. Wyckoff, Jour. Am. Chem. Soc., 42, 1100, 1920; Ralph W. G. Wyckoff and Eugen Posnjak, ibid. 43, 2292, 1921.

dral and cube faces. These showed clearly an absence of planes of symmetry; hence it is evident that the symmetry of the arrangement of the atoms of this crystal is either tetartohedral or paramorphic hemihedral (pyritohedral). Interpretation of these photographs in the usual manner[7] showed that in general planes of all sorts appear in the first order region. The fundamental lattice must consequently be the simple cubic lattice. There are four zinc atoms within the unit, and it is both natural and in accord with previous experience to consider them equivalent. If, merely to serve as a starting point for considering the various possible space groups, this assumption of the equivalence of the zinc atoms is made, we find that there are four tetartohedral and paramorphic space groups built upon a simple cubic lattice which have as special cases four equivalent positions within the unit, namely the groups T^1,T^4,T_h^2,T_h^6.

An inspection of the criteria for distinguishing between these space groups (see the preceding article) suggests the investigation of those planes having one of the indices zero. Some data for first order reflections of such planes from a Laue photograph with the X-rays roughly normal to an octahedral face are given in Table I.

TABLE I. Laue Photographic Data.

From a Plate taken with the X-rays roughly normal to (111).

Appearing Planes.

Indices of plane	Wave Length	Form of plane
$03\bar{2}$	0.480 A. U.	032
$\bar{3}40$	.285	034
$5\bar{4}0$	.376	054
$0\bar{5}6$	.415	056
$\bar{5}80$	.313	058
$07\bar{4}$	.357	074
$0\bar{7}8$	.264	078
$12,0,\bar{5}$	.443	0,5,12
$0,\bar{7},10$	.379	0,7,10
$0,\bar{7},12$	.434	0,7,12
$\bar{8},0,11$	.281	0,11,8

---

[7] Ralph W. G. Wyckoff, this Journal 50, 317, 1920.

Absent Planes.

$70\bar{4}$	.453	047
$05\bar{3}$	.431	053
$0\bar{5}9$	.432	059
$\bar{5}06$	.336	065
$0\bar{6}7$	.325	067
$11,0,\bar{6}$	.329	0,6,11
$\bar{5}07$	.460	075
$0\bar{7}9$	.330	079
$0,\bar{7},11$	.400	0,7,11
$8\bar{5}0$	.448	085
$0,\bar{8},11$	.318	0,8,11
$0,\bar{8},13$	.351	0,8,13
$09\bar{5}$	.304	095
$\bar{7},0,10$	.338	0,10,7
$0,11,\bar{5}$	.362	0,11,5

From this table it will be seen that the only planes of this type which appear in the first order region are of the forms $\{h0l\}$, where h is even and l is odd; it is also apparent that many planes of the forms $\{0hl\}$ and of the forms $\{0kl\}$, where both k and l are odd, were in suitable positions to reflect but did not do so. Results in complete agreement with these data and from planes of still different forms are obtained from the interpretation of a photograph taken with the X-rays approximately normal to a cube face. In comparing the data obtained from two different Laue photographs of either a tetartohedral or paramorphic crystal, it must of course be remembered to choose the H and K axes in the same way in both cases; this is readily accomplished by observing planes of two forms $\{hkl\}$ and $\{khl\}$ which show marked differences in reflecting power and are common to the two photographs to be compared.

The data recorded in Table I are seen to be in entire accord with the criteria which determine the space group T_h^6. Since these criteria uniquely distinguish this space group from every other group, it is evident that the symmetry of crystals of zinc bromate hexahydrate is that of T_h^6. From this knowledge of the corresponding space group and the fact that four chemical molecules are to be associated with the unit cube, the manner of arrangement of the atoms of zinc bromate hexahydrate is definitely determined to be as follows:

Zinc atoms: Arrangement 4b,

$$000;\ \tfrac{1}{2}\tfrac{1}{2}0;\ 0\tfrac{1}{2}\tfrac{1}{2};\ \tfrac{1}{2}0\tfrac{1}{2}.$$

Bromine atoms: Arrangement 8h,

$$uuu;\ u+\tfrac{1}{2},\ \tfrac{1}{2}-u,\ \bar{u};\ \bar{u}.\ u+\tfrac{1}{2},\ \tfrac{1}{2}-u;\ \tfrac{1}{2}-u,\ \bar{u},\ u+\tfrac{1}{2};$$
$$\bar{u}\bar{u}\bar{u};\ \tfrac{1}{2}-u,\ u+\tfrac{1}{2},\ u;\ u,\ \tfrac{1}{2}-u,\ u+\tfrac{1}{2};\ u+\tfrac{1}{2},\ u,\ \tfrac{1}{2}-u.$$

Bromate oxygen atoms: General positions,

$$xyz;\ x+\tfrac{1}{2},\ \tfrac{1}{2}-y,\ \bar{z};\ x,\ y+\tfrac{1}{2},\ \tfrac{1}{2}-z;\ \tfrac{1}{2}-x,\ \bar{y},\ z+\tfrac{1}{2};$$
$$zxy;\ \bar{z},\ x+\tfrac{1}{2},\ \tfrac{1}{2}-y;\ \tfrac{1}{2}-z,\ \bar{x},\ y+\tfrac{1}{2};\ z+\tfrac{1}{2}.\ \tfrac{1}{2}-x,\ \bar{y};$$
$$yzx;\ \tfrac{1}{2}-y,\ \bar{z},\ x+\tfrac{1}{2};\ y+\tfrac{1}{2},\ \tfrac{1}{2}-z,\ \bar{x};\ \bar{y},\ z+\tfrac{1}{2},\ \tfrac{1}{2}-x;$$
$$\bar{x}\bar{y}\bar{z};\ \tfrac{1}{2}-x,\ y+\tfrac{1}{2},\ z;\ x,\ \tfrac{1}{2}-y,\ z+\tfrac{1}{2};\ x+\tfrac{1}{2},\ y,\ \tfrac{1}{2}-z;$$
$$\bar{z}\bar{x}\bar{y};\ z,\ \tfrac{1}{2}-x,\ y+\tfrac{1}{2};\ z+\tfrac{1}{2},\ x,\ \tfrac{1}{2}-y;\ \tfrac{1}{2}-z,\ x+\tfrac{1}{2},\ y;$$
$$\bar{y}\bar{z}\bar{x};\ y+\tfrac{1}{2},\ z,\ \tfrac{1}{2}-x;\ \tfrac{1}{2}-y,\ z+\tfrac{1}{2},\ x;\ y,\ \tfrac{1}{2}-z,\ x+\tfrac{1}{2}.$$

Water oxygen atoms: General positions with different values of x, y and z.

Hydrogen atoms: Two sets of general positions. The coördinates and terminology are taken from the writer's book entitled "An Analytical Representation of the Theory of Space Groups" which is shortly to be published by the Carnegie Institution of Washington.

An inspection of the special cases of the space group T_h^6 shows that the arrangement outlined above is the only reasonable one for the atoms of zinc bromate hexahydrate, since any other would string out sets of eight equivalent atoms along the body diagonals of the unit cube. Though it is impossible at the present time to obtain the positions of other than the zinc atoms, it is probable that the value of u, the parameter defining the bromine atoms, is in the neighborhood of $\tfrac{1}{4}$ and that the values of x, y and z for the bromate oxygen atoms are such as to cluster these atoms more or less closely about the bromine atoms. It will also be observed that the groups of atoms constituting the water molecules cannot be unequally distributed between the metal atoms and the bromate groups, but must all be related in exactly the same manner to the zinc atoms (or to the bromate groups). This distribution is in accord with that found for the ammonia groups in the hexammonate nickel halides[8] and in nickel nitrate hexammonate.[9]

Summary.

From a study of the Laue photographs to which crystals of zinc bromate hexahydrate give rise, it is shown that they must have the symmetry of the space group T_h^6. Though it is impossible to determine the positions of the atoms in this crystal, such knowledge of the underlying space group defines uniquely the manner of arrangement of its atoms. The length of the side of the unit cube which contains four chemical molecules is found to be 10.31 A.U.

Pasadena, California,
May, 1922.

---

[8] Ralph W. G. Wyckoff, Jour. Am. Chem. Soc., June, 1922.
[9] Idem. ibid.

Art. XIX.—*On the Symmetry and Crystal Structure of Sodium Hydrogen Acetate,* $NaH(C_2H_3O_2)_2$; by Ralph W. G. Wyckoff.[1]

[Contribution from the Gates Chemical Laboratory of the California Institute of Technology, No. 17.]

Introduction.

This study of the structure of sodium hydrogen acetate was undertaken in the attempt to find the arrangement of the atoms in some organic compound.

Sodium acid acetate was prepared by the long continued digestion of fused sodium acetate, glacial acetic acid and acetic anhydride in sufficient quantity to remove the small amounts of water which may be present.[2] It was thus obtained in cubes which under the polarizing microscope prove to be isotropic. Assignment to a particular class of symmetry on the basis of the ordinary crystallographic evidence has never been made.

The Study of the Structure of Sodium Hydrogen Acetate.

Comparison reflection spectra from the (100) face of calcite and the (100) face of sodium acid acetate showed three orders of reflection for the latter which stood in the ratio of 2:3:4 (experimental conditions did not permit of the first order registering itself). Measurements upon these photographs combined with the density, $\rho = 1.402$, as determined by a flotation Westphal balance method, gives the mean value 3.07 for the ratio m/n^3, m being the number of chemical molecules within the unit cube and n the order of the reflection. There are thus either three or 24 chemical molecules of the composition $NaH(C_2H_3O_2)_2$ within the unit. The length of the side of the cube having three molecules within it, as determined by these same measurements, is 7.98^9 A.U. ($7.98^9 \times 10^{-8}$cm.).

Several Laue photographs taken with the X-rays nearly normal to the cube face of crystals from two dis-

---

[1] Member of the Staff of the Geophysical Laboratory of the Carnegie Institution of Washington.

[2] The writer is under obligation to Prof. H. J. Lucas and to L. M. Kirkpatrick for some of these preparations.

tinct preparations were studied. Some pertinent data from the interpretation of one of these photographs are given in Table I. In this table the wave-lengths of the reflected X-rays have been calculated on the basis of a small unit containing three chemical molecules. The voltage applied to the X-ray tube during the making of these photographs was such that no reflections are ordinarily present in wave lengths shorter than $\lambda = 0.24$ A.U. Since, as reference to Table I shows, appreciable effects with values of $n\lambda$ as low as 0.180 are to be found upon the photographs, the correct unit must contain 24 and not three molecules.

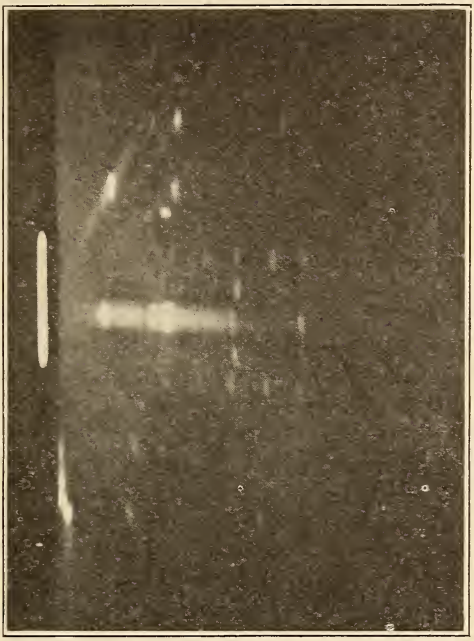
TABLE I. Laue Photographic Data.

Indices of plane	Intensity	Wave Length
381	m	0.232 A. U.
581	f	.239
781	f	.227
$\bar{1}61$	s	.261
$\bar{3}41$	m	.263
$\bar{5}\bar{2}1$	s	.217
$\bar{3}\bar{8}1$	m	.206
$1\ \overline{10}\ 1$	f	.243
$\bar{3}92$	f+	.206
2 13 3	f	.241
6 13 3	f	.244
$7\ \overline{10}\ 1$	f	.253
$\bar{5}72$	m –	.211
$\bar{7}52$	f	.179
$\bar{7}32$	f	.233
$\overline{11}\ 5\ 4$	f	.268
$\bar{7}\bar{5}2$	m	.256
$\bar{3}\ \overline{14}\ 3$	f	.240
$\bar{5}\bar{9}2$	f	.243

NOTE:—In this table spots having an intensity *f* are faint, those marked *m* are of medium intensity and those designated by *s* are amongst the strongest appearing upon the photograph.

This result was sufficiently unexpected, especially in view of the fact that a simple structure containing three molecules was not only possible on the grounds of symmetry but was chemically plausible, that it seemed worth while to obtain a direct spectrum observation of a reflection in the first order from this larger unit. This could be done by studying the secondary spectra from a cube face reflection. If a spectrum is taken from a crystal face in the usual manner, not only is the reflection from

Figure 1.



this face observed upon the photographic plate, but reflections from various other faces which are brought into position by the continuous rotation of the crystal during the course of the experiment will be registered at the same time at various angles to the principal spectrum. Such a composite spectrum was prepared by passing the X-rays through a section of a crystal of $NaH(C_2H_3O_2)_2$ mounted so that one of the cubic axes was coincident with the axis of its rotation and hence lay in the plane of the slit of the spectrograph. A reproduction of this spectrum is shown in fig. 1.

The identification of the secondary spectra on this photograph can be carried out with the aid of the gnomonic net which has previously been described.[4] The distance from the crystal to the photographic plate can if necessary be accurately calculated from the measurement of the principal spectrum (in this case the (100) reflection). It is then a simple matter to prepare a gnomonic ruler[4] for plotting on a radius of five centimeters the projections of the various secondary spectra. By making the distance from the crystal to the plate exactly five centimeters, it would be possible to use directly the same gnomonic ruler which serves for Laue photographs; by making this distance 10 cm., as is more satisfactory, the same ruler can of course be used by dividing by two the readings of the scale giving distances from the central spot. While, during the course of the experiment, the crystal is rotated back and forth, the gnomonic projections of the various reflecting planes will travel along the hyperbolas of the gnomonic net if it is so placed that the zero degree hyperbola (a straight line) coincides in position with the principal spectrum. By rotating the mean projected positions of these reflecting planes (which in the present instance form a simple square network of points) through the angle of rotation suffered by the crystal, portions of hyperbolas will be decribed which will pass through the gnomonic projections of the observed reflections for those planes that can reflect for this particular setting of the crystal. By superposing, then, the gnomonic projection of the photograph over the series of hyperbolic paths obtained in this manner, it is possible to identify the various reflections upon the photograph. Considerable care must be taken in such a determination and some ambiguity may of necessity arise because it frequently happens that reflections from different planes, especially planes in different orders of reflection, give effects at about the same positions upon the plate.

By making this sort of an interpretation of the transmission spectrum photograph from sodium hydrogen acetate, reflections from planes belonging to a number of forms, such as {161}, {721}, and {521}, were observed in

---

[4] H. Hilton, Min. Mag., **14**, 18, 1904; Ralph W. G. Wyckoff, this Journal, **50**, 317, 1920.

the first order from the large unit containing 24 chemical molecules.

The Laue photographs show clearly the absence of planes of symmetry. The crystals of this compound must then have either tetartohedral or paramorphic hemihedral (pyritohedral) symmetry. It was further observed that all of the planes giving reflections in the first order region on the basis of the large unit have two odd and one even indices. This points to an underlying body-centered lattice.[5] The four space groups T^3, T^5, T_h^5 and T_h^7 have the appropriate symmetry and are built upon Γ_c''. Distinction between the first three of these is impossible upon the basis of the diffraction effects to which they give rise. Crystals corresponding T_h^7 would give no reflections[5] in odd orders from planes of the forms $\{0kl\}$, where both k and l are odd. Neither upon the Laue photographs nor upon the transmission spectrum photograph were any such planes found in odd orders, even though some were in suitable positions for reflection. This would make it necessary to assign to crystals of sodium acid acetate the symmetry of T_h^7. The unit is so large, however, that with moderate degrees of tilt from symmetrical Laue photographs the few planes which reflect in the first order region have complicated indices and are of weak intensity. Consequently in order to place this assignment of symmetry beyond any legitimate questioning, it would be desirable to study Laue photographs from crystals inclined farther from the symmetrical position than those here investigated. It did not, however, seem worth while to make these additional experiments at the present time.

Accepting this assignment to the space group T_h^7 as correct, the general coördinate positions of the atoms in sodium acid acetate are defined. Depending upon what equivalence is assumed for the two acetate groups and for the atoms within these groups, all of the atoms of the crystal will be arranged according to either the 48 generally equivalent positions[6] of T_h^7 or the 24 equivalent

---

[5] Ralph W. G. Wyckoff, see the first article by the writer in this number of this Journal.

[6] These general positions are stated in abbreviated form by A. Schoenflies, Krystallsysteme und Krystallstruktur, p. 551, Leipzig, 1891. Also in detail by P. Niggli, Geometrische Krystallographie des Discontinuums, p. 368, Leipzig, 1919.

positions of the special case 24e. It is of course impossible now to determine the positions of any of these atoms. The coördinates of both of these arrangements are given in the book by the writer entitled "The Analytical Representation of the Theory of Space Groups" which is shortly to be published by the Carnegie Institution of Washington.

When it is considered that such a relatively simple substance as this sodium acid acetate has such a very complicated structure as it has here been shown to possess, it scarcely needs to be emphasized that any studies of the structures of organic compounds should be made with extreme care and in order to be of any value should make use of the most powerful diffraction methods now at our disposal.

Summary.

It is shown that the unit cell of sodium hydrogen acetate must contain 24 chemical molecules. The length of the side of this unit cube is found to be 15.98 A.U. The determination of the underlying space group as probably T_h^7 defines the general manner of the arrangement of the atoms of this crystal, though it is impossible to obtain the positions of these atoms. A graphical method is outlined for identifying the planes causing the secondary spectra upon a reflection spectrum photograph.

Pasadena, California.
May, 1922.

Art. XX.—*Cone-in-Cone;* by W. A. Tarr.[1]

Cone-in-cone is a structural feature found in shales and rarely in coal. It is usually associated with concretions but not necessarily so. An occurrence of cone-in-cone in coal and its development in bands of calcite are such exceptions. The cone-in-cone structure consists of a series of cones within cones, adjacent cones uniting to form lenses or layers. When associated with concretions the cone-in-cone may occur on the upper or lower surface, or, more rarely, within the concretion.

The structure was recognized and called cone-in-cone in the early part of the last century. It was not so called by all, however. Hildreth, in 1836 (see literature at end for all references), described it as a "fossil columnar Madrepore." It has also been called "cone-in-cone coral." The German name for cone-in-cone is "tutenmergel" and was given to it as early as 1823.

Cone-in-cone has been described by Marsh, Sorby, Newberry, Jukes, Dawson, Daintree, Young, Sach, Garwood, Gresley, Broadhead, and many others. Their descriptions are all very similar, although their conclusions regarding the origin of cone-in-cone differ considerably.

Probably the majority of investigators have regarded cone-in-cone as having been caused by pressure which was due (since the structure is so frequently seen in association with concretions) to the expansion of concretions through growth. Thus, most cone-in-cone structures are regarded as of secondary origin. Some of those holding this view are Marsh, Geikie, Dana, Gresley, Grimsley, and Chadwick. Others have regarded the structure as being due to crystallization or to "imperfect crystallization." Owen, Newberry, Geikie, Sach, Grabau, and Keyes have advocated one or both of these methods.

Odd suggestions have been made by Sorby, who supposed that oolites had formed the sides of the cones; by Daintree, who believed the cones were chemical precipitates; and by Young, who says unequivocally, that they

---

[1] The writer wishes to acknowledge his indebtedness to many friends for material furnished for this study. Mr. H. L. Griley and W. H. Twenhofel have furnished some excellent material. The late G. C. Broadhead collection at the University of Missouri contained several excellent small specimens.

are due to gases rising through the muds. A view similar to that of Young has been expressed by Lawson. This view has been adequately disproved by Gresley and Harker.

After a careful review of the literature on cone-in-cone the writer feels that there are still many points upon which more data are desired. He has studied a suite of specimens from many places, and it is the object of this paper to give the results attained, in the hope that others will give some attention to a very difficult, yet extremely interesting problem.

Description of Cone-in-Cone.

The general features of cone-in-cone are essentially the same for all occurrences. This similarity is true even of the minor features of the structure. The structure consists of a series of right circular cones, which may fit one inside the other (fig. 1). This is the common mode of occurrence, but cones may also occur singly (fig. 2). They are usually grouped along a plane (fig. 3), which, if it occurs on the surface of a concretion, may be curved to fit the surface (fig. 4). Cone-in-cones are usually associated with concretions and in areal extent are generally co-extensive with them. The writer has observed this structure in concretions five feet in diameter. The cones are generally perpendicular in the central part of the layer (at *a* in fig. 4), but near the edge they are inclined (as at *b*, fig. 4).

Fig. 1.

Fig. 2.

Fig. 1.—Cone within cone.
Fig. 2.—Single cone.

The height of the cones varies from a thirty-second of an inch to eight or nine inches. Those from one to four inches in height are the most common. The diameter of the base depends upon the height and upon the angle of slope of the sides of the cones. In many cones this diameter is nearly equal to the height of the cone. The included angle (*a*, fig. 2) at the apex of the cone ranges from 25° to 70°. If the cone is well developed this angle is generally 60° to 70°. Partially developed cones are sharper.

Fig. 3.

Fig. 3.—Cones along a plane.

The sides of the cones are rarely perfectly smooth. Striations such as are seen on slickensided surfaces are common. What Gresley calls "conic scales" (fig. 5) are also very common. The sides of the cone may be ribbed or fluted, thus giving a notched outline on the base (fig. 6).

Fig. 4.

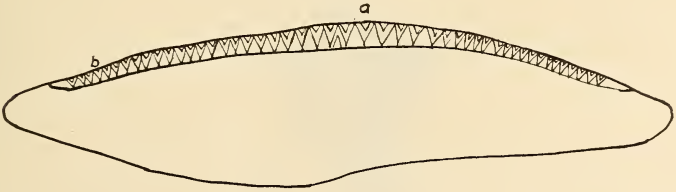


Fig. 4.—Concretion with layer of cone-in-cone (scale 1 inch equals 1 foot).

The inside of a cone into which another cone fits is always ribbed with circular rings, which are darker in color than the material composing the mass of the cone-in-cone (fig. 7). These rings are always on the inside of the cone. They vary in width from mere lines to over one quarter of an inch. Within a given cone they are very fine near the apex, and coarsest near the lower edge. This holds true for all specimens examined by the writer and has been so described by others. These rings are composed of clay, usually dark as mentioned above, and are free from carbonates. The ring of clay occupies a depression on the inside of the cone (fig. 8, A and B). This clay is similar to the insoluble residue of the cone-in-cone. The rings are broadest and most numerous in the more impure specimens of cone-in-cone. The ridges between the rings are striated and have the same slope as the outer surface of the cone, fitting into the cone-cup.

Fig. 5.

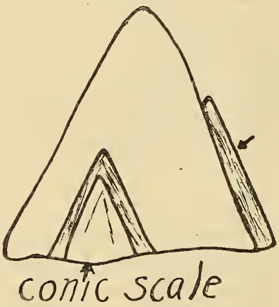


Fig. 6.

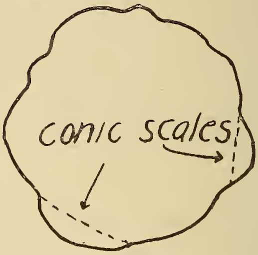


Fig. 5.—Conic scales on the side of cone.
Fig. 6.—Basal outline of a cone, with conic scales on the sides.

Fig. 7.

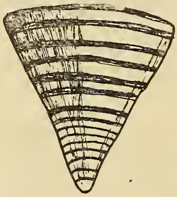


Fig. 7.—Rings in cone-in-cone.

The cones may be oblique especially near the edge of a cone layer. Some may have the apex removed and others may be more or less bent and twisted. A peculiar feature of the cones in layers, not associated with concretions, is the flaring of the base and the acute apex (see fig. 9). Such cones are common in Bond Co., Illinois, and in some thin lenses of cone-in-cone in Boone Co., Missouri. The fibers composing the cone-in-cone layers are parallel or inclined. If the latter, they are parallel to the surface of the cones.

Fig. 8.

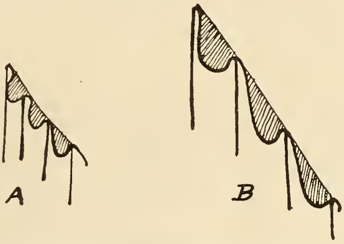


Fig. 8.—Section of clay rings showing relationship to fibers of calcite. A—natural size. B—enlarged three times.

The composition of cone-in-cone is significant. Analyses show from 60 to 98 per cent $CaCO_3$, with the remainder usually clay and other insoluble materials. The common occurrence of cone-in-cone in shales and always in association with calcareous portions of the shales would account for the presence of the clay. Probably the association of cone-in-cone with calcareous concretions has a bearing on their occurrence. The writer has found them in thin lenses of fibrous calcite in the Pennsylvanian shales in Boone Co., Missouri.

Fig. 9.

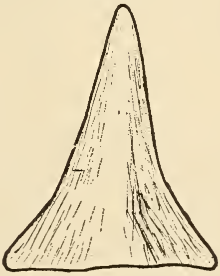


Fig. 9.—Cone showing flaring of base.

A point of much value in discussing the origin is whether the cone-in-cone is dominantly calcite or aragonite. Where determinable in the writer's specimens the material is calcite. Cone-in-cone occurs with ferruginous concretions in various localities, hence it is possible that some cone-in-cone is ferruginous, but no cone-in-cone composed of siderite has been seen by the writer or reported in the literature.

Mode of Occurrence of Cone-in-Cone.

Cone-in-cone usually occurs in shales in association with concretions. It may occur as a layer on the upper side of the concretion, as bands within them, or as a layer on the lower side. The bands within the concretions usually extend from one side to the other, and may be several inches wide. There may be several bands in one concretion. The layers of cone-in-cone above and below a concretion may attain a thickness of several inches, but they usually thin out at the edges of the concretion. Young claims that the cone-in-cone may fold back upon itself, thus forming two bands of cone-in-cone with their apexes pointing toward each other. Such parallel bands are fairly common, but there is no evidence to support Young's view as to the cause of the parallelism.

The structure may occur as one or more layers, not in association with concretions. The occurrences in the Devonian shales in Pennsylvania, described by Gresley, show three to five layers associated with a band of sandstone. Such layers may have great variability in plan as well as diverse shapes when seen in section.

More rarely single layers of calcite showing cone-in-cone may occur within shales. The layers range from one half inch to two and one half inches in thickness. The cone-in-cone may extend entirely across the layer or it may be developed on one side only.

A very rare occurrence is in coal. Well developed cones from four to six inches high are found in the British coal beds. Their sides are highly polished and slickensided.

Distribution of Cone-in-Cone.

Geographically cone-in-cone structure has been reported in various places in the United States. The localities first noted were those in western New York, Pennsylvania, and *Ohio*. Other localities are in *Michigan, Illinois,* Iowa, *Missouri, Texas, Kansas,* Nebraska, *South Dakota, Wyoming, Montana, Colorado,* Utah, and California. (The writer's collection includes specimens from the states in italics.) It is probable that the structure is more widely distributed than is indicated above, for its occurrence is only mentioned incidentally in most of these cases and there is usually no reference to it in the index of the reports. It is known to be rather widely distributed in England, France, and Germany.

Geologically there is apparently nothing significant about the geological occurrence of cone-in-cone structure. It has been reported in middle Cambrian beds in Utah. It occurs in the Devonian in New York, Pennsylvania, Ohio, and Michigan. The Pennsylvanian in Illinois, Iowa, Missouri, and Kansas has furnished numerous specimens of cone-in-cone. The Permian in Kansas, Montana, and South Dakota, and the Eocene in Texas have been found to contain the structure. In Europe it has been found principally in the Carboniferous and the Jurassic formations.

Origin.

The published views regarding the origin of cone-in-cone are extremely vague. Pressure is regarded by some as a factor, but *why* pressure should produce cone-in-cone is not explained. The presumption is that pressure in forcing the material of the structure through the adjacent rock produced cones. Crystallization is also suggested, but why it should develop cones is again not explained. Many minerals are known which may crystallize in radiating masses, but such masses are spherical, or closely related forms, and not conical. It is not clear why crystallization should develop only a fraction of a sphere and do it as perfectly as has been done in the case of cone-in-cone.

The following suggestions represent the conclusions to which the writer has come from his past and recent studies. Future studies will call for much revision and possibly the discarding of parts or all of these suggestions.

The suggestion made here is that cone-in-cone structure has been formed through a combination of pressure, more or less localized, and solution. Contributing factors are both the radial and parallel arrangement of the crystals of calcite composing the structure, and the cleavage of the original carbonate.

Evidence of movement—The fibrous calcite constituting a layer of cone-in-cone is often banded horizontally. When the structure is developed in such a layer these bands are displaced by the cone-in-cone. This displacement is analogous to a fault, but careful study showed that the layer has not been faulted along a plane; it is the cone which has moved. Another proof of such movement is the occurrence of the cones within each other. A large cone (fig. 10) may contain a small one which has penetrated the large one, yet has not displaced the outer surface of the large cone. The inward movement may amount to from one quarter to one half an inch in a cone which is two to two and one half inches high.

Fig. 10.

Fig. 10—Shows small cone penetrating large cone which does not show any evidence of displacement in the large cone.

Evidence of solvent action—The last statement in regard to movement also furnishes proof that some material has been removed through solvent action. The small inner cone could not have moved inward without displacing the material of the larger cone. As there is no external evidence of such displacement the cone must have been enabled to move because of the solution of the material previously occupying the space between the small cone and the large one. This would be the material in the shaded area in figure 11. The removal of this material in solution would enable the cone to penetrate the larger cone.

Fig. 11.

Fig. 11.—Shaded area shows the material removed in solution, to permit the movement of the inner cone.

The rings of dark clay on the interior of the cone cup have lost all their carbonate content and represent merely the insoluble residue obtained by dissolving the material composing the cone. A careful study of these rings showed that they contained more material near the base of the cone, due to the fact that more carbonate material has been removed by solution from that portion of the cone. The ring of dark clay occupied a depression on the inside of the cone cup. These depressions may be one-eighth inch or more deep, and are separated from each other by a thin partition of calcite (fig. 8, B). The ring of clay fits into this depression.

The facts cited above prove that movement and solution have taken place during the development of the cone-in-cone structure. The conclusion may be drawn that the movement certainly involved some pressure, and as material was removed by solution the cone slipped down (or up) inside the larger cone.

Source and amount of the pressure—It can hardly be doubted that some pressure was involved in the formation of the structure. This pressure probably was not large, because most occurrences of cone-in-cone were never deeply buried. Many have thought that the pressure, where the cone-in-cone was associated with concretions, was due to the growth of the concretion. If the concretion actually developed in place a certain amount of pressure would have developed. However, the writer[1] has proved that certain concretions occurring with cone-in-cone over them were syngenetic in origin, hence no pressure would have developed in such cases. If it can be assumed that the growing strength of a calcareous concretion is equal to the crushing strength of similar material, the pressure so produced would be considerable, but would be dependent upon the compressibility of the enclosing materials. That some pressure would be produced in the case of epigenetic concretions cannot be denied, but some other source of pressure must be sought when the cone-in-cone is not associated with concretions, or when the concretions are syngenetic. The cone-in-cone unassociated with concretions is as perfectly developed as when associated with them. This is especially true of cone-in-cone in coal.

Another possible source of pressure exists, if the original form of the calcium carbonate was aragonite and had been changed to calcite. This change involves a volume increase of 8.35 per cent, sufficient to produce considerable pressure. But is there any reason for assuming that the original form was aragonite? No cone-in-cone the writer has examined is composed of aragonite now. This very fact, however, may mean that cone-in-cone develops only where aragonite has altered to calcite as will be discussed below. All cone-in-cone structures show fibrous calcite, but that this was originally aragonite cannot be proved. Fibrous calcite from Boone Co., Missouri has been sold to mineral dealers as aragonite, showing that this structure was regarded as evidence of the material being aragonite. The development of cone-in-cone *only* in a crystalline, fibrous calcite is significant, however, and certainly suggests that aragonite was the original form of the calcium carbonate. According to Clarke[2] "aragonite alters easily to paramorphs of calcite, but the reverse change rarely, if ever, occurs." Calcite is the more stable form.

It does not seem likely that either the growth of concretions or the weight of overlying sediments would be an

---

[1] Tarr, W. A.: Syngenetic Origin of Concretions in Shales, Bull. Geol. Soc. Am., vol. 32, pp. 373-384, 1921.

[2] Clarke, F. W., Data of Geochemistry, U. S. G. S., Bull. 695, p. 549.

important source of pressure. The change of aragonite to calcite would give an adequate source of pressure and seems to be the most likely source. What sources of pressure other than this exist in the rocks associated with the cone-in-cone are not evident to the writer. Those which are there certainly function, as it is doubtful if much movement could have taken place without some pressure.

Origin of the Conical Form.

The origin of the conical shape of the cone-in-cone is extremely puzzling. If the angle of the slope of the cones was always the same, and if it was similar to the cleavage angle of the material composing it, the problem would be much simpler. But the cleavage angle in calcite is approximately 105°, which is far greater than that of the cone-in-cone. This may mean that the cone-in-cone is not related to the cleavage, or, that the original substance was not calcite and thus had a different cleavage angle. As the original substance was calcium carbonate, it may be that aragonite was the original mineral. But the best cleavage in aragonite is pinacoidal whereas the cleavage parallel to the brachydome is poor. Since a series of brachydomes is possible on aragonite, forms with acute domes might have a poor cleavage with angles similar to those of the cone-in-cone. The poor cleavage of aragonite along this plane, however, does not favor the possibility that the initial form of the cone-in-cone was due to it.

Another possibility, if the original form of the material was aragonite, should be considered. Radiating structures are very common in aragonite. This structure may give rise to stalactites, spherical masses, or radiating tufts. The tufts have considerable significance in this problem. If the mineral were deposited along a plane with deposition occurring at many points, a layer consisting of an aggregate of such radiating tufts would result. The spacing of the tufts along the plane would determine their size, and incidentally the angle of the outermost fibers on the tuft. Close spacing would give a sharp angle, and wide spacing a low angle. If, now, pressure were brought to bear on the layer, movement would be greatly aided by the fact that the outermost layers would have the distinct cleavage of the pinacoidal and prismatic faces. The fact that the cone surface is parallel to these radiating fibers is compatible with this suggestion. Gümbel has made an interesting suggestion along these lines. He thinks that water might find its way through a bed and form stalactites on the under side, each stalactite having a cone shape.

It should be noted that the most perfect cones are always developed in radiating aggregates of fibers. When the fibers are parallel the peculiar cone with a flaring base and a long slender body develops.

It is very probable that those who have expressed the view that cone-in-cone was due to crystallization were thinking of radial aggregates as the initial cause of the conical form. Such radial aggregates may be seen in concretions. And it cannot be said that crystallization might not form aggregates which would be the real cause of the cone-in-cone structure. Such a radial aggregate would provide the form, without resorting to cleavage as a factor in initiating movement in the cone-in-cone.

Aside from the possibility of the influence of radial fibrous aggregates and the cleavage of aragonite, both of which would influence the initiation of the cone-in-cone while the material was still aragonite, there are two other suggestions as to the origin of the conical form that are of value. One is dependent upon pressure and the other upon the alteration of the aragonite to calcite.

That pressure alone might produce cones was suggested to the writer as the result of testing some cubes of limestone to determine its crushing strength. Perfect and imperfect cones were formed during the tests, the largest ones being two inches across the base. Many were remarkably perfect and showed several features seen in the cone-in-cone. The included angle at the apex of the cone was from 30° to 60° and in some cones the angle was greater near the base than at the apex, a feature noted in some cone-in-cone. In the mechanical production of cones there also may be seen an explanation of cone-in-cone structure, because, on the base of the larger cones mentioned above, there were numerous minute circular cracks, which indicated that another cone might develop within the first. When the fibers of the calcite are radial, pressure upon the base of such a group might easily induce a fracture, more or less parallel to the fibers, which would be circular. Thus the outline of the cone would be inaugurated. Solution along this fracture would then become a very important factor. The cones formed in coal were certainly due to pressure unaided by solution.

The other method by which a conical shape might be induced hinges upon the original form of the calcium carbonate being aragonite and subsequently altering to calcite. Conceivably this alteration, being brought about by water, would start along the joint in a bed of cone-in-cone and proceed inward. As the aragonite changed to calcite there would be a volume increase and expansion of the outer portion, leaving a suggestion of a cone on the interior. How effective this would be is problematical; very likely the effect would be slight.

But a combination of the above factors could very well give rise to the cone-in-cone structure. The radial aggregates, when acted upon by pressure, would favor the development of fractures along which solutions might enter, dissolve, and remove material, thus permitting further movement. Artificially formed cones, taken in conjunction with the fact that a majority of cone-in-cone occurs in layers of radial fibers, lends strong plausibility to this suggestion.

The development of cone within cone might conceivably be accomplished in the following manner. Solutions entering along a joint might convert the aragonite to calcite. This change would progress inward from the joint a variable distance, where another fracture plane would develop by the expansion of the material in changing from aragonite to calcite. Thus a series of cones might be formed, one within the other. Another method has been indicated above, that is, pressure producing a series of minute cracks on the base of a cone. These were parallel to the circumference of the base and continued pressure might easily have started another cone within the first. But the most probable method would seem to be by means of the radial structure of the calcite.

Was the Material Originally Aragonite?

Reference has been made so frequently in the above discussion to the possibility of the calcite having been originally aragonite that it would seem well to summarize the reasons for believing that this may have been the case.

1. The cone-in-cone is always found in material of fibrous form, a structure more common to aragonite than calcite.
2. The fibers are dominantly radiating, also a common arrangement for aragonite.
3. Aragonite easily alters to the paramorph calcite.
4. The change from aragonite to calcite involves a volume increase of 8.35 per cent, a change that would give a marked pressure, and pressure has been involved in the formation of the cones.
5. Radial aggregates with pinacoidal cleavage (both common in aragonite) would be favorable factors in the formation of the cones.
6. Aragonite is more readily soluble in groundwaters than calcite.
7. The combination of factors given above would hardly be fortuitous.

Conclusions.

Cone-in-cone is best developed in shales and is generally composed of calcium carbonate in the form of calcite, it having been originally, possibly, aragonite. The calcium carbonate always contains more or less argillaceous material. Studies show that there must have been some movement in the development of the cone structure and also that a certain amount of solvent work had taken place. The insoluble material in the calcite is left behind, through the removal of the calcium carbonate, and forms the rings of material (usually dark) which are seen on the interior of all cones that are well developed. The fibrous structure of the calcium carbonate has favored the parallel arrangement of the rings within the cone.

The cones are probably the result of pressure due to (1) weight of overlying sediments, (2) growth of concretions, (3) (the most important) an increase in volume due to the change of aragonite to calcite, acting in connection with the radial or parallel arrangement of the calcium carbonate fibers; and to solution, which became effective when the pressure had induced the first crack in the layer, groundwater entering and removing the material along this joint. The removal of material along this fracture permitted the further movement of cone within cone.

Mineralogical Laboratory,
University of Missouri,
Columbia, Mo.

BIBLIOGRAPHY OF CONE-IN-CONE.

Barbour, Carrie A.: Neb. Acad. Sc. Proc., vol. 7, pp. 36-38, 1897.
Broadhead, G. C.: Cone-in-Cone, Science, vol. 26, p. 15, 1919.
Chadwick, G. B.: Bull. Geol. Soc. Am., vol. 32, p. 26, 1921.
Daintree, R.: Quart. Jour. Geol. Soc., vol. 28, p. 283, 1872.
Dawson, J. W.: Acadian Geol., pp. 676-677, 1868.
Garwood, E. J.: Geol. Mag., vol. 9, p. 334, 1892.
Geikie, Sir A.: Textbook of Geology, 4th edit., pp. 421, 1902.
Grabau, A. W.: Prin. of Stratigraphy, pp. 788-789.
Gresley, W. S.: Geol. Mag., vol. 9, p. 432, 1892.
Gresley, W. S.: Geol. Mag., vol. 4, p. 17, 1887.
Gresley, W. S.: Cone-in-Cone, Quart. Jour. Geol. Soc. London, vol. 50, pp. 731-739, 1894.
Grimsley, G. P.: Mich. Geol. Sur., vol. 9, pp. 100, 109, 1903-1904.
Harker, Alfred: Geol. Mag., vol. 9, p. 240, 1892.
Hildreth, S. P.: this Journal, vol. 29, pp. 99-100, 1836, plate 14.
Jukes: Manual of Geology, 1872.
Keyes, C. R.: Cone-in-Cone, Proc. Iowa Acad. Sc., vol. 3, pp. 75-76, 189.
Lawson, A. C.: Bull. Geol. Soc. Am., vol. 32.
Leonhard, K. C. von: Charakteristik der Felsarten, p. 418, 1823.
Marsh, O. C.: Proc. Am. Assoc. Adv. Soc., vol. 1, p. 211, 1873.
Newberry, J. S.: Geology of Ohio, vol. 1, p. 211, 1873.
Owen, D. D.: Report of the Geol. of Wis., Iowa, and Minn., p. 112, 1852.
Sach, A. J.: Geol. Mag., vol. 9, p. 505, 1892.
Sorby, H. C.: "On the Origin of Cone-in-Cone," Brit. Assoc. Adv. Sc., vol. 29, p. 124, 1859.
Young, John: Geol. Mag., vol. 9, pp. 138, 278, 480, 1892.

ART. XXI.—*Notes on the Flora of the Payette Formation;* by RALPH W. CHANEY, Carnegie Institution of Washington.

The Payette flora as described by Knowlton in 1898[1] is made up of 32 species. It was referred by him to the Miocene because of its resemblance to the Upper Clarno and Mascall floras of the John Day Basin which were supposed at that time both to be of Miocene age. Later[2] the same author determined the age of the Payette as Upper Eocene, because of its resemblance to the Upper Clarno flora which his later work had shown to be of Upper Eocene age.

The present paper is based on observations and collections made in southwestern Idaho and adjacent Oregon during the season of 1921 under the auspices of the Carnegie Institution of Washington. Its purpose is to add to the number of forms of fossil plants known from the horizon, to present further evidence regarding their age, and to make suggestions regarding the conditions under which they lived.

The Payette formation comprises several hundred feet of sediments overlaying a basalt series which appears to be an eastward continuation of the Colombia lavas. According to Buwalda[3] its basal portion is interstratified with these lavas on the south side of the Snake river valley. Where studied in connection with its plant fossils, the Payette is made up largely of a fine gray salmon-colored shale, highly indurated. In the vicinity of Montour, Idaho (the Marsh postoffice locality of Knowlton and Lindgren), there are conspicuous white shales made up of diatomaceous sandy material. Lignite seams are of common occurrence, and locally the sediments appear to be made up of broken-down granite. Fossil plants are found most frequently on small slabs of the highly indurated shale which have been weathered loose and scattered over the slopes of the hills. They have been collected by the writer at the following localities:—

---

[1] Knowlton, F. H.; Fossil Plants of the Payette Formation, U. S. Geol. Survey, 18th Ann. Rept., Pt. 3, pp. 721-744, 1898.

[2] Knowlton, F. H.: Fossil Flora of the John Day Basin, Ore., U. S. Geol. Survey, Bull. 204, pp. 110-111, 1902.

[3] Buwalda, John P.: Letter of Nov. 6, 1921.

1. 12 miles west of Weiser, Idaho on the hills north of the Snake river.
2. Ballantyne ranch, ¾ of a mile southeast of the ranch house in a group of white hills. The ranch is 13 miles southwest of Homedale, Idaho, and this portion of it is in Malheur Co., Oregon.
3. Ballantyne ranch, along the ridge running northwest of the ranch house.
4. Sucker creek, 5 miles southwest of The Rocks, Idaho, on the hills south of the valley, near the Idaho-Oregon line.
5. Sucker creek, 4½ miles southwest of The Rocks, and on the north side of the valley.
6. Cartright ranch on Shafer creek, 7 miles south of Horseshoe Bend, Idaho, in a gulch about ½ mile southwest of the ranch house.

The locality west of Weiser is about 75 miles north of the southernmost locality on Sucker creek, and is 50 miles west of the Cartright ranch which lies farthest east.

Of the material collected, some fifteen forms are reserved for later treatment because of their fragmentary nature. Of the material which is readily determinable, there are 30 species which may be tabulated as follows:—

Number of species included in previously described Payette flora	13
Number of new species	4
Number of species previously known and referred for the first time to Payette	13
Total	30

It will be seen that the previously described flora is increased by 17 species, 4 of which are new, the whole representing an addition of over 50 percent. That only 13 species or less than half of those previously known from the Payette are represented in my collections may be explained by the fact that only one of the localities from which Knowlton secured his material was visited, and this one was represented by only four species in his collections. The total number of forms known from the Payette may therefore be placed at 49, of which 17 are here recorded for the first time:—

Acer gigas
Acer n. sp.
Aesculus simulata
Odostemon simplex
Betula n. sp.
Glyptostrobus europœus
Laurus princeps
Pinus knowltoni
Platanus dissecta
Prunus n. sp.
Quercus clarnensis
Quercus dayana
Quercus n. sp.
Salix californica
Salix perplexa
Sapindus oregonianus
Ulmus californica

Regarding the four new species, it has been thought best to delay describing and figuring them until further collections have been made and their relations are more fully understood. In so far as they resemble fossil or living forms, they will be considered in correlation, and their ecological significance also will be discussed below.

The following table shows the distribution of the 21 species which are common to the Payette and to other localities where the age of the beds is known with reasonable certainty:—

	Eocene				Oligocene		Miocene			
	Raton	Green River	Chalk Bluffs	Upper Clarno	Eagle Creek	Quilchena, B. C.	Mascall	Ellensburg	Table Mt.	Corral Hollow
Acer gigas							X			
Aesculus simulata							X			
Glyptostrobus europaeus							X			
Juglans oregoniana							X			
Laurus princeps										X
Odostemon simplex				X						
Pinus knowltoni					X					
Platanus dissecta			X				X	X	X	X
Populus lindgreni							X			
Quercus clarnensis				X						
Quercus consimilis				X						
Quercus dayana							X	X		
Quercus simplex	X			X						
Quercus simulata					X					
Salix angusta		X					X			
Salix californica									X	
Salix perplexa						X	X			
Sapindus oregonianus							X			
Sequoia angustifolia						X	X			
Ulmus californica			X				X	X	X	
Ulmus speciosa				X	X					
Total species	1	1	2	5	3	2	12	3	3	2

As in the case with most of the Great Basin floras, the Payette flora most closely resembles the floras from the Upper Clarno and Mascall horizons of the John Day Basin, with 5 species and 12 species in common, respectively. This is due both to the close geographic relation of the two localities and to the fact that the floras from the John Day Basin have been more fully described than from any other Great Basin locality. In considering the age of the species common to the Payette and other floras, the following summary makes the relations clear:—

Payette species occurring in the Eocene...........	8
Payette species occurring in the Oligocene.........	5
Payette species occurring in the Miocene	14

Of the 8 Eocene species, 4 are restricted to the Eocene, while 1 is found also in the Oligocene and 3 in the Miocene. Of the 5 Oligocene species, 2 are restricted to the Oligocene, while 1 is found also in the Eocene and 2 in the Miocene. Of the 14 Miocene species, 9 are restricted to that horizon, while 3 occur also in the Eocene and 2 in the Oligocene. A summary of the number of Payette species which are restricted to the several Tertiary systems shows:—

Payette species found elsewhere only in the Eocene......	4
Payette species found elsewhere only in the Oligocene....	2
Payette species found elsewhere only in the Miocene.....	9

Several other aspects of the stratigraphic relations of the Payette flora should be considered. Of the forms doubtfully determined and not here listed, *Ilex* cf. *leonis,* and *Celastrus confluens?* are Miocene species, while *Rhus* cf. *myricæfolia* and *Betula heteromorpha?* are typically Eocene. Of the new species, a species of Prunus may be related to two species of the same genus from the Mascall, and species of Betula, Acer, and Quercus find their closest relation to living species. Of still greater importance is the bearing on the problem of a flora recently collected at Austin, Oregon, which appears to be certainly from the Mascall formation of Miocene age. In this flora, associated with typical Mascall species, are *Quercus consimilis, Quercus clarnensis,* and *Ulmus speciosa,* all of which are typical Upper Clarno species.

If these three species are thus shown to range into the Miocene, the preceding summaries must be changed, as follows:—

Payette species occurring in the Eocene	8
Payette species occurring in the Miocene	17

and

Payette species found elsewhere only in the Eocene	2
Payette species found elsewhere only in the Miocene	9

From a numerical standpoint, the Payette flora is more closely related to the Miocene floras than to those of any other Tertiary system. However, mere numbers of common species are not, in themselves, the sole criteria for placing the age of a flora. The two species which remain to make up those limited to the Eocene are *Odostemon simplex* and *Quercus simplex*. The former is represented in the collections from the Upper Clarno at Bridge Creek by a single specimen; it is closely similar to several of the living barberries. *Quercus simplex* differs only slightly from several other species of western fossil oaks which range up into the Miocene. Neither of these species carries great weight in indicating Eocene age. Again both *Quercus simplex* and *Salix angusta* are species with somewhat indefinite characteristics, so that the record of the range of the former from the Raton to the Upper Clarno and of the latter from the Green River to the Mascall may be in each case in error. On the other hand, the presence in the Payette of species which are characteristic of several localities of the Miocene gives more weight to an age reference to that horizon than the occurrence in it of several species from another horizon which are of restricted distribution and rare occurrence. In this regard, *Platanus dissecta* and *Ulmus californica*, both originally described from the auriferous gravels,[4] are typical Miocene species. By reference to the tables of distribution, it will be seen that *Platanus dissecta* has been found in the Miocene of the John Day Basin (Mascall formation), of Table Mountain, California (Auriferous Gravels), of Corral Hollow, and of central Washington (Ellensburg forma-

---

[4] Lesquereux, Leo: Fossil Plants of the Auriferous Gravel Deposits of the Sierra Nevada, Mus. Comp. Zool. Mem., vol. 6, No. 2, pp. 1-62, 1878.

tion). Although it also occurs in the Chalk Bluffs locality of the Auriferous Gravels, which is commonly considered to be of Eocene age, Lesquereux states (4, p. 14) that it is more characteristic at the Table Mountain locality. A recent study of the type material of *Acer bendirei,* one of the most typical Miocene species in the west, tends to show that it is to be referred to the genus Platanus rather than Acer, and that certain specimens of *Platanus dissecta* are identical with it. *Platanus dissecta* is one of the more common species of the Payette flora, and is of wide occurrence in the Miocene of several adjacent states. Clearly it is a strong indicator of the Miocene age of the Payette. Likewise, *Ulmus californica* of the Payette flora has a Miocene distribution in the John Day Basin, at Table Mountain, California, and at Ellensburg, Washington. It, too, occurs in the Eocene horizon of the Auriferous Gravels, probably as a geologic pioneer, for it is not recorded elsewhere from the Eocene. In the same way, *Sapindus oregonianus,* which is one of the more abundant species of the Payette, is found in at least three widely separated Miocene localities of Oregon, and has never been noted outside of this system.

A close similarity between certain Payette species and living forms is again taken as an indication of the closer relation of the Payette flora to the Miocene than to the Eocene. The similarity of three new species to modern representatives of their genera has already been mentioned; *Quercus* n. sp. is strikingly like the western *Q. chrysolepis* now living in California; *Betula* n. sp. closely resembles *B. occidentalis* of the Pacific Coast; and *Acer* n. sp. is hardly to be distinguished from *Acer glabrum,* also a tree of the west. Of the previously described species. Knowlton comments[5] on the similarity of *Aesculus simulata* to *Ae. octandra* and *glabra* of the eastern United States; he names *Populus eotremuloides*[6] having in mind a close relation with the living *P. tremuloides;* certain specimens of *Populus lindgreni* have a striking resemblance to living poplars of the balsamifera type; Lesquereux[7] mentions a simi-

---

[5] Knowlton, F. H.: Fossil Flora of the John Day Basin, Ore., p. 78.

[6] Knowlton, F. H.: Fossil Plants of the Payette Formation, p. 725.

[7] Lesquereux, Leo: Fossil Plants of the Auriferous Gravel Deposits, pp. 14 and 16.

larity between *Platanus dissecta* and *P. occidentalis* now living in the eastern half of the United States, and between *Ulmus californica* and *U. alata* of the southeastern United States. In the case of *Platanus dissecta,* its resemblance to the western species, *P. racemosa,* seems even closer than to *P. occidentalis.* This resemblance between various forms of the Payette flora and living plants adds further weight to the reference of the Payette to the Miocene rather than to an older period.

A probable explanation of the conflicting evidence of age as shown by Eocene as well as Miocene representatives in the Payette flora is that the disparity in age is more apparent than real. The writer has not yet brought together all the necessary evidence, but recent field studies in the John Day Basin and at other points in eastern and central Oregon point to the placing of the Upper Clarno formation in the Oligocene rather than the Eocene. If this is correct, and the supporting evidence will be brought forth in a subsequent paper, there are no typical Eocene plants in the Payette flora, but rather an increased number of Oligocene forms which may be supposed to have been precursors of the Miocene flora to follow.

The position of the Payette formation, above basalt lavas, is in accord with the relation of the Miocene Mascall formation to the Columbia lavas in Oregon. Vertebrate remains collected from the Payette formation by Buwalda are referred by him to the Middle or Upper Miocene[8]. There appears, therefore, to be an agreement between the evidence of the flora, the fauna, and the stratigraphy in pointing toward the Miocene age of the Payette formation. So far as the plants are concerned, the age would not be younger than Middle Miocene, and in view of the inclusion of Oligocene and possibly Eocene forms, it might better be considered as Lower Miocene. The present knowledge of the western floras does not justify an attempt to draw the lines of age too sharply, and at this time the writer is satisfied to make the reference to the Miocene without further specification.

The Payette flora has a composition so like that of the forests in certain parts of the Pacific Coast region

---

[8] Buwalda, John P. Letter of Feb. 10, 1922.

today that the physical conditions under which it existed may be postulated with a reasonable degree of accuracy. The most dominant genus is Quercus, with 7 species. It may be said, although further mention of the taxonomic aspects of the flora is not within the province of this paper, that several of these species can hardly be considered distinct in view of the large number of intergrading specimens and the great variation among living oaks of a single species. But the genus Quercus is dominant even without regard to the number of species in that its individual leaves outnumber all others together. There is a close resemblance of all the fossil species of oak to the type represented by the living species *Quercus chrysolepis* and *Q. sadleriana.* Both of these species occupy the dry slopes of the upper foothills and summits of the coast ranges and the west slopes of the Sierras and Siskiyous of northern California and southwestern Oregon. Their fossil relatives appear to have had the coriaceous texture which is characteristic of leaves in such a habitat, and to have made up a forest on the slopes of an area of high relief and consequent exposure. And while these oaks may have ranged down into the canyons, as does *Quercus chrysolepis* today, the typical stream border flora comprised *Platanus dissecta, Acer* n. sp. *Juglans oregoniana,* and the various species of Salix which are found in the Payette. Swampy stream or lake borders are indicated by the fragments of Typha (?), grasses, and Equisetum. The local dominance of *Populus eotremuloides,* which is found with birches of the occidentalis type only at the Cartright ranch locality, may be due to the presence of certain moist slopes, or possibly to a forest fire and the subsequent development of a burn subsere. *Sequoia angustifolia,* which is abundantly represented in the Mascall flora of the John Day Basin, is of rare occurrence in the Payette, suggesting a lower humidity. In accord with the idea of a dry slope habitat, as suggested by the abundance of chrysolepis oaks and the scarcity of Sequoia, is the occurrence of *Pinus knowltoni* and the scrub species of Odostemon, which is closely related to the living Oregon grape, and of Castanopsis, Philadelphus, and Rhus, all three of which have been doubtfully recorded because of incomplete material.

In general, the Payette flora indicates a habitat with a higher relief than occupied by the Mascall and other floras of the Miocene. There is some support for the idea of high relief in the coarser phases of the Payette formation, though these are decidedly inconspicuous. The bulk of the formation appears to be made up of volcanic ash, which may well have been transported by wind, along with the leaves of the upland oaks. From the nearly uniformly fine character of the Payette sediments, a still-water type of deposition may be postulated. The fact that there are no evidences of stream deposits,—lenticular bodies of gravel and sand, and fossil leaves turned into two or three planes during deposition—supports the idea of an area of high relief in which the streams were eroding rather than depositing. In such a region, accumulation of fine sediments and pyroclastics would be going on most conspicuously in the basins of lakes, into which there would also be blown or washed the leaves of trees growing on the slopes above and on the borders of the water bodies. In some such way the plant-bearing portions of the Payette formation may be thought to have accumulated during the Miocene period, with a climate much like that of northern California and southwestern Oregon today.

Iowa City, Iowa.

ART. XXII.—*Notes on the Structure of the Triassic Rocks in Southern Connecticut;* by CHESTER R. LONGWELL.

I. A GROUP OF SMALL FAULTS.

Good exposures transverse to the strike of the rocks are rare in the Connecticut Lowland, and accordingly all students of structure in this region have found it necessary to draw generously on inference in reaching their conclusions. It is therefore especially important that every available exposure should be studied and described in detail. Dr. H. H. Robinson, Superintendent of the Connecticut Geological and Natural History Survey, recently called the writer's attention to a tunnel through Saltonstall Ridge about four miles east of New Haven. This tunnel, constructed in 1901 by the New Haven Water Company, was described from the engineer's viewpoint by Mr. Edward E. Minor,[1] but apparently its existence has not been commonly known among geologists. The purpose of the tunnel is to conduct water from Farm River into Lake Saltonstall, an important reservoir, at times of protracted drouth. Ordinarily the north end of the conduit is kept closed and the floor is covered by only a few inches of water. Mr. Minor, General Manager of the water company, kindly gave permission for a study of the tunnel and furnished equipment for the purpose. Dr. Robinson assisted in making the necessary measurements, and the writer has discussed the results with him. A part of the information for the following description was taken from Mr. Minor's paper, referred to above.

Description of the Tunnel Section.

The accompanying sketch map (fig. 1) shows the location of the tunnel and indicates the general geology of the immediate area. The rocks are Triassic sandstones and shales with three interbedded lava sheets. Throughout the Connecticut Lowland these rocks have a general inclination eastward, but evidently there has been considerable warping which is responsible for local variations in dip and pronounced curvature of surface out-

---

[1] Proc. Conn. Soc. Civil Eng., 1904, pp. 12-21.

crops. Saltonstall Ridge is the surface expression of the middle or main trap sheet. Immediately north of Lake Saltonstall the ridge curves abruptly eastward, following the strike of the rocks, and at the location of the tunnel the strike is almost directly east, with the dip toward the south. Throughout its length the ridge traces the rim of an incomplete structural basin, aptly referred to by Davis[2] as a ''dish'' or ''half-boat-like basin,'' which terminates abruptly against the great fault bounding the Triassic area on the east.

The tunnel cuts the ridge in the direction N11°E. South of the brick conduit indicated in the section (fig. 2) there is no lining except for a few feet in a shatter zone between stations 10 and 11. Thus the solid rock is exposed practically without interruption for a distance of 1800 feet. In the cut near the south portal coarse Triassic sandstone is exposed, dipping 35° south. The top of the lava sheet is amygdaloidal, and extreme decomposition prevents location of the exact contact with the overlying sandstone. Inside the portal the amygdaloidal rock gives way to massive basalt, and this is succeeded by diabase as coarse-grained as that from large intrusive sheets such as West Rock. Columnar jointing is evident, but not prominent. Near the base of the sheet the diabase again grades into dense basalt, which rests on hard conglomeratic sandstone. The surface of contact, sharply defined and essentially a plane, is inclined 35° to the south. Thus the tilt of the lava sheet may be taken as 35°, and its computed thickness, allowing for the obliquity of the tunnel, is 475 feet. Possibly this figure is slightly in excess of the actual thickness, because of small normal faults which are not obvious in the massive igneous rock. No evidence was seen that more than one flow is represented, but such evidence might easily escape notice in the narrow section given by the tunnel.

No metamorphism is apparent below the contact, but such effect is not expected, inasmuch as the topmost sedimentary beds are of conglomerate and coarse sandstone. The beds exposed between the lava sheet and the brick

---

[2] Davis, W. M.: Structure of the Triassic Formation of the Connecticut Valley, U. S. Geol. Survey, 7th Ann. Rept., p. 478, 1886; also, The Triassic Formation of Connecticut, U. S. Geol. Survey, 18th Ann. Rept., part 2, p. 85, 1897.

conduit have an average dip of 35° to 36° southward, and the apparent thickness of the section is 535 feet. Probably at least 50 or 60 feet should be deducted because of duplication by small faults. About one-fourth of the section would be classed as fine-grained sandstone and sandy shale, the remainder as coarse sandstone and conglomerate. Layers with different textures are interbedded, with no apparent order. In conglomerate layers there are numerous well-rounded pebbles of quartz, but fragments of granitic rocks, more or less angular, are the

Fig 1.

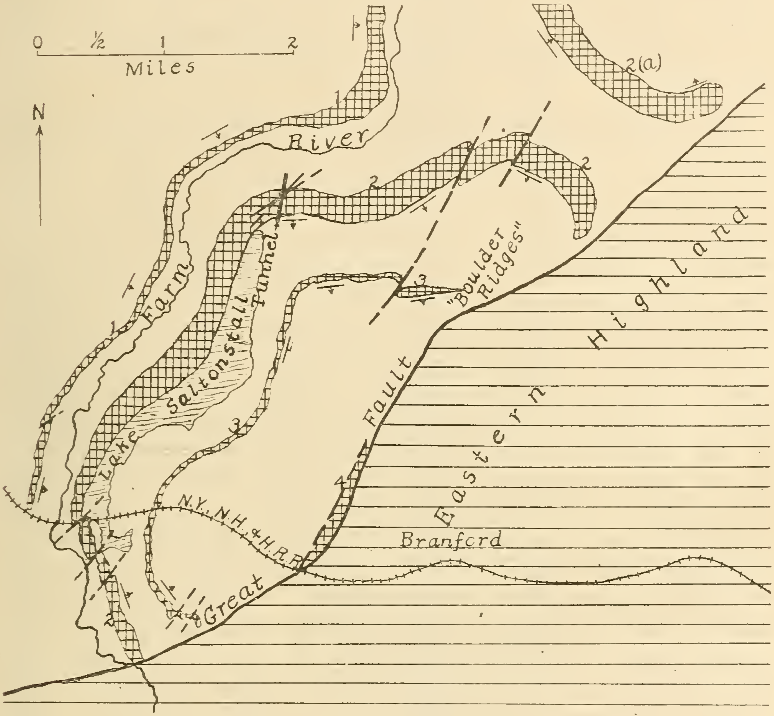


Fig. 1.—Generalized geologic map of Saltonstall Ridge and vicinity. Horizontal lining represents the area of old crystalline rocks. Cross-hatching represents the exposed edges of buried basaltic lava flows; 1, the lower or "anterior" sheet; 2, the middle or "main" sheet, forming Saltonstall Ridge; 2(a), the same sheet in Totoket Ridge; 3, the upper or "posterior" sheet; 4, probably a part of the upper sheet dragged up along the great fault. Triassic sediments underlie the areas shown in plain white.

most conspicuous constituents. The sandstones are distinctly arkosic, and have a firm cement of calcium carbonate with some ferric oxide. Throughout the section the predominant color is reddish or pink, although some of the coarser-grained layers are gray. As exposed in the tunnel the beds appear quite regular in thickness, but no doubt in more extensive exposures a lenticular character would be revealed. The only noticeable variation in dip occurs between stations 11 and 12, where the beds are distinctly buckled and are almost horizontal for a few feet.

The sedimentary beds are cut by numerous joints, but these are not closely spaced except in a few narrow zones. Most of the joints strike northeastward. Only those fractures on which displacement could be detected were studied particularly, and these are indicated in fig. 2. They are sixteen in number, including one in the lava sheet just above the sandstone. No doubt other small faults affect the igneous rock, but in the absence of bedded structure it is difficult to find evidence of displacement. One of the faults represented in fig. 2 was not studied directly, because it is hidden by lining, made necessary by the shattered condition of the rock; but data concerning it were furnished by Mr. Minor, who was present during the construction of the tunnel, and some inferences may be drawn from examination of the closely associated fractures just outside of the concealed zone. The exact strike of this fault is in some doubt. Of the other fifteen, ten lie between N60°E and N75°E (averaging N65°E), and five between N35°E and N50°E (averaging N45°E). All of the planes (including the one now concealed) dip to the northwest, although one is nearly vertical. The traces shown in the section are in every case flatter than the actual planes, because the tunnel intersects the faults obliquely. The true values of the dips, in order from north to south, are: 66°, 88°, 58°, 70°, 51°, 68°, 65°, 65° (inferred from study of associated fractures, and from Mr. Minor's description), 67°, 70°, 65°, 70°, 62°, 76°, 58°, 72°. The average is 67°.

The normal character of practically all the faults is quite conclusive, and probably this is true of all of them. Definite horizons are difficult to locate in the section, because beds of similar nature and thickness are repeated many times. Observed slickensides are too poorly devel-

FIG. 2.

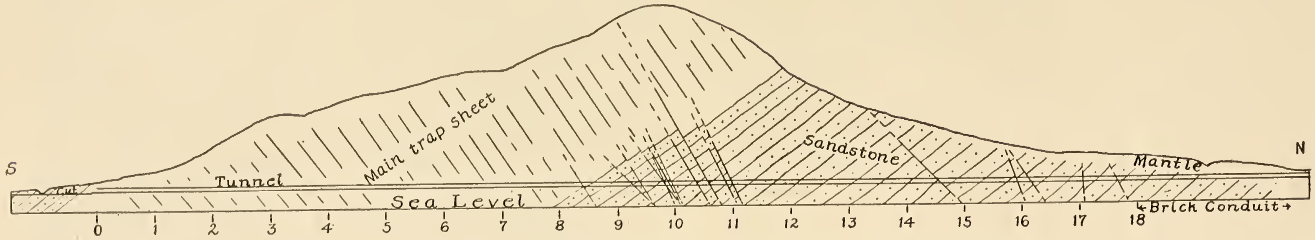


FIG. 2.—Cross section of Saltonstall Ridge at the tunnel. Horizontal and vertical scales are the same. Figures represent hundreds of feet, measured from the south portal.

oped to give definite information, but they at least suggest that the lateral component of movement was negligible. In most cases the throw is small, ranging from a few inches to a few feet. The combined offset effected by the ten faults between stations 9 and 11 is determined approximately, by projecting dips. Before the construction of the tunnel began, the surface of the ridge was surveyed accurately, and the contact between the lava sheet and the sandstone on the north slope was uncovered in order to measure the inclination. Therefore the position of the contact at the surface as indicated in fig. 2 is exact, and the offset between this point and the base of the tunnel, measured at right angles to the bedding, is 40 feet. Any representation of the quantitative distribution of this offset between the several faults involved can be suggestive only, but it is probable that the greater part of the throw is effected by one fault, the eighth in order from the north. This fault is marked by abundant gouge and a shatter zone of considerable width, features that are absent or but faintly developed in connection with the other dislocations.

Possible Relationship to Larger Structural Features.

Of course the section described above cannot be used by itself as the basis for generalizations regarding regional structure. Minor faults are numerous in the Triassic of Connecticut, and many of them doubtless have strictly local explanations. Development of joint systems may well have attended the warping shown in the curvature of Saltonstall Ridge, and minor displacements might be expected to occur either contemporaneously with the formation of the joints or at a later date. However, certain characteristics of the faults in the tunnel are highly suggestive. All of the planes strike generally to the northeast, all of them dip northwestward, and apparently all represent normal faulting. It is natural, therefore, to attribute the entire group to a common cause. A suggestion that this cause is local warping leads to an examination of the Saltonstall "dish" as a unit. The map shows a number of faults affecting the basin, but all of them appear to strike northeastward. Fractures developed as a consequence of the warping would be expected to exhibit some symmetry with respect to the curve of the "dish," and not a common parallelism. The faults of the Saltonstall basin have the trend characteristic of the region. Davis pointed out that faults in the southern part of the Connecticut Lowland extend generally from southwest to northeast,[3] and a glance at the geologic map of Connecticut confirms this statement. Davis and other students of the region have also called attention to the predominance of faults with apparent downthrow on the west. Thus the small faults at the tunnel appear to fit into the regional scheme, and we are led to suspect that they are related genetically and chronologically to the larger faults nearby; in other words, that they are "sympathetic faults."

Our knowledge of the existence of large faults affecting the Triassic area depends mainly on the repetition or offsetting of trap ridges, and not on actual observation of fault surfaces. Because of the character of the evidence the exact nature of displacements is largely speculative, and in this connection two especially obvious questions are presented.

(1) To what degree was the displacement lateral, parallel to the strike of faults?

(2) What is the direction of dip on the major fault planes?

Some indirect evidence bearing on the first question is found for certain parts of the Triassic area. Thus the absence of important offsetting in the outcrops of the great dikes in the towns of Hamden and Wallingford may be taken to indicate that the dikes are essentially vertical and that displacement on the large oblique faults which evidently extend from the vicinity of Meriden southwestward had no important lateral component.[4] There are grounds for a similar conclusion regarding the faults that affect the Saltonstall basin. The map (fig. 1) shows that in the northern part of the "dish" the trap ridges are offset toward the north on the west side of faults, whereas in the southern part the offset is universally in the opposite sense. This arrangement—the "receding order" and "advancing order" of Percival—is exactly that to be expected if all of the faults occurred

---

[3] 7th Ann. Rept. U. S. Geol. Survey, p. 474.

[4] Davis, W. M.: 18th Ann. Rept. U. S. Geol. Survey, part 2, p. 102.

with relative downward displacement on the west and with no appreciable lateral movement.

Evidence relating to the second question is very meager. There are some facts to indicate that the great boundary fault on the east side of the Triassic area dips westward, at least in part of its course, and some geologists have assumed that the other faults are generally of the normal type. A study of the diagrammatic cross-sections in the literature, however, reveals striking differences of conception. The vertical fault-traces in some diagrams evidently represent efforts to appear noncommittal as to the actual attitude; but a fault which is now vertical may well have had an original eastward inclination, if we conceive that the blocks suffered some rotation during the tilting of the entire Triassic area. In Barrell's sections[5] most of the faults are shown as reverse, with a steep inclination of the planes to the east. Evidently this conception is permitted by the surface evidence, which merely indicates that in most cases there has been *relative* downthrow on the west. Barrell sought an explanation of the general eastward dip of the Connecticut Triassic in a geanticlinal uplift along the old Taconic axis, and conceived that during the uplift subcrustal flow from the limb toward the crest might produce shear in the overlying crust, breaking the sediments by steep reverse faults. As the movement continued the blocks would be rotated, and thus some of the faults may have been turned to a nearly vertical position.[6]

There is little probability that this question will be settled by direct observation. It is possible, however, that an accumulation of indirect evidence may lead to general acceptance of one view or the other. Groups of minor faults which appear to be of the "sympathetic" type should give valuable testimony, for they should in general imitate the inclination as well as other characteristics of the major fractures. It is readily seen that the attitude of the small faults at the Saltonstall tunnel favors the view of normal faulting for the Saltonstall basin. The average inclination determined for these planes (67°)

---

[5] Barrell, J.: Central Connecticut in the Geologic Past, Conn. Geol. and Nat. Hist. Survey, Bull. 23, 1915.

[6] Personal communication. These ideas are also outlined in a manuscript left unfinished by Professor Barrell.

agrees well with the average for normal faults in general. It is true that if we imagine the beds turned back to a horizontal position (or perhaps a few degrees past the horizontal, to allow for an original westward dip on a bajada slope), most of the faults would then be inclined steeply eastward; but this would represent the extreme conception that faulting began precisely at the time of initial tilting, and even with this allowance the planes would be so nearly vertical that they could not be considered as the result of ordinary shearing stresses.

The testimony furnished by this one group of structural features is of course only suggestive, and is presented here merely as a possible small part of the cumulative evidence through which we may eventually determine, with a reasonable degree of assurance, the mechanics of post-Triassic faulting in the Connecticut Valley.

II. TRIASSIC FAN DEPOSITS.

The prevalence of coarse sediments along the eastern border of the Triassic area has attracted the attention of all geologists who have worked in the region. Coarse conglomerate containing an abundance of fresh feldspar is the type of rock found almost universally in outcrops immediately west of the great bounding fault. Pebbles and bowlders of crystalline rocks included in this conglomerate can be traced to their sources in the metamorphic and igneous formations of the Eastern Highland. As a rule the bowlders are fairly well rounded and do not exceed a few inches in diameter; but at certain localities adjacent to the fault the fragments in the conglomerate are unusually large and many are remarkably angular. Some of the fragments belong to exceptional and distinctive rock types which can be seen in place only in bodies of limited size exposed immediately east of the fault. The distance to which these coarse deposits were originally distributed westward cannot be ascertained, because the beds now dip steeply to the east and have been bevelled by post-Triassic erosion. Along the strike the coarse material at a typical locality has a center of maximum thickness and coarseness, grading into finer sediments in either direction. This peculiar distribution, considered in connection with the rude and lenticular bedding, the angularity and lack of assortment displayed by the fragments, and the evident source of the material, leaves no doubt that the coarse sediments were deposited in the form of fans at the base of a steep scarp or slope by small streams flowing westward.

A number of these fans are recognized along the fault between Branford and Durham. Perhaps the most conspicuous example is exposed in the bluff on the west side of Lake Quonnipaug, several miles northeast of the area represented in the map, fig. 1. At that locality the angularity of the fragments making up the fan is truly remarkable. Even in the Great Basin the writer has not seen products of erosion which show as little evidence of transportation except in talus deposits, and yet the material at Lake Quonnipaug has the rude bedding characteristic of coarse fans. We can only conclude that the sediments now exposed at that place were deposited directly in front of a cliff, and the fragments were supplied by very local streams.

The best example of a fan in the Saltonstall basin is located about two miles from Branford in a direction slightly east of north. (See fig. 1.) E. O. Hovey[7] and J. D. Dana[8] commented on the unusual character of the conglomerate at this locality. Hovey refers to the area occupied by the deposits as the "bowlder ridges," and he has described the essential features of the section as follows:

> "The region containing the most interesting part of the conglomerate, i. e. the ridges, is about three-fourths of a mile long from S. W. to N. E. and perhaps half a mile wide. There are several of these ridges each of which is 300 to 400 yards long; and their general trend is N25°E. They are narrow, begin and end abruptly, have almost precipitous sides, and rise about 125 feet (aneroid measurement) above the brook and meadow bounding their region on the east and south. The valleys between them are narrow and from 40 to 60 feet deep. ....
>
> "The rock of the ridges is exceedingly coarse. Well rounded bowlders a foot in diameter are very numerous, while others two, three, and even four feet long are by no means rare. Much trap

[7] Hovey, E. O.: Observations on some of the trap ridges of the East Haven-Branford region, with a map: This Journal, 3d ser., vol. XXXVIII, pp. 361-383, Nov. 1889.

[8] Dana, J. D.: The Four Rocks, with walks and drives about New Haven, p. 191, 1891.

is present in the rock. In some of the western ridges the conglomerate is mainly composed of trap fragments with a small amount of coarse sandstone cement; the middle ridges contain many bowlders of quartzite, mica and hornblende schist, gneiss, and granite; while the eastern ridges seem to have rather more of the latter constituents than of trap. Bowlders of coarse sandstone also occur in this rock, and many of the fragments of trap have coarse sandstone adhering firmly to them and forming a part of the bowlders imbedded in the conglomerate. The pieces of trap are either angular, subangular, or well rounded, compact or amygdaloidal, and quite fresh or much decomposed. Many of them contain long, vermiform cavities, either empty or filled with calcite. . . . . But few of the trap bowlders, and those widely scattered, occur in the western and southern part of the conglomerate area.''[9]

After careful field study the present writer indorses the foregoing description with the exception of one essential item—namely, the alleged occurrence of sandstone bowlders and of sandstone adhering to trap fragments as constituent parts of original bowlders. Obviously the presence of such fragments would be of great interest, and of considerable importance in interpreting the history of the deposits, inasmuch as the only sandstone in the region is of Triassic age. Accordingly determination of this point was made a special object of field study, and the conclusion has been reached that the sandstone masses mentioned in the description are probably parts of the fan matrix, which is composed almost entirely of the coarse arkose characteristic of the Triassic sediments in the region. Between large angular bowlders the matrix commonly has the form of isolated slabs or irregular masses, which in weathered outcrops might be mistaken for angular pieces originally deposited in the fan. It appears that the original constituents were derived only from the crystalline formations and fissure veins in the Eastern Highland and from masses of basalt.

The valleys separating adjacent ''bowlder ridges'' are peculiar in that they do not follow the strike of the beds but cross it at a large angle. The parallelism of the valleys, and the fact that some are not now occupied by continuous stream courses, suggest a common and special origin. Their trend corresponds closely to the apparent

---

[9] Hovey, E. O.: loc. cit., p. 375.

direction of faults recognized to the north and west (see fig. 1) and of the great fault immediately southwest of the ridges. Accordingly it is suggested that they are depressions developed along fault zones.

The fan deposit is in the upper part of the Triassic section as it is known in Connecticut, and it forms the top of the section at this particular locality. Its thickness certainly is measured in hundreds of feet and may exceed a thousand feet near the middle of the fan. The greatest degree of coarseness and angularity occurs above the upper or ''posterior'' lava sheet, although typical fan deposits continue to a much lower horizon. It appears that the lava flow wedges out in the fan, for there is a progressive thinning of the sheet eastward, and no outcrops of it can be found in the area of coarsest and thickest fanglomerate. Fragments of basalt, many of them vesicular and others quite compact, occur in large numbers beneath the ''posterior'' sheet as well as above it. The present dip of the beds is in a direction slightly east of south and averages about 35°, although dips as high as 45° are found locally.

The special interest of the fan lies in its bearing on the structural history of the region. In this connection the large size and extreme angularity of the fragments are very significant features, testifying to the presence of a steep scarp near the present border of the Triassic area late in the period of sedimentation. Sediments thousands of feet in thickness had already accumulated in the Triassic trough, and without doubt much of this material was stripped from the Eastern Highland during long continued erosion. The coarse detritus in the fan, therefore, furnishes strong evidence of important faulting along or near the line of the great boundary fault before the close of the Triassic period.

Abundance of vesicular basalt in the fanglomerate is another notable feature. It is to be expected that the lava flows would furnish some detritus before their burial, but their widespread distribution in the Lowland and the apparent absence of important unconformities in the Triassic section indicate continued low relief during sedimentation within the area where the flows now exist. Moreover it is evident that the fan materials came from the Eastern Highland, and therefore we must conclude that lava once covered a portion of the crystalline rocks east of the great fault. Basalt dikes cutting those rocks are not uncommon, and it is quite conceivable that eruptions occurred there contemporaneously with the flows in the Lowland. It is also possible that the main sheet formerly extended farther eastward. The view is held that recurrent faulting maintained steep topography east of the area of sedimentation during much of Triassic time; but the scarp may have receded considerably to the east during intervals of quiet, and it is not at all unlikely that the heaviest flows, aggregating hundreds of feet in thickness, encroached somewhat on the crystalline area even if the eruptions occurred only in the Lowland. With later displacement on the fault the lava on the upthrown block would be stripped away, furnishing part of the material for the burial of the main body of the sheet. Davis's diagrams[10] express the conception that the entire Triassic section once extended considerably east of the present boundary, with later faulting and complete removal of the sediments and lavas from the area of the Eastern Highland. There is good suggestive evidence, however, that recurrent faulting maintained the eastern border of the Triassic area near its present position during a considerable part of the period of sedimentation. In addition to the testimony of the fanglomerate, discussed here, features and relationships observed by Mr. W. L. Russell during recent work along the fault zone testify to recurrent faulting and renewal of the scarp through the period represented by the section including the three trap sheets.

The essential uniformity of dips in all parts of the Saltonstall basin is noteworthy. In the tunnel section, discussed above, the dip is 35°, and this figure may be taken as the average for the main sheet throughout the length of Saltonstall Ridge. The fanglomerate beds, which lie more than 1000 feet higher in the stratigraphic section, are also inclined toward the boundary fault at an angle of about 35°, although at the time of their deposition these coarse deposits must have had a slight inclination in the opposite direction. It appears, therefore, that

---

[10] The Triassic Formation of Connecticut, U. S. Geol. Survey, Ann. Rept. 18, part 2. See especially Plate 20.

any faulting immediately preceding the fan deposition was not accompanied by perceptible tilting of the Triassic floor in this area. It is also to be noted that in a complete section across the Triassic at this latitude the dips are much steeper on the east than on the west. In the vicinity of West Rock the eastward inclination is 20° to 25°; at East Rock it is about 20°; between Fair Haven and East Haven it ranges from 20° to 30°; and from East Haven to the eastern boundary the average is about 35°. This relationship is directly the opposite of that observed for the Connecticut Valley as a whole. Davis[11] was the first to point out a perceptible decrease in dip from west to east, basing his statement on the observed inclination of basal beds exposed on both sides of the valley. He interpreted this relationship as favoring the hypothesis of downfolding of the Triassic trough during sedimentation. Others consider the entire section exposed on the eastern side of the area as younger than the basal beds on the west, and have cited the decreasing dip from west to east as favoring the hypothesis of repeated faulting along the eastern side during sedimentation, with progressive tilting of the Triassic floor.[12] Another possible interpretation is suggested here. If the monoclinal tilting of the Connecticut Triassic is due to uplift along a geanticlinal axis to the west—and this is a popular conception—we should expect a gradual decrease in dip toward the east, with increasing distance from the axis of uplift. It is seen, therefore, that the relation between dips on the two sides of the valley agrees with several different hypotheses but actually proves none. However, as discussed above, there is other and more direct evidence of recurrent faulting on the east.

A ready explanation of the higher dips on the east in southern Connecticut, in contrast with the general relationship, is found in the powerful warping reflected by the curving of Saltonstall and Totoket ridges. This pronounced folding, which has materially modified the monoclinal structure, appears only in the southern part of the Triassic area.

---

[11] Davis, W. M., op. cit., pp. 38-39.

[12] Foye, W. G., in a paper on Connecticut structure presented before the Geological Society of America, 1921; Rice, W. N., in discussion of Foye's paper.

Art. XXIII.—*Amphisymmetric Crystals*[1]; by Edgar T. Wherry.

That the symmetry-class to which a given crystal belongs is not always evident from external features is too well known to require discussion. The methods commonly applied in discovering hidden symmetry may be divided into two groups, designated in a general way as physical and chemical, respectively. The individual methods falling in each of these groups are listed in Table I.

Table I.—Methods of Discovering Hidden Symmetry.

(*A*) Physical:
  (*a*) Excitation of pyroelectricity.
  (*b*) Observation of rotation of the plane of polarized light.
  (*c*) Study by X-rays.
(*B*) Chemical:
  (*a*) Development of etch-figures by momentary action of solvents.
  (*b*) Production of growth forms by causing rapid crystallization, by adding impurities to the solution, etc.

When the results obtained by applying all of these methods agree in placing the crystal in a single symmetry class, the relation is merely that of mimicry or pseudosymmetry and requires no further attention. However, as pointed out in a previous paper, in a not inconsiderable number of cases the different methods do not agree[2]; and for this lack of agreement the term *amphisymmetry* is here suggested.

In cases of amphisymmetry, crystallographers have in general selected as characteristic of the substance one of the classes indicated by the special methods of study, and have disregarded the other. The most influential factor in making the choice appears to have been the circumstance that certain forms are common to crystals of two or more symmetry classes, so that if only such forms are

---

[1] Presented in abstract at the meeting of the Mineralogical Society of America, Amherst, Mass., Dec. 29, 1921.

[2] E. T. Wherry, J. Wash. Acad. Sci., 8: 480, 1918; questioned by A. E. H. Tutton, *ibid.*, 9: 94, 1919.

developed, a crystal may seem more symmetrical than it really is (pseudo-symmetry). Accordingly, when different methods have indicated different classes (amphisymmetry) it has been customary to select as typical that possessing the lesser degree of symmetry. For example, the alkali halides show consistently, when studied by the methods of group A, cubic holosymmetry (Class 32); yet, just because those of group B yield forms with the lower cubic gyroidal symmetry (Class 29), this series of compounds is assigned by practically all crystallographers to the latter class. On the other hand, in diamond the methods of group A indicate cubic holosymmetry (32), those of B hextetrahedral (31). In this case some crystallographers follow the same rule as with the halides, and assign diamond to the class of lower symmetry, while others equally arbitrarily assign it to the higher.

As long as crystallography was of little interest to anyone working in other sciences, the fact that symmetry classes were at times selected arbitrarily does not appear to have attracted any particular attention; but after Laue thought of passing X-rays through crystals and his striking results led physicists to read up on crystallography, considerable perplexity began to be registered.[3] Thus the Braggs in "X-Rays and Crystal Structure," p. 157, say:

> "This structure [worked out by X-rays] has holohedral symmetry. If the copper and oxygen atoms have these exact geometrical positions, the crystal of cuprite ought to exhibit holohedral symmetry. Instead of this, certain uncommon forms of the crystal show that its symmetry is in reality holoaxial [Class 29]. If this holoaxial symmetry corresponded to a large distortion . . . it is probable that the spectra would show the influence of this distortion . . . . On the other hand the crystallographic evidence

---

[3] Since the submission of this paper for publication, Wyckoff (This Journal, 3: 177, 1922) has brought out the difficulty in a striking way. He urges further study of the crystallography of ammonium chloride (and inferentially of other halides). It is shown in the present contribution that what is needed is a more discriminating interpretation of existing data; the "crystallographic information" supposed to point "to an enantiomorphic hemihedry" does not do anything of the sort, but merely shows that the atoms when set free from the crystal structure exhibit some enantiomorphic features, which their electron arrangement necessitates in any case. Ammonium chloride, one of the 15 members of the sodium chloride group tabulated below, is structurally holosymmetric and only latently gyroidal (enantiomorphic). Compare also footnote 6, below.

would seem to show that the distortion of the structure is slight. The etch figures of cuprite indicate a holosymmetric [Class 32] crystal, and the crystal does not rotate the plane of polarization of light. It is only on account of the existence of crystals which show a holoaxial hemihedrism that cuprite is assigned to the holoaxial class.

"These observations apply equally well to the case of potassium chloride . . . . assigned by crystallographers to the holoaxial class of the cubic system . . . . examination by means of the X-ray spectrometer indicates . . . . perfect cubic symmetry . . . . When a potassium chloride crystal is etched with water, it displays . . . . holoaxial symmetry . . . . Again however there is no trace of rotatory polarization."

It appears to the writer that in order to avoid misunderstandings and reproaches crystallographers should no longer make arbitrary choices in cases of amphisymmetry, but should face the issue squarely and state both symmetries represented in each case. The mode of statement suggested in his cited paper is, however, capable of improvement, and it is the purpose of the present contribution to further develop the idea. In this connection, the writer wishes to express his thanks to Dr. Elliot Q. Adams, formerly of this Bureau, for many helpful suggestions.

The only reasonable interpretation of amphisymmetry which suggests itself is that some of the methods for bringing out hidden symmetry yield information as to the symmetry of the structure or point-system as it stands, while others indicate the symmetry which the constituent atoms or molecules may exhibit when released from the crystal,—in other words, a symmetry *latent* in the atoms. It is therefore in order to consider the significance of the several methods, and the group of alkali halides may well be used throughout by way of illustration.

(*A*) *Physical group.*—When pyroelectricity is excited in a crystal, the opposite charges develop at the ends of axes which are structurally polar, having different kinds of atoms present at their opposite ends. The alkali halides yield no pyroelectricity, indicating the absence of polar axes in their structure and showing definitely that the structures cannot possess the symmetry of the gyroidal class.

When polarized light traverses a crystal, in any direction whatever if it is isotropic, or along an optic axis if anisotropic, rotation of the plane will occur if the directions of attraction between atoms are to any extent gyroidally arranged, or if, as it is called in stereochemistry, ''asymmetric'' atoms are present. As the alkali halides show no trace of rotation of the very sensitive plane of polarized light, their structure can certainly not be to the least extent gyroidal, nor their atoms asymmetric.

Since crystals affect X-rays in accordance with the spacings between layers of atoms or molecules in various crystallographic directions, this method of study permits the recognition of the character of the structure. The alkali halides behave toward X-rays as if they are in every respect cubic-holosymmetric. To be sure, since the theoretical rate of decrease in intensity of reflection with order is not definitely known, slight deviations might not be recognizable, but it is noteworthy that this result agrees with those of the more certain methods previously discussed.

(*B*) *Chemical group.*—When a solvent is applied momentarily to a crystal face, it starts to act at imperfections, and develops there minute pits, bounded by more or less vicinal faces. Such faces may also be produced during the growth of crystals, especially when rapid. Vicinal faces may be explained most simply by combining the views of the three principal writers on the subject.[4] Surface tension tends to make crystal surfaces curved, while the building up of atoms or molecules in regular rows in obedience to the attractive forces acting between them tends to fill out all curves or depressions and produce plane faces with sharp intersections. The actual surface features of a given crystal will be the result of equilibrium between these two opposing tendencies, in such a way that the vicinal faces actually produced represent the maximum deviation from normal angular position which is possible without increasing the growth rate sufficiently to cause the filling up of the resulting gaps in the surface layers of atoms or molecules.

In the course of momentary solution as applied in the production of etch figures, the symmetry represented in

---

[4] G. Wulff, Z. Kryst, Min., 34: 449, 1901; H. A. Miers, Phil. Trans. A, 202: 459, 1903; P. Niggli, Z. anorg. allgem. Chem., **110**: 55-80, 1920.

the arrangement of attraction directions around the atoms, whether it is exhibited in the structure or is suppressed by their mode of combination, has a chance to make itself felt. In the alkali halides the etch figures occasionally show gyroidal symmetry in their bounding vicinal faces, indicating this arrangement of the attraction directions around one or both kinds of atoms present.

When there is present, in the solution of a compound, an impurity which is attracted to one of the constituents in directions other than those perpendicular to the principal faces, this impurity will tend to deposit on the growing crystal in the crystallographic positions corresponding to the attractions and, by preventing the normal constituents from building on there, it may produce crystal forms other than those typical of the pure substance. It should be pointed out in this connection that the relation between the attraction directions and the faces developed is the opposite of that shown in the stereochemist's diagrams of atoms. In the latter, valence lines (attraction directions) emerge at apexes of solids, whereas directions along which impurities are attracted lie perpendicular to the resulting faces. The addition of a large amount of magnesium chloride to a solution of one of the alkali halides, potassium chloride, is recorded to produce general (*hkl*) forms of varying indices, probably though not certainly gyroidal in arrangement.[5] The magnesium may well be attracted to chlorine along force lines perpendicular to (*hkl*) faces, and prevent some potassium from taking up its normal position, so that these faces appear on the crystals. This, like the preceding method, is thus adapted to bring out the symmetry of the attraction directions of atoms.

The current theory of the constitution of alkali halide crystals is that each metal atom has given over an electron to a halogen, so that the surfaces of both kinds of atoms are completed octets. The structure is then capable of becoming relatively highly symmetrical, and the evidence in fact indicates cubic holosymmetry. Apparently, however, when atoms are dissolving away or when impurities are depositing, the single surface electron of the free metal, or the seven surface electrons of free halogen, being obviously incapable of highly symmetrical arrange-

---

[5] L. Wulff, Sitzb. Akad. Wiss. Berlin, 1894, 1, 387.

ment, exert attractions in gyroidal fashion. In general, it is to be inferred that the methods here grouped as chemical may bring out, not the actual symmetry of the crystal structure or of the atoms as they stand, but symmetry latent in those atoms.

The recognition that the various methods of bringing out hidden symmetry differ in significance, as above outlined, makes it possible to replace arbitrariness by rationality in the choice of symmetry class. If it is desired to base the classification of a crystal on its actual structure or point system, then the physical methods, which bring out the symmetry of that structure, should be depended upon as indicating the class. If, on the other hand, the purpose is to study atomic forces, then the indications of the chemical methods, which bring out the latent symmetry of the atoms or molecules, may be followed. X-ray workers need consider in general only the structural symmetry, but chemists may be interested more in the latent symmetry relations.

In the alkali halides pyro-electricity, polarized light, and X-rays all agree in indicating the structure to be cubic holosymmetric, and they should in general be so classified. On the other hand, etch-figures show that the constituent atoms have latent gyroidal symmetry, so that in any application of the properties of the halides to working out the features of alkali metal or halogen atoms, they may be assigned to the cubic-gyroidal class. The statements concerning amphisymmetric substances in current crystallography books are accordingly inadequate. Groth in his ''Chemische Krystallographie'' states that potassium chloride is ''Kubisch (pentagonikositetraedrisch),'' i.e., cubic (gyroidal). A better statement would be: ''Cubic; structurally holosymmetric; latently gyroidal'' (or, if class numbers are preferred, ''structurally of class 32, latently 29''). To cite an entirely different example, Dana in his ''System of Mineralogy'' describes scheelite, calcium tungstate, as ''Tetragonal; with pyramidal hemihedrism.'' In this case neither pyroelectricity nor polarization-plane rotation could occur, so that this statement represents all that could be ascertained about the mineral at the time. However, the ''hemihedrism'' (or merosymmetry) is shown only by rare faces, probably produced by films of impurities, and recent X-ray study has shown the structure to be holosymmetric, making it now possible to be more specific: "Tetragonal; structurally holosymmetric; latently pyramidal."

In conclusion, there is presented (Table II) a list of substances which give evidence of being amphisymmetric, with their respective structural and latent symmetry classes, as far as these are at present known. Where a group of compounds shows similar relations throughout, only one typical member is given, but the number of members included is indicated by numerals in parentheses after the mineral name. The order is in general that of increasing complexity of the compounds and of decreasing symmetry. Class names and numbers are modified from Groth's "Physikalische Krystallographie."

TABLE II. AMPHISYMMETRIC SUBSTANCES.

		Symmetry Classes.	
Mineral name.	*Formula.*	*Structural.*	*Latent.*
Diamond	C	Cubic holosym. (32)	C. hextetrah. (31)
Alabandite	MnS	Cubic holosym.	C. hextetrah.
Sodalite gr. (4)	$Na_4Al_3ClSi_3O_{12}$	Cubic holosym.	C. hextetrah.
Bromyrite	AgBr	Cubic holosym.	C. diploidal (30)
Kalinite gr. (40)	$KAl(SO_4)_2.12H_2O$	Cubic holosym.	C. diploidal
Halite gr. (15)	NaCl	Cubic holosym.	C. gyroidal (29)[6]
Cuprite	Cu_2O	Cubic holosym.	C. gyroidal (29)[6]
Nitrobarite gr. (3)	$Ba(NO_3)_2$	Cubic hextetrah. (31)	C. tetartoidal (28)
....	$NaSrAsO_4.9H_2O$	Cubic hextetrah.	C. tetartoidal
Langbeinite	$K_2Mg_2(SO_4)_3$	Cubic hextetrah.	C. tetartoidal
Cobaltite gr. (5)	CoSAs	Cubic diploidal (30)	C. tetartoidal
Nephelite gr. (3)	$NaAlSiO_4$	Hexag. holo. (29)	Hex. pyr. (23)
Spangolite	$Cu_6AlClSO_{10}.9H_2O$	Hexag. holo.	Ditrig. pyr. (20)
Scheelite gr. (4)	$CaWO_4$	Tetragonal holo. (15)	Tetr. bipyr. (13)
Scapolite gr. (5)	$Na_4Ca_4Al_9ClSi_{15}O_{49}\pm$	Tetragonal holo.	Tetr. trapez.
Rutile	$TiTiO_4$	Tetragonal holo.	Tetr. trapez. (12)
Phosgenite	$Pb_2Cl_2CO_3$	Tetragonal holo.	Tetr. trapez.
....	$NiSO_4.6H_2O$	Tetragonal holo.	Tetr. trapez.
....	KH_2PO_4 gr.	Tetragonal holo.	Tetr. scaleno (11)
Wulfenite	$PbMoO_4$	Tetragonal holo.	Tetr. pyr. (10)
Stephanite	Ag_5SbS_4	Orthorh. holo. (8)	Orth. pyr. (7)
Manganite	MnOOH	Orthorh. holo.	Orth. pyr.
Aragonite gr. (4)	$CaCO_3$	Orthorh. holo.	Orth. pyr.
Sulfur	S	Orthorh. holo.	Orth. bisphen. (6)
....	$AgNO_3$	Orthorh. holo.	Orth. bisphen.
....	$H_2Na_2P_2O_6.6H_2O$	Monoclinic holo. (5)	Monocl. domat. (4)
Diopside	$MgCaSi_2O_6$	Monoclinic holo.	Monocl. domat.
....	$Li_2SO_4.H_2O$	Monoclinic holo.	Monocl. sphen. (3)
....	$Sr(C_2H_3O_2)(NO_3).1\frac{1}{2}H_2O$	Triclinic holo. (2)	Asymmetric (1)

---

[6] It is noteworthy that since all of the supposedly cubic-gyroidal substances are amphisymmetric, no crystal is known which structurally belongs to this class.

SUMMARY.

The fact that different methods may not agree in their indications as to the symmetry class of a given crystal is re-emphasized, and the term *amphisymmetric* is proposed for this relation. Physical methods show the symmetry of the structure, chemical methods bring out latent symmetries of the separate atoms or molecules. It is recommended that in stating the crystallization of an amphisymmetric substance the two classes indicated be given, one designated structural, the other latent. Finally, a table of a large number of substances which give evidence of being amphisymmetric is presented.

Bureau of Chemistry,
U. S. Department of Agriculture,
January, 1922.

Art. XXIV.—*A New Trilobite Appendage;* by Thomas H. Clark.

Among all of the faunal assemblages in the Lévis formation the most interesting and the richest in hitherto unrecognized fossils is the so-called Shumardia limestone. Billings referred to this as ''thin-bedded limestone interstratified in the graptolitic slates'' (Pal. Foss. Can. 1865, p. 93) in recording the locality of the single new fossil which he described from it. That only one species should have been known at that time is very remarkable, for in places it is crowded with fossils of all descriptions. To be sure, the limestone is difficult of access in place, and it may be that Billings was not content with fallen blocks at the base of the cliff. T. C. Weston, lithologist for the Canadian Geological Survey, later made large collections from this horizon, which he named the Shumardia limestone on the labels which he affixed to his specimens. Dr. Raymond recognized the name in his paper on the succession of the faunas at Lévis, and listed under his Zone D, the fauna then known to characterize that bed. Recently the writer has made a large collection of this horizon which includes all of the previously recognized species, and a great many new ones. An incomplete summary of the fauna, which is not yet thoroughly worked over, is as follows:—

Plants	Obscure algæ.
Graptolites	19 species.
Brachiopods	
Inarticulate	11 species.
Articulate	2 species.
Crustacea	
Trilobites	10 species.
Ostracods	Numerous.
Cirripedea	2 species.
Annelids (?)	
Conodonts	4 species.
Serpulites	1 species.

With the exception of a few small articulate brachiopod shells, all of the specimens of the species listed above are now composed of black carbonaceous material, which indicates that their original shell or skeleton was of chitin or of some similar organic compound. This holds true for the fossils of the black shales with which the Shumardia limestone is interstratified. Without doubt the fauna of the shale and the limestone was a pelagic one, well adapted to a floating or a swimming existence, and preserved in such abundance in the rocks of the Lévis formation because of the absence of any indigenous benthonic predaceous or scavenging forms. The abundance of carbonaceous matter in the shales, and the absence of any truly benthonic forms, indicate that the bottom of the Lévis sea was not capable of sustaining a fauna; this would account for the preservation, almost in their entirety, of many very delicate graptolites and thin-shelled brachiopods.

One of the most remarkable fossils from this horizon is a single detached appendage of a trilobite. It is small, less than 5 mm. in length and about 1 mm. wide. It consists of the outer part of a coxopodite, a large exopodite, a fragmentary endopodite, and one or two other members to be discussed later. The accompanying figure shows the disposition and relations of these parts. It should be borne in mind, however, that this figure represents the writer's interpretation of the specimen. The proximal parts are somewhat crushed, so that other interpretations are possible.

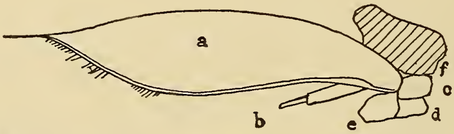


Fig. 1.—Sketch of the trilobite appendage from the Shumardia limestone, Lévis formation, Lévis, Quebec. × 12.
a. Exopodite. b. Endopodite. c. Coxopodite. d. Second coxopodite. e. Second exopodite. f. ?Ventral membrane.

The exopodite is by far the largest and the most prominent member. Its outline is as shown in the sketch, blunt at the inner end, terminating in a long spine at the distal extremity, widest beyond the middle. The posterior margin carries a score or so of setae, which are short, stout and pointed outwards. These appear to be *inserted in* the margin of the exopodite, rather than outgrowths of it, for the border is thickened and the setae appear to come out from under it. Moreover, adjacent setae, none of which appears to be flexible, emerge from the border at varying angles, a condition which could scarcely obtain were they prolongations of the substance of the exopodite. Inserted setae on trilobite appendages have hitherto been found upon endopodites only. The thickened border extends along the posterior side of the exopodite, which has been crushed flat, as is shown by the many cracks and slight displacements.

The endopodite is incomplete. Two or three segments are shown, but it does not appear that the whole member, if completely restored, would be as much as 3 mm. long; it probably would not exceed 2 mm. It is circular in section, and was undoubtedly stout, for the thickened border of the exopodite may be seen to bulge above it.

The coxopodite, adjacent to the blunt end of the exopodite, is small, but probably incomplete. It is roughly rectangular, and crushed flat.

Below this are two fragments which the writer interprets as a second coxopodite, and the base of a second exopodite, both belonging to a single segment. Above the whole is a large patch of black, but less shiny, material, shown by shading in the sketch, which, if it be part of this assemblage at all, might represent a fragment of the ventral membrane of the trilobite. This is purely conjectural, but it lies where the ventral membrane would be looked for, immediately above the exopodite.

Apart from the presence of inserted setae in the exopodite, the most remarkable feature about this specimen is the relation in size between the exopodite and the endopodite. That the animal which bore this appendage was not adapted for crawling is certain; no trilobite with such reduced endopodites could have been a successful benthonic inhabitant. On the other hand, the large paddle-like exopodite might well have been adapted to a nectonic or a planktonic mode of existence. This is in accord with the conclusion reached with regard to the whole Lévis fauna.

This limb does not agree exactly with any of the known trilobite appendages. In Neolenus the endopodites are relatively very large, much longer than the exopodites.

In the Asaphidae, no exopodites are definitely known, but the endopodites are long, although slender. In Triarthrus, the basipodites, ischiopodites and meropodites are for the most part much modified in form, but in any case the endopodites are as long as, if not longer than, the exopodites. In the form of the exopodite alone, some comparison might be made between the present specimen and Walcott's figured specimen of *Ptychoparia cordillerae* Röminger.[1] In all other trilobites the exopodites are no longer than the endopodites. Thus, on anatomical grounds alone, it would be impossible to connect this form with any trilobite whose appendages are known. Of the genera represented in the Shumardia zone only Isotelus and Triarthrus have so far yielded recognizable appendages. The most abundant trilobite is *Shumardia granulosa* Billings, which outnumbers all others about five to one; but this species is much too small to have possessed the appendage in question. The remaining genera represented in the Shumardia limestone are Agnostus, Endymionia, Symphysurus, Telephus, and Holometopus, to any one of which this appendage might belong. There seems to be no evidence for placing it within any particular one of these genera.

Museum of Comparative Zoology,
Cambridge, Mass.

---

[1] Smithson. Misc. Coll., vol. 67, pl. 21, figs. 3-5, 1918.

Art. XXV.—*Cyprine and Associated Minerals from the Zinc Mine at Franklin, N. J.*; by J. Volney Lewis and Lawson H. Bauer.

The following notes refer chiefly to cyprine, the sky-blue variety of vesuvianite, in intimate microscopic mixture with willemite, and to the associated rhodonite (var. bustamite) and andradite (var. polyadelphite).

1. *Vesuvianite, var. Cyprine.*—Bluish green fibrous cyprine was found in granite in the Parker shaft, at Franklin, in 1905, and was described by Professor Palache,[1] who also published the analysis by Steiger, which is quoted below for comparison.

The mineral here described was found in the ore body near the hanging wall in a crosscut 374.5 feet south and 361.5 feet west of the Parker shaft, and 10 feet above the 850-foot level. It is sky-blue in color; in texture it varies from fine granular and fibrous to dense. To the naked eye, and even under the hand lens, it appears to be homogeneous. The analysis (A, below) showed nearly 22 per cent. zinc oxide, and since the oxide ratios fell within the limits of variation of vesuvianite, it was supposed that a new variety of this mineral had been found.

Thin sections showed, however, that while vesuvianite is the dominant mineral, it is plentifully sprinkled with rounded grains and hexagonal crystals of willemite, with dimensions up to .16 mm. in diameter. Measurements by the Rosiwal method showed that this mineral constitutes 29 per cent. of the volume, or 33.3 per cent. of the mass. If the zinc, iron, and manganese of the accompanying analysis (A) are assigned to willemite, the calculation gives 32.68 per cent. of this mineral. The remaining constituents, calculated to 100 per cent., represent approximately the composition of the vesuvianite. A few minute particles of metallic copper were visible under the microscope, but doubtless most of the copper determined is in combination.

The analysis of this mixture and the results of the calculations are given here, together with Steiger's analysis[2] of cyprine from the Parker shaft.

---

[1] Charles Palache: Contributions to the Mineralogy of Franklin Furnace, this Journal, (4), 29, p. 184, 1910.

[2] U. S. Geol. Survey, Bulletin 591, p. 315, 1915. This statement of Steiger's analysis, which is followed here, differs slightly from that given by Professor Palache.

Analyses of vesuvianite from Franklin, New Jersey.

	(A)	(B)	(C)	(D)
SiO_2	32.42	8.70	35.14	36.41
Al_2O_3	14.07		20.86	17.35
FeO	.77	.77		1.86
MnO	1.50	1.50		1.75
ZnO	21.71	21.71		1.74
CuO	.99		1.47	1.48
CaO	25.22		37.40	33.21
MgO	1.08		1.60	1.38
H_2O	2.38		3.53	(— .24
				(+3.51
Others	....	....	....	1.15[a]
	100.14	32.68	100.00	100.08

A. Vesuvianite-willemite mixture, apparently homogeneous. L. H. Bauer, analyst.

B. Willemite calculated from A.

C. Remainder of A, recalculated to 100 per cent.—approximately the composition of the vesuvianite.

D. Steiger's analysis of vesuvianite from the Parker shaft. Sp. gr. 3.451, carefully freed from specks of metallic copper.

2. *Rhodonite, var. Bustamite.*—Pale pink in color; elongated cleavable to coarsely fibrous in texture. Calcium replaces manganese to a remarkable degree, as shown by the analysis (E), by L. H. Bauer, with which is compared (F) the mineral from Långban, Sweden, as given by Dana (System of Mineralogy, p. 380):

Analyses of bustamite from Franklin, N. J. and Langban, Sweden.

	(E)	(F)
SiO_2	46.72	47.66
Al_2O_3	1.34	
FeO	.46	.48
MnO	26.51	31.65
ZnO	1.34	
CaO	22.24	18.16
MgO	1.27	1.18
Others		.98[b]
	99.88	100.11

[a] PbO tr.; Na_2O .44; K_2O .50; F .36; less O = F .15.

[b] BaO .19; alkalis .27; gangue .52.

3. *Andradite, var. Polyadelphite.*—The brown granular garnet associated with the vesuvianite approaches typical andradite in composition (analysis G, by L. H. Bauer) more nearly than the specimens from Franklin represented by the older analyses, (H) and (I), quoted by Dana:

Analyses of Andradite from Franklin, N. J.

	(G)	(H)	(I)
SiO_2	34.28	34.83	33.72
Al_2O_3	3.12	1.12	7.97
Fe_2O_3	25.53	28.73	17.64
MnO	7.41	8.82	16.70
CaO	29.20	24.05	25.88
MgO	.39	1.42	(Ign. .08)
	99.93	98.97	101.99

Besides the minerals named above, brown and reddish brown phlogopite is also abundant in scales and crystals, and in places coarse cleavable feldspars. Some of the latter give extinction angles corresponding to labradorite and others to anorthite. There are also very rare grains of pyrite, a small amount of cleavable calcite, and a little dark green pyroxene.

October 26, 1921.

SCIENTIFIC INTELLIGENCE.

I. Miscellaneous Scientific Intelligence.

1. *Stratigraphy of Northwest Greenland;* by Lauge Koch. Med. dansk geol. Forening, **5**, 1920, No. 17, 78 pp. map, 1:2,500,000; sections, views and diagrams; bibliography of 29 titles.—The Second Danish Thule Expedition to North Greenland in 1916-18, headed by K. Rasmussen, included Lauge Koch as geologist, who has presented a valuable summary of his results. A great part of the region consists of a plain of Archean gneiss, sloping gently to the northwest, where it is covered by nearly horizontal early Paleozoic strata, 400 meters in maximum thickness, consisting of conglomerates, sandstone, slate and limestone, apparently of shallow-water formation. Non-disintegrated feldspar grains in the coarser strata and a prevailing red color

suggest that they represent deposits eroded from a neighboring part of the Archean plain under arid conditions. The fossils include brachiopods, graptolites and corals. In strong contrast to this undisturbed region, the northwest coast is occupied by a well folded and greatly degraded and dissected mountain chain, presumably of Devonian deformation, which is continued obliquely across Robeson and Kennedy canals into Grinnell land. Koch regards this mountain belt as a curved extension of the Caledonian folding of northwestern Ireland, Scotland, western Norway, and western Spitzbergen. W. M. D.

2. *Revue de Géologie et des Sciences connexes.*—This Review, of which the third year began with January, 1922, is a monthly publication issued under the patronage of the Société Géologique de Belgique at Liége, Belgium. It deserves the support of all geologists and mineralogists. Subscription for 1922 fifty francs; address the General Secretary, Laboratoire de Géologie, Université de Liége.

3. *First Pan-Pacific Commercial Conference.*—This important conference has been called by the Pan-Pacific Union to meet at Honolulu on October 25. A wide range of topics has been announced for discussion, the sessions extending until October 31. Following this date a week will be given to a series of attractive excursions, the return to San Francisco being scheduled for November 8.

4. *First Congress of Industrial Chemistry.*—The first Chemical Exposition, organized by the *Société de Chimie Industrielle,* will be opened at the National Conservatoire des Arts et Metiers on October 7. The program already announced is a guarantee of an important and valuable meeting.

OBITUARY.

DR. ALEXANDER GRAHAM BELL, the inventor of the telephone, died on August 2 in his seventy-sixth year, at his estate at Beinn Bragh near Baddeck, Nova Scotia. Born in Scotland, he came to this country at the age of twenty-two, and in 1876 his first telephone patent was granted. What the telephone to-day, in its present form, means to the activities of the civilized world is too well known to need remark. The story of his active, useful life, with its many signal achievements besides the one to which his name has been so long attached, is picturesque and remarkable and will always be of general interest. The many honors he received were not more than his contributions to science and humanity merited.

CONTENTS.

SCIENTIFIC INTELLIGENCE.

VOL. IV OCTOBER, 1922

Established by BENJAMIN SILLIMAN in 1818.

THE
AMERICAN
JOURNAL OF SCIENCE.

EDITOR: EDWARD S. DANA.

FIFTH SERIES

VOL. IV—[WHOLE NUMBER, CCIV].

No. 22—OCTOBER, 1922.

NEW HAVEN, CONNECTICUT.

1922.

THE TUTTLE, MOREHOUSE & TAYLOR CO., PRINTERS, 123 TEMPLE STREET.

Published monthly. Six dollars per year, in advance. $6.40 to countries in the Postal Union; $6.25 to Canada. Single numbers 50 cents; No. 271, one dollar.
Entered as second-class matter at the Post Office at New Haven, Conn., under the Act of March 3, 1879.

THE

AMERICAN JOURNAL OF SCIENCE

[FIFTH SERIES.]

Art. XXVI.—*Jones's Criticism of Chamberlin's Groundwork for the Study of Megadiastrophism;* by T. C. Chamberlin.

In the June number of this Journal there appeared an article by William F. Jones entitled "A Critical Review of Chamberlin's Groundwork for the Study of Megadiastrophism,"[1] which calls for analysis and comment.

Doubt at once arises as to the real subject of the article, for immediately after the title there follows, without an intervening word, the heading: "Summary of Thesis," under which five subjects not of the nature of critical reviews are outlined, while at the close of the "Introduction" immediately following, the *purpose* of the paper is given in these words:

> "The purpose of the present paper is to bring together in summary form from the various sources the evidence leading to the conclusions that the earth passed through a molten stage and that there exists at no great depth a zone which yields to diastrophic differential stresses."

Immediately following the first paragraph of the introduction concerned with formal statements, the discussion opens thus:

> "It is evident that the study of megadiastrophism is to be one of the application of wedge-dynamics to continental areas. To consider continental areas as the upper surfaces of deeply point-

---

[1] Diastrophism and the Formative Processes. XIV. Groundwork for the Study of Megadiastrophism. Part I. Summary Statement of the Groundwork already laid: Thomas C. Chamberlin. Part II. The Intimations of Shell Deformation: Rollin T. Chamberlin.

This paper is essentially a digest of thirteen previous papers and of several collateral articles. Part I consists of 77 propositions or specifications giving as briefly as practicable the essential features of the fuller papers. Part II embraces certain intimations as to the downward extension of deformative action drawn from studies on accessible features by a method which deduces the under-configuration and deeper phases of the deformed mass.

ing wedges implies, of course, that the earth lacks an asthenosphere or yield zone'' (p. 394).

As if the critical review of a digest of thirteen long articles, the treatment of the five themes of a thesis, and the bringing together in summary form from the various sources of the evidences that support a molten stage and an asthenosphere, afford insufficient scope, the author adds a prophecy of what ''the study of megadiastrophism is to be'' and his interpretation of what that means. The sweep, however, is made wider still; the fundamental issues of the schools are set in array, as follows:

> ''This postulate is fundamental. The issue is thus sharply drawn between the two schools of thought. The basic problems of diastrophism, isostasy, and vulcanism must be attacked and interpreted in two diametrically opposite ways by the two schools. The one school, as represented by T. C. and R. T. Chamberlin, interpret these problems from the viewpoint of an earth which has maintained perfect solidity through the formative eras and down to the present..... The other school, as represented by Daly and the late Barrell, interpret these problems from the viewpoint of an earth which passed through a stage of fusion'' (pp. 394-5).

To deal with this frontal screen may be a little tedious but it is necessary to clear the air if any accurate practice is to follow. And first comes the prophecy. Part II of the paper on the ''Groundwork'' touched upon wedge-dynamics and it is a fair inference that wedge-dynamics will play some part in the superstructure built upon the groundwork and an equally fair inference that it will play the same sort of part that it does in the inquiry cited in the paper. But instead of shaping his forecast critically on these lines, the reviewer introduces a characterization of a radically different sort. The right-minded reader will want to know:

What are the intimations of wedge-dynamics as set forth in Part II of the paper on ''Groundwork.'' The purpose of Part II was to call attention to the fact that there is available a working method of using the intimations of the accessible deformations in determining the downward extension of deformative action, and to bring this extension into service as a part of the start already made in the study of the larger questions of diastrophism.

The prime function of the method is to disclose the actual zones of weakness, or at least *zones of yield,* that is, one type of asthenozones. Though the matter dealt with was solid, it was not ''perfect solidity'' in the sense implied by the reviewer's statement. Obviously, as the diagrams and text of the original papers abundantly show, it was a *yielding solidity.* In its application to the Appalachians of Pennsylvania and the Colorado Rockies, the method disclosed plunging zones of yield, but at the same time *the masses enclosed within these yield tracts* showed the same sort of deformation that had usually been assigned them by advocates of a molten earth. The wedge-body did not show ''absolute rigidity'' or imply the ''non-existence of a yield-state'' ''for almost any condition of stress'' (p. 396). The plunging zones of yield are supplemental asthenic zones, and add just so much of detectable yield to what was known from the accessible deformations above. Thus, far from being inhibitory of horizontal yield—the assigned function of the asthenosphere—the plunging yield-zones do good service by revealing the mode by which horizontal yield actually took place in these particular cases.

The real question of an asthenosphere in the earth as it actually is.—Our critic's definition of the asthenosphere as a zone at no great depth ''which yields to diastrophic differential stresses'' is so broad as to include any view that accepts general internal deformation. Under the new view of the constitution of matter, it seems clear that all zones yield to diastrophic differential stresses. The real question is whether there is a zone at no great depth below the surface which yields *in a special degree* compared with the zones above and below.

The doctrine of an asthenosphere as set forth by its author, Dr. Joseph Barrell, was made to relate mainly to *a solid elastico-rigid zone,* as will be seen by reference to the original papers.[2] He assigned a mode of movement

---

[2] J. Barrell, ''The Strength of the Earth's Crust,'' Part VI. Relations of Isostatic Movements to a Sphere of Weakness—the Asthenosphere; Part VII. Variations of Strength with Depth as Shown by the Nature of Departures from Isostasy. Sec. A. Presentation of Theory, Sec. B. Applications of the Theory; Part VIII. Physical Conditions Controlling the Nature of Lithosphere and Asthenosphere. Sec. A. Relations between Rigidity, Strength, and Igneous Activity. Sec. B. Relations with other Fields of Geophysics. Jour. Geol., vol. 22, pp. 655-83, 729-41, 1914. vol. 23, pp. 27-44, 425-32, 499-515, 1915.

of the same nature as that of glaciers, as interpreted by Chamberlin (VIII, p. 433), and that of "solid rock-flow," as interpreted by Van Hise (VIII, p. 428). In dealing with this question, then, on the lines laid down by its author, we have nothing directly to do with the molten state of the earth. If any indirect effect is inherited from the molten state, it is merely the favorable or unfavorable condition of the solid matter it has left. The practical question of to-day is merely the alternative whether *a solid zone formed by congelation from a molten state* would be more, or would be less, favorable to yield than *a zone formed from minute mixed solid accretion.* To me it seems that the accretional mixture offers somewhat the greater susceptibility to yield in glacier or solid-rock-flow fashion, but if someone else would give different values to the respective susceptibilities, it need not put us into "diametrically opposite" camps. So also in the matter of continental warping, Barrell placed the zone at 50 to 500 miles below the surface. It seems to me that such a small direct up-lift—of the wedging type if you please—as the relief of the continents implies, would be as little likely *to destroy the weakness of the zone* as an equal warp by lateral crumpling or any other mode of deformation. Neither would seem to me quite fatal to the weakness of the zone.

The assignment of personal attitudes.—The reviewer's sweeping introductory statement gives the impression that R. T. Chamberlin and T. C. Chamberlin are sharp antagonists of the doctrine of an asthenosphere and are about to promulgate a scheme of wedge-dynamics that, if successful, will "of course" be fatal to it. As a matter of fact, R. T. Chamberlin has been accustomed to teach his classes that an asthenosphere, in the sense of a special yield-zone, is at least a possibility. As his special method of investigating mountain diastrophism is designed to show where the yield-zones actually are—so far as implied by the features of shell deformation—and as his studies are no more than fairly begun, he naturally remains merely a hospitable student of the doctrine of an asthenosphere and refrains from propagandism until the evidences of the case return their verdict. I am not now teaching and I have refrained from going into print on this subject. Instead, I have been trying to gather the import of the new concept of matter and to make use of that as a guide in the study of this and other phases of megadiastrophism, as indicated in my last serial article.[3] Under the new dynamics of matter, it seems clear that the greater diastrophisms must affect the whole globe in due proportions, but these proportions are far from being equal at all depths. The question of special degrees of diastrophism in particular zones remains. I have been trying to balance the considerations that favor special diastrophism in the zone of magmatic generation against the considerations that favor special diastrophism in the zones of least resistance near the surface, but I have not closed the study and have not furnished any matter on this particular topic for the reviewer to review.

The reviewer's intimation of sharp antagonism seems to do Dr. Barrell even more injustice than us. In a letter (Dec. 3, 1913) transmitting to me, as Editor of *The Journal of Geology,* the first part of his manuscript on "The Strength of the Earth's Crust,"—in the VIth, VIIth, and VIIIth articles of which he makes his initial statement of the doctrine of an anesthenosphere—he says:

> "I am sending you the first four parts before the fifth is completed because I just read this past week the series of papers on Diastrophism and the Formative Processes which you are beginning to publish. My paper falls so much in line with that subject that I think it might be considered as a part of the series."

Nor, in suspending my series and giving precedence to Barrell's—because the two could not well run simultaneously, in fairness to other contributors and to readers more interested in other subjects—did I feel that there was anything antithetical in the doctrines we were advocating, though they might differ in sub-features. I think the reader will not find in the three original articles on the asthenosphere any intimation that a planetesimal constitution of the zone of weakness was in any respect whatever inhibitory of an asthenosphere. Our critic does the doctrine of asthenosphere poor service when he ties it up with the theory of a molten stage. Nor is the service

---

[3] Diastrophism and the Formative Processes: XV. The Self-Compression of the Earth as a Problem of Energy, Jour. Geol., 29, pp. 679,700, Nov.-Dec., 1921.

improved by listing reserved and cautious students of the doctrine as its fundamental and necessary opponents.

Where then does the sharp issue really lie?—During the last century and before, a molten earth was almost universally accepted by geologists. It was a logical inference from a self-developing or monoecious planetary evolution, whatever its particular form. During the first decade of the present century, an origin by means of a dioecious, or coöperative, or bi-parental evolution was proposed, because the conviction had been reached that no monoecious system of evolution could give rise to the singular dynamic features presented by our planetary system. This postulated coöperative evolution was such as to give rise to a growth of the earth essentially in a solid state by means of the slow ingathering of planetesimals. There thus arose a radical difference between two classes of postulates because of their cosmological inheritances. The practical difference between them centered in a molten *vs.* a solid state of the earth. Along these lines, there is a fundamental issue.

As a sub-phase in the development of the accretional view, an attempt has been made to cut off the top of the standard planetesimal tree, so to speak, and graft on the stump a molten state instead. I have not specifically discussed, in print, the congeniality of such engrafting, and I am reluctant to do so now—for personal reasons too obvious to need mention—but it is made necessary.

Is a molten state compatible with a planetesimal origin?—The planetesimal basis is herein taken for granted. If the conditions of formation thus postulated permitted free speculation, it might be assumed that the planetesimals were gathered in fast enough to force a molten state. But the postulated conditions are far from permitting free speculation; they are rather severely restrictive as we shall at once see.

A molten state under planetesimal conditions could normally arise only when the mass of the nucleus was large enough to give great heat by its own condensation and, at the same time, had strong enough attraction to draw in the planetesimals rapidly, and even then the planetesimal orbits must be favorably distributed. There is no gain by supposing that the planetesimals grew into large masses, for (1) there would be some loss of energy and much loss of time in such aggregation, (2) what is gained in the mass would be lost in the longer intervals between infalls, and (3) the energy of infall largely takes the form of *mechanical dispersion.* The larger meteorites melt less proportionally than the small ones. The great infall that produced Meteor Crater (Coon Butte) gave a most impressive illustration of the largeness of the energy dispersed in the form of side thrusts, of lateral scattering of material, of outward radial dispersion by the violent reactive explosion that followed the impact, and of cooling in the act of dispersion as shown by the vesicular state. On the other hand, the meagerness and evanescent nature of the melting was equally surprising.[4]

According to the planetesimal hypothesis, the material for the formation of the earth was erupted from the sun under the stimulus of a passing body which drew the projected matter into orbital courses while in its flight. To be conservative let us assume that the erupted mass of solar gas had only twice the diameter of the present dense earth. The central mass of this matter would normally be projected vertically or radially from the sun's center, and at the same time, as it issued from the sun, would be subject to gaseous expansion, while it would also be affected by eruptive dispersion and by internal motions which would have a dispersing effect in general. The values of the expansional and dispersive effects are matters of estimate, but it is easy to follow rigorously the vertical projection of the central part. The distance projected from the surface of the sun was roundly 215 times the distance of the erupted mass from the center of the sun when it started; hence the diameter of the erupted mass when it reached its orbital distance would have been 430 times the diameter of the present earth. To catch the meaning of this, we must now consider the power of such a mass to control itself against the competing attraction of the sun, *for this power of self-control determined the size and mass of the collecting nucleus.* No power of self-control would develop in the erupted mass until after it had passed outside the Roche limit of the sun. At the distance of the earth the sphere of control *of the present full-*

---

[4] Diastrophism and the Formative Processes: XIII. The Bearing of the Size and Rate of Infall of the Planetesimals on the Molten or Solid State of the Earth, Jour. Geol., vol. 28, pp. 686-95, Nov.-Dec., 1920.

grown earth is 194 diameters of the earth. The sphere of control of the self-controlled portion of the erupted mass obviously could not have been so large as this. Taking the ultra-maximal sphere of control as a working basis to give a margin of safety, the volume of the erupted mass due to radial dispersion simply—430 times the earth's diameter—compared with the volume of the present sphere of control—194 times the earth's diameter—shows that less than one-tenth of the erupted mass lay within even the ultra-maximal sphere of control. To this dispersion should be added the dispersive effects of gaseous expansion and of eruptive scattering. Over against these additional dispersive factors there is only the allowance to be made for the inward curvature of the projected constituents due to their mutual gravity during their swift short flight under the projectile forces.

I think that every competent reader will see that, without laying stress on any factor that depends upon personal judgment, the collecting nucleus would only have included a minor fraction of the projected matter. The rest must have gone into independent orbits from which collection by orbital dynamics would have been very slow and the development of a holomolten state of the earth quite out of the question.

It thus appears clear to the point of practical demonstration that a molten state would not arise normally under the terms of the planetesimal hypothesis, and that the attempt to graft such a state on the hypothesis merely gives rise to an incompatibility, not to an issue.

Contrasted views of rigidity.—It has thus taken much space to clarify the issues projected in the Introduction before any semblance of real review began, but another such projection immediately follows relative to the meaning of rigidity, as follows:

> "The term 'rigidity' has been generally loosely interpreted. Rigidity is dependent not only on the stress applied but upon the time the stress is applied. A material may be rigid for one set of stress conditions and non-rigid for another. . . . . Rigidity, then, is merely a relative term."

There is just enough of truth and of misconception in this to make it very misleading. Two things are easily confounded: (1) the *property* of rigidity whose values are usually given by geo-physicists in terms of "*constants* of rigidity," and (2) the *effects* of stresses brought to bear on *bodies* possessed of this property, which may be as various as the imagination chooses to make them. In considering the effects of stresses of course the time of continuance of the stress is important. But before entering upon discriminations, let us clear away the impression the reader is quite likely to get from the stress laid on the alleged variability, that here is something of importance not known to us—and perhaps not to the reader: In the very article under criticism and on the very subject of the *relations* of the more mobile, more deformed parts of matter undergoing diastrophism to the less mobile, less deformed parts, under conditions of differing depths, R. T. Chamberlin says:

> "No limiting depths can be assigned, for the time-element plays an important part, though not easy to evaluate. To quick-acting stresses the earth reacts as an elastico-rigid body; under long-continued stress it yields to slow movement. With greater depth molecular rearrangement and recrystallization should presumably take precedence" (p. 418).

Now the vital question is not what *might* happen under imagined conditions of stress, but *what is the real state of the earth's matter as revealed by three independent lines of evidence interpreted in the light of the stress-conditions, time-conditions, pressure-conditions, temperature-conditions, and other conditions that actually exist, in great variety, in the earth.*

This state of the earth substance is what I have emphasized in my papers. I have referred to the state of the internal matter as elastico-rigid—or some equivalent of this double phrase—with a uniformity and persistency that has made it wearisome to my friends and myself because such reiteration seemed necessary to avoid the ambiguities that cling about the colloquial term "rigidity." I have tried to use the compound term strictly as a definition of the *properties* imparted to the matter under consideration by its constitution. I think this is at least not at variance with established scientific usage. At any rate, my use is definite and requires recognition in a critical review, whether approved or not. The important point is to keep clear the distinction between the elastico-rigid state and the viscous state. The essential considerations in the former state are *fixed attachments* of the constituents to one another at *particular points* by a force which *resists displacement,* attended by a *reacting elastic force* which tends to *restore* any displacement that may take place. There is thus implied a resisting-yielding-restorative combination. In the viscous state displacement also requires force but displacement is not followed by restorative action. The elastico-rigid state is not, as its name clearly indicates, a state of "absolute" rigidity, but one of *elastic yield.* It thus becomes the basis for certain typical modes of deformation and even of continuous movement under differential stress, as in the case of glacial motion and solid rock-flow as now interpreted by the most critical students of these fields.

In my serial paper on the self-compression of the earth[5] —which, as my only paper as yet built on the "groundwork," should be taken as the chief index as to what "the study of megadiastrophism is to be"—I have cited the lucid illustration of this property offered by the electromagnetic poles developed by the revolution of electrons about positive nuclei. Attachment by minute intense poles of this type affords an ideal picture of fixation at particular points conjoined with a restorative force. This is probably the actual mode of formation of the elastico-rigid state, but as it may be premature to insist upon this, let it serve merely as a clear-cut index of the type of view held.

Now this is a very different picture from that which my critic paints for me. As already stated he seems to me to confound the *effects of possible stresses not necessarily connected in any way with the organization* of the matter, with the *properties* of the matter arising from the mode of its organization. A spring balance is an illustration of an elastico-rigid mechanism, but the properties of the balance belong to one category while the varying strains of commodities put on it to be weighed belong to a different category. A modern steel bridge is a rigido-elastic structure, but examining engineers are accustomed to report its properties in fixed terms, not in variables dependent on the stresses of a hand-car or a freight train

---

[5] Diastrophism and the Formative Processes: XV. The Self-Compression of the Earth as a Problem of Energy, Jour. Geol., vol. 29, pp. 679-700, 1921.

that may happen to be crossing it. Expert geophysicists give the earth-qualities under discussion in terms of "*constants* of rigidity" and "*constants* of elasticity."

The summary characterization of Chamberlin's views.—Immediately following his exposition of rigidity from "the relative viewpoint," and without quoting a sentence from the paper announced as being under review, or adducing evidence of any other kind, the reviewer proceeds to characterize my interpretations as follows (p. 396):

> "Now Chamberlin's interpretation of the evidences of this rigidity—that is rigidity shown under tidal stress and seismic vibrations, implies that this state of rigidity and elasticity holds good for stress differences of all magnitudes and of all time durations. Under this interpretation the terms rigidity and elasticity become practically absolute instead of dependent. But such an interpretation is essential if he is to postulate the non-existence of a yield state anywhere within the earth for almost any condition of stress" (p. 396).

This is a very remarkable statement. It does not represent, or even resemble, any thing stated in my paper on the groundwork for the study of diastrophism, or in any of my diastrophic papers. I have not the slightest thought of postulating "the non-existence of a yield zone anywhere within the earth for almost any condition of stress." On the contrary I postulate yield everywhere. My views of yield and movement in elastico-rigid matter, in the mooted case of glacial motion, have been outstanding for more than twenty years.[6] My views on such action in megadiastrophism are definitely indicated and concretely illustrated in my serial paper next following that on the "Groundwork."[7] By reference to that paper, it will be seen (1) that the need of a revision of fundamental ideas of the constitution and behavior of matter in accordance with the new disclosures is put to the front; (2) that these imply a dynamic organization as open relatively as a planetary system and hence responsive to all stresses; (3) that these revelations afford a concrete con-

---

[6] "Glacial Studies in Greenland," Presidential Add., Geol. Soc. Am., vol. 16, pp. 209-14, 1895.

[7] The Self-Compression of the Earth as a Problem of Energy, Article XV of the series Diastrophism and the Formative Processes, Jour. Geol., vol. 29, pp. 679-700, Nov.-Dec., 1921.

cept of the yielding nature of the elastico-rigid state of matter; (4) that the relations of crystalline organization to atomic and molecular organization is more intimate than appeared under the old view and hence the crystalline state is more fundamental and presumably more pervasive than heretofore supposed; (5) that the proportion of heat energy in the earth to the organizing and maintaining energies has been greatly exaggerated; (6) that the new concept of an open dynamic structure clears away many of the seeming obstacles to idiomolecular action; and (7) finally, a concrete sketch is given of the way in which idiomolecular readjustments act under relatively low stresses in producing deformative movement without involving the liquid state. The whole working concept has the nature of indefinite capabilities of compression, deformation and metamorphism by means of a system of interchanges facilitated by the open revolutional mechanism of the constituent atoms, and molecules. *It is therefore responsive to every force brought to bear upon it. It is a yield system par excellence and yet a resisting system of the dynamic type with fixed forms.* With such a basal view, it is impossible for me to entertain such notions of intractability as those assigned me.

Substitution of part for the whole.—It seems necessary to take notice of another phase of this statement relative to my views, to wit:

> "Now Chamberlin's interpretation of this rigidity—that is the rigidity shown under tidal stress and seismic vibrations, implies," etc.

This naturally carries the impression that my interpretation of rigidity has been based solely upon tidal stresses and seismic vibrations, whereas in the very first specification of the paper professedly under critical review, I mention in addition to tidal and seismic evidence, "*nutation and collateral evidences.*" The following from the paper just cited shows the way in which I usually put my view:[8]

> "Tidal[9] and nutational[10] evidences concur in indicating a

---

[8] Diastrophism and the Formative Processes: XV. The Self-Compression of the Earth as a Problem of Energy, Jour. Geol., vol. 29, pp. 691-92, 1921.

[9] A. A. Michelson and Henry G. Gale: "The Rigidity of the Earth," Jour. Geol., vol. 27, pp. 585-601, 1919.

[10] W. Schweydar: "Ueber die Elastizität der Erde," Naturwissenschaften, Part 38. Potsdam, Germany, 1917.

higher degree of rigidity and elasticity in the interior, taken as a whole, than in the outer shell. Seismic waves add very specific confirmatory evidence, so far as the outer seven-eighths of the volume of the earth is concerned. The seismic evidence for the remaining central part is as yet obscure, and is differently interpreted by the special students of the subject. In a general way, the whole of the interior is covered by the tidal and nutational evidences. These favor the interpretation of the central part as highly rigid and elastic, since these qualities fit the general import of the evidence, but for the present it is prudent to leave the question of the state of the center to be settled in the future. It is to be observed that the increasing density of the interior tends to dampen the speed of the seismic waves, and that correction for this effect must be made in deducing the inward increase of rigidity and elasticity from the seismic records. When allowance is made for this, the generalization that rigidity and elasticity are notably higher in the interior than in the outer shell is put beyond serious question.''

Now a special significance attaches to nutation in *the combination of evidences* because much emphasis has been laid on the shortness of the seismic and tidal vibrations and the *possibility* that they might not mean much. The Chandlerian cycle of the nutation has a period of about 14 months (432.8 days according to Schweydar).[11]

Now I think that the reader will agree that, in view of this putting of a part for the whole and of the assignment of ideas of wedges and rigidity quite foreign to my own, I am entitled to disclaim any responsibility for such other views as my critic may assign me in the rest of the paper, and that it is best that I should use what space remains available in discussing some of the more vital issues raised. Foremost among these is the question, rendered acute by the criticism:

What is really implied by the properties of rigidity and elasticity disclosed by seismic waves, the body tides, the earth's nutation and associated evidences?

The elastic rigidity disclosed by the seismic waves.—Setting aside the earth's nucleus for later consideration, there is agreement among seismologists that the outer portion of the earth to a depth of 3000 kilometers or more transmits transverse or distortional seismic waves and that this implies an elastico-rigid state. So far as the

---

[11] Op. cit.

seismic vibrations themselves are concerned, they simply show the presence of the elastico-rigid property under existing conditions. They tell nothing directly as to what might or might not be the state of the interior under other conditions. As a first step toward reaching the wider meaning we must consider what the existence of the disclosed state of rigidity and elasticity signifies under all the heat, pressure, differential stress, and coöperative influences that now affect the outer seven-eighths of the earth's body. We must bear in mind further that these conditions are inherited from a previous chain of conditions that ran back as far as geologic inheritances go, and that this brings in the effects of the time factor. Now looking at the matter from the positive or constructive point of view, the case may be put this way:

The outer seven-eighths of the earth is to-day elastico-rigid—to a degree not determined by the seismic waves—notwithstanding all the heat, all the pressure, and all the differential stresses within it, together with all coöperating effects, as also any help that may have been inherited from past geologic time.

Or, from the negative or destructional point of view, the case may be put in this way:

All the differential stresses in the outer seven-eighths of the earth's body, all the heat and pressure in this part, and all coöperating effects, together with any help that may have been inherited from past geologic time, have not proved sufficient to destroy the elastic and rigid properties of this part of the earth.

Now these existing conditions are not simply those that prevail at some one horizon but those that exist in all parts of the outer body of the earth. *They undoubtedly include stress-differences of quite different orders of magnitude, some of which are presumably high.* Their significance, therefore, is not to be escaped by academic assumptions about dependence.

The seismic waves have a peculiar value in that they search out the special states of matter in the various parts of the interior. Their cumulative evidences have now practically shut out the molten state from serious consideration in present-day problems, such as the asthenozones, the loci and methods of magmatic generation, etc.

The rigidity and elasticity disclosed by the body tides.—The body tides are simply the yielding and restoration of the earth in response to differential stresses from the moon and sun. The quick restoration to form implies a high state of elastic rigidity. The evidence in this case differs from that of the seismic waves in that the tidal oscillation shows that the earth's action *as a whole* is that of a highly elastic rigid body under existing conditions. The periods of action are also longer than those of the earthquake vibrations but still relatively short.

Now, as before, the body tides show the existence of the properties of rigidity and elasticity in the earth acting as a whole in spite of all effects of the earth's present temperatures, pressures, differential stresses and inherited effects.

The rigidity and elasticity disclosed by the nutation of the earth.—Nutation may be regarded as a third line of testing or sampling the rigidity and elasticity of the earth. Like the tides, it discloses the response of the earth as a whole to differential stresses, but it supplements the testimony of both tides and seismic vibrations in an important way because its changes of stress are slow and the oscillations long, the period of the Chandlerian cycle being about 14 months; besides which there is an annual cycle, and some deviations that imply other slowly changing stresses. Now the significance of the properties of rigidity and elasticity under these slower stress actions is to be interpreted, as before, *in the light of all existing temperatures, pressures, and stress differences now affecting the earth.*

We have thus three lines of independent testimony, differing in kind and in period, and *yet none of them has revealed the limits of the elastic and rigid properties.* It falls to anyone who *assumes* any specific limits to give the evidence of such limits, or frankly acknowledge that his assumptions are simply speculative.

By correlating these three lines of evidence with other data, as has been done by Schweydar, rather definite quantitative values may be reached. Schweydar concludes that the constant of rigidity of the earth is 3×10^{11}

dynes at the surface and 30×10^{11} dynes at the center, with a mean rigidity of 2½ times that of steel.[12]

What follows the rigid-elastic state when the strain limit is passed?—It has now been amply shown by protracted researches on glacier motion, solid rock-flow and dynamic metamorphism, that while the viscous state and even liquefaction *may,* in particular cases, follow when the strain limit is reached, and also that faulting, granulation, or massive shear may follow in others, the more widely prevalent, more characteristic and more fundamental sequence, when the pressure is not over-intense and the time is ample, is *the passage of one elastico-rigid state into another elastico-rigid state.* The new state is often more perfectly and highly organized in respect to the elastico-rigid property than the previous state. Thus movement may go on to great lengths, in time, simply by this succession of solid states, as in the case of glacial flow and dynamic metamorphism. *The earth seems to be progressively passing into more and more highly organized states of elastic rigidity,* or in other words, metamorphism is in progress in the solid earth. This change seems to be effected largely by *idiomolecular* action, *i.e.* individual action atom by atom or molecule by molecule. The main mass remains solid while the shifting atoms or molecules act as *individual elastico-rigid organizations.* And further, even this individual action is not necessarily, and perhaps not normally in the depths, liquid action, nor gaseous action, for liquids and gasses are *assemblages* of molecules, while these shifting atoms or molecules act individually. As such individuals, they are, under the new views, elastico-rigid mechanisms of an ideal type. In being individually detached from its hold on one crystal or particle, the atom or molecule is probably shot through the dynamic—not bodily—resistances of the space lattices or equivalent opennesses, until it is arrested and oriented by a new fixed attachment. The rigido-elastic arrangements of the countless atoms and molecules in the solid earth body are held to be giving way as differential stresses rise to the requisite degree, and thus to be passing from old to new relationships. Thus a "flow" like that known to affect glaciers and rocks under-

---

[12] W. Schweydar; "Über die Elastizität der Erde," Naturwissenschaften, Part 38, p. 22, 1917, Potsdam, Germany.

going dynamic metamorphism is probably in constant progress in the earth. This, however, does not seem to be adequate to relieve all increases of stress, and so accumulations arise and bring on special stages of diastrophism of a more vigorous type.

The state of the earth nucleus.—So far, to avoid complication, the state of the earth's nucleus has been neglected. As already stated in a quotation from my last paper,[13] *it is necessary to correct the velocities of the seismic waves for density to give the full state of rigidity and elasticity.* If such correction is applied to the best data now available as to the velocities of the seismic waves, it shows *a rise of elastic-rigidity as far toward the center as good records go.* The necessity for this correction seems to have been overlooked by those who have inferred the existence of a state of non-rigidity near the center. If question is raised about the trustworthiness of the correction, it may be recalled that the mean density is much higher than the surface density and that the precession of the equinoxes implies higher density in the deep interior. To satisfy these approximately, correction may be made by use of the classic law of density of Laplace, or still better, it may be made by means of the formula of Roche which was devised especially to give a distribution of internal density in as close accord with the astronomical requirements as possible.

The dying out of the distortional waves when the chords get so long as to cut the radius about half way from the surface to the center has been much stressed recently as though it were evidence that rigidity ceases at about that depth, but the ways in which *both* transverse and longitudinal waves become feeble and die out as the chords lengthen, puts another aspect on the matter. They must die out sooner or later in the nature of the case. It is remarkable that they are able to traverse as long chords as they do. The fact that *both* kinds of waves die out in traversing chords much short of the diameter of the earth seems to point to their natural death by progressive exhaustion. The brachistochronic chord of 140° is about the extreme limit of penetration by the longitudinal waves, while the similar chord of 110°-

---

[13] Diastrophism and the Formative Processes: XV. The Self-Compression of the Earth as a Problem of Energy, Jour. Geol., vol. 29, pp. 679-700, 1921.

120° is about the limit for the transverse waves. Both kinds give increasingly imperfect records as their penetrations become great, but not equally so. The longitudinal waves have a speed about fifty per cent greater than that of the transverse waves, evidence that they are actuated by a more effective elasticity—that of volume—than are the distortional waves, which depend on elasticity of form. It seems logical, therefore, that the longitudinal waves should maintain themselves longer than the transverse waves. As a matter of fact they do not retain their integrity as much longer than the transverse waves as might be expected from their superior velocity. They grow feeble and doubtful progressively as do the distortional waves, and at the depth where the latter cease to be identifiable they have already become dubious. If the distortional waves were strong and gave good records uniformly up to a certain depth and then suddenly ceased, while the longitudinal waves continued on and gave good records up to 180°, the inference of a change from the elastico-rigid to a viscous state would at least be plausible, but as the case now stands, such an interpretation does not seem to be the natural one. This does not invalidate the view of Oldham that there is a change in the nature of the material at about the half-radius depth, for this is compatible with a solid state.

The correction of the seismic records for density brings the seismic evidence into general harmony with the tidal and nutational evidences and makes the presumption strong that rigidity and elasticity increase from the surface to the center as held by Schweydar.[14] The following quotation from Walker, a seismologist who had unusual experience with instruments and records, lies in the same line:

> "At the present time the evidence in favor of a solid earth is very great but the alternative view that the interior of the earth is fluid retarded for a considerable time the progress of seismological theory which requires the earth to possess the properties of an elastic solid. As astronomical theory agrees with the seismological in demanding a solid earth, we accept this as a primary condition." [15]

---

[14] W. Schweydar: "Über die Elastizität der Erde," Naturwissenschaften, Part 38, 1917, Potsdam, Germany.

[15] G. W. Walker, Modern Seismology, p. 13. (Longmans, Green and Co., London, New York, Bombay and Calcutta, 1913.)

The separation and transmission of seismic vibrations.—My critic makes the claim that the texture of an accretional earth would not be capable of transmitting seismic vibrations, and that an ''isotropic'' medium is necessary for the *separation* of the vibrations. Specifically he says:

> ''The two types of waves travel at different velocities but can only become distinctly separated out in a homogeneous medium; that is, homogeneous as to stress effects, or, in other words, isotropic. The resultant vibrations which travel circumferentially from the shock center pass through what we know is a heterogeneous medium. The wave types are not separated in the earth's surficial shell'' (p. 398).

The waves here spoken of as ''resultant vibrations,'' and elsewhere as ''undifferentiated,'' are, as I understand, the long waves. The medium necessary to the separation is later spoken of as ''a non-crystalline isotropic material similar to 'undercooled' liquids'' (p. 399).

I understand the facts and their natural interpretations to be these:

That the seat of the earthquake, the point of origin of all the seismic waves, lies within the shell not very far below the surface; that the vibrations generated there are very heterogeneous and mixed in the utmost confusion; that these vibrations are propagated at different speeds strictly because of their natures and their relations to the elasticity of the transmitting earth substance; that they are separated *as a necessary effect of their different velocities;* that the separation is not dependent on any mysterious virtue of an isotropic medium or any 'undercooled' liquid; that they separate *in any medium that is capable of transmitting them;* that there is no special separation but merely a progressive separation as long as they keep going; that *all known types* are transmitted through the *shell* and undergo progressive separation while being so transmitted; that nothing is known of waves that cannot be transmitted through the shell; that the longest, most abundant, most conspicuous, best defined, most notably organized, most far-penetrating and scientifically most interesting waves, the undæ longæ and the coda, are transmitted *by the shell;* that these are sometimes so well transmitted that they are recorded at stations from both circumferential directions, one of which of course is usually more than 180° from the point of origin; that the primary (longitudinal) and secondary (transverse) waves are very inconspicuous features of the seismograms as such—though extremely interesting as evidences of the state of the interior;—that their courses are far shorter than those of the long waves; that even these transmitted waves are not perfectly separated but are attended sometimes by irregular or adventitious waves to such an extent as to embarrass their interpretation (Walker); that they are weakened as they penetrate the interior material to greater and greater distances until both types die down beyond distinct identification; that this takes place before their penetrations reach the diameter of the earth; and that therefore there is no substantial ground for postulating any special separating substance, "undercooled liquid" or otherwise.

The fatalities of the molten theory.—Among the evidences from various sources relative to the doctrine of a molten earth, this singular effort to fill the interior with non-crystalline material similar to "undercooled liquids," the effort to divorce rigidity and elasticity from crystallinity by the overstrained affirmation that "It is evident that both rigidity and elasticity are totally independent of crystallinity" (p. 397), the disparagement of the evidences of elastic rigidity and similar strained efforts, are tokens of the desperateness of the endeavor to stem the tide of calamity that has been sweeping so mercilessly over the molten theory in recent years. First came the ancient glaciations in surprisingly low latitudes, those of the late Paleozoic in the lead, and then those of the very early Paleozoic, followed by those of the Proterozoic, which together swept away all climatic evidences of an early hot stage. Almost hand in hand with the adverse testimony of ice invasions, came the loss of the basal credentials of the theory. The early advocates of the molten theory were able to point with much show of cogency to the great granitic embossments so often found lying under the fossiliferous series as direct testimony to the light acidic layer of igneous material postulated as the outer zone of the molten earth, but the field studies of the last few decades have shown that these granitic masses are batholitic intrusions into older sedimentary deposits and are no more evidence of an original molten state than the great granitic intrusions of Jurassic age along our western coast, as recently remarked by Coleman.[16] And then came radioactivity and robbed the molten theory of almost its only resource for actuating diastrophism, viz.: the cooling of the earth; while close on the heels of this came the seismic waves and their allies which are now heaping up irrefragible evidence that, if there ever was a molten state, it is now a thing of the past, and that the great dynamic problems of the day, diastrophism, metamorphism, asthenozones, magmatic generation, vulcanism, isostasy, paleogeography, and the like, must all be worked out on the basis of a solid elastic earth. If the molten earth is an issue at all in present day problems, apparently it can be only in the sense of an issue over the estate left behind by the departed.

---

[16] A. P. Coleman, Nature, vol. 109, p. 775, June 17, 1922.

University of Chicago,
July 19, 1922.

Art. XXVII.—*Relation of Sea Water to Ground Water along Coasts;*[1] by John S. Brown.

Contents.

Introduction.

Coastal ground-water problems:—The water from wells and springs near seacoasts is often salty. On most coasts saltiness due to sea-water is limited in shallow wells to a narrow zone, usually a few hundred feet in width, near the shore, but at some places it extends much farther inland. Many wells near the shore encounter fresh water near the surface and salt water at greater depths. Pumping plants often yield salty water, especially after long-continued operation at a high rate. The circumstances of contamination by sea water are modified greatly by the kind of rocks and their structure and by the topography adjacent to the shore, as well as by climatic factors.

Scope of field work.—In 1919 the writer made a study of the groundwater resources of the New Haven area, Connecticut.[2] This area includes a section of the coast of Connecticut, lying east and west of New Haven, which will be referred to hereafter as the New Haven coast. The length of this section is 30 miles in a straight line, but owing to small irregularities, the actual coast line is much longer than 30 miles. This work afforded a particularly favorable opportunity to observe some of the conditions under which ground water is contaminated by sea

---

[1] Published by permission of the Director of the U. S. Geological Survey. The illustrations were prepared by the Survey.

[2] Brown, John S.: Ground water in the New Haven area, Connecticut, U. S. Geol. Survey Water-Supply Paper [awaiting publication].

This work was done in co-operation with the Connecticut State Geological and Natural History Survey, under the direction of Herbert E. Gregory.

water.[3] Some valuable information also was obtained during a few days spent on the coast of Florida in April, 1920.

Previous investigations.—In the United States many geologists and engineers have described contamination of ground-water by sea water, and a few writers have discussed at some length phases of the problem incidental to other investigations. However, there has been no systematic investigation of the problem or serious attempt to assemble and apply the data already published. In Europe, the denser settlement and more intensive development of water supplies caused the problem to be recognized earlier, and in Holland, Belgium, France, and Germany many data have been collected and numerous papers published on the subject. The present writer has used the published material to supplement the information obtained on the New Haven coast and confirm the conclusions reached.

Methods of investigation.—In the course of this investigation a geologic map of the region was made. Records of wells, springs, and pumping plants and details of their construction, use, and operation were collected. Topographic features were noted carefully. In order to determine the degree of contamination by sea water many samples of water were analyzed. As in many previous investigations, the chloride[4] content of the samples has been used as the chief criterion for determining the presence or absence of sea water. Chloride is not always a reliable indicator of contamination by sea water, for it may come either from salt in the rocks or from sewage and factory wastes. The rocks of Connecticut, however, yield very little salt, and in areas free from polluted drainage the ground water contains but little chloride,—in fact, 10 or 12 parts per million is usually the maximum quantity present from both these sources.[5] In this investigation, it was generally possible to tell from the surroundings whether chloride from sewage or waste was to

---

[3] A complete report, of which this paper is a summary, entitled "A study of coastal ground water, with special reference to Connecticut," is to appear as a Water-Supply Paper of the U. S. Geological Survey.

[4] The term chloride is used here to denote the chloride radicle (Cl).

[5] See Jackson, D. D., The normal distribution of chlorine in the natural waters of New York and New England: U. S. Geol. Survey Water-Supply Paper **144**, 1905.

be suspected, and samples collected where the circumstances seemed to indicate such pollution were rejected. A small assay kit was carried in the field for the purpose of making approximate determinations of chloride, but check samples were sent to the water laboratory of the United States Geological Survey for analysis. The laboratory analyses are given in this paper.

Sketch of the New Haven coast.—The New Haven coast is a ''drowned coast'' and is consequently very irregular in outline. There are large areas of flat tidal marshes and in some places many small islands near the shore. Portions of the coast have been cut away by waves, and other portions have been built up. Spits and bar beaches are common features.

The bed rocks of the New Haven coast consist mainly of gneiss and schist. At most places they are concealed by glacial drift, which is generally not more than 30 to 40 feet in thickness, but portions of the coast are bare and rocky, and small exposures of bedrock are common over much of the region. The drift consists of till and stratified drift. The till is generally variable in composition and texture and is in places somewhat clayey. The stratified drift has been re-worked by water and is usually clean, well-bedded sand or gravel. It is confined mainly to the valleys and certain low coastal plains of small extent. Besides these formations there is a recent deposit of black, slimy mud which covers the bottom of New Haven Harbor and the tributary tidal estuaries and whose thickness probably does not exceed 25 or 30 feet.

Occurrence of ground water.—In the bedrocks ground water is held mainly in open fractures, such as joints and cleavage planes, and the water table is irregular. In the stratified drift, which is very porous, the water table is in general fairly smooth and stands but little above the level of the sea or above adjacent streams. In the till, owing to its varying porosity, the water table is irregular, but usually water is found within a few feet of the surface.

Sea water in shallow wells.

Most of the shallow wells on the New Haven coast are either dug or driven and are less than 30 feet in depth. More than half of them penetrate stratified drift. The table below shows the number of wells examined in several successive zones parallel to the shore and the number and percentage of wells contaminated by sea water in each zone. Three degrees of contamination, based on an arbitrary scale, are distinguished—"trace" (from 25 to 100 parts per million of chloride), "moderate" (100 to 300 parts), and "high" (more than 300 parts). More than 300 parts per million of chloride is generally apparent to the taste. For a few wells where samples could not be obtained, positive statements of reliable persons have been accepted as evidence of contamination.

Contamination by sea water in shallow wells on the New Haven Coast.

Limits of zone in feet from high-tide shore line.	No. of wells in zone.	No. of wells contaminated in different degrees.			Total No. of contaminated wells.	Percentage of contaminated wells.
		High.	Moderate.	Trace		
0- 25	13	4	2	3	9	69
26- 50	17	1	2	5	8	47
51-100	35	2	6	6	14	40
101-200	23	1	4	2	7	30
201-500	31	0	0	1	1	3

The above table summarizes very briefly a large mass of data from which the conclusion is drawn that on the New Haven coast the zone in which the shallow ground water is contaminated by percolation or diffusion of salt water is very narrow. The greatest distance from the shore at which even slight contamination is suspected is 250 feet.

Similar conditions were observed at Cedar Keys, Fla., where the annual rainfall is very nearly the same as at New Haven and where the ground is sandy, comparable to the stratified drift of Connecticut. At Cedar Keys open pits are often constructed on the beaches of small islands to furnish water for stock (fig. 1). The water of the pit shown in fig. 1 contained 516 parts per million of chloride but was usable for stock. Water in a similar pit 120 feet from the reach of normal high tides contained only 92 parts per million of chloride. Of six wells in a zone between the limits of 125 and 350 feet from the high-tide shore line, two were slightly contaminated and in another salt water apparently was induced by heavy pumping.

From the evidence set forth above and that given by other writers the conclusion seems warranted that sea water mingles with the shallow ground water over only a narrow area near the shore line. Wherever the natural conditions are disturbed, however, as through a heavy drain on the ground water by pumping, conditions are immediately altered and sea water may be drawn great distances inland. Also, although data on the matter are lacking, it would be logical to suppose that on arid coasts, where the rainfall is insufficient to maintain a body of ground water, sea water would penetrate a much greater distance inland than in humid regions. Undoubtedly, too,

Fig. 1.

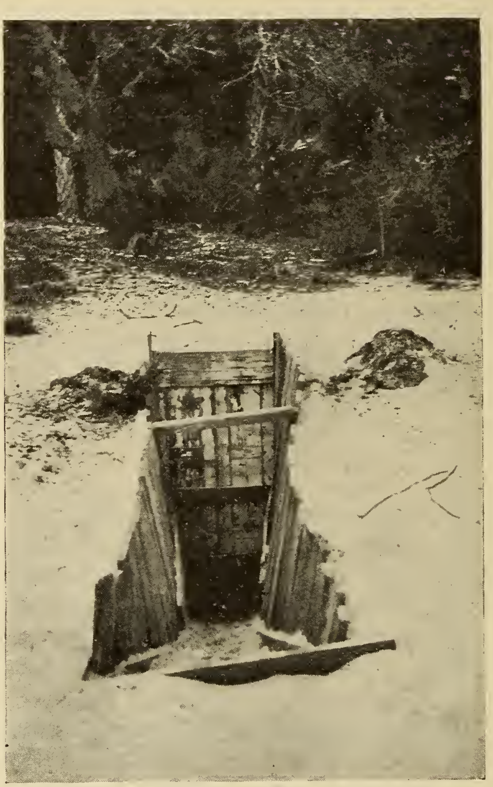


Fig. 1.—Open water hole yielding fresh water on the beach of a small island near Cedar Keys, Fla.

the penetration of salt water inland is affected by the character and structure of the rocks along the shore. As just indicated on sandy parts of the Florida coast fresh water saturates the ground almost to the shore line. Yet Sanford[6] says that the main Florida Keys, which are composed chiefly of limestone very full of seams and crevices, "may be underlain by salt water about at tide level; this is the condition in islands as wide as 3 or 4 miles in the Bermudas and also on many Florida Keys."

Sea water in deeper, drilled wells.

Most of the deeper wells on the New Haven coast were drilled with the percussion type of drill rig and are 6 inches in diameter. Wells from 100 to 300 feet deep are fairly common as sources of domestic supply. A few wells of greater depth have been drilled by manufacturing concerns in the hope of obtaining industrial supplies, but most of these have been failures because the quantity of water was insufficient or its quality was unsatisfactory. Out of 29 wells examined, 10 were definitely contaminated by sea water and 2 others probably were slightly contaminated. Moreover, as wells that yield bad water are generally abandoned and forgotten, and their records are almost impossible of verification, the ratio is really higher. It is not unlikely that half the drilled wells in a zone a few hundred feet wide along the shore are more or less contaminated.

Nearly all the drilled wells on the New Haven coast penetrate bedrock and draw their water from open joints and crevices. The possibility of obtaining water at all in the crystalline rocks is difficult of prediction, and the likelihood of obtaining salt water in deep wells is doubly uncertain. One well very near the shore may penetrate crevices connected only with the fresh ground water and yield water of good quality; another may penetrate crevices connected with the sea and yield only salt water. Undoubtedly the danger of obtaining salt water increases rapidly with the depth of drilling, and once salt water is struck there is very little chance of finding fresh water at greater depth. The distance inland at which salt

---

[6] Matson, G. C., and Sanford, Samuel: Geology and ground waters of Florida, U. S. Geol. Survey Water-Supply Paper 319, p. 261.

water may be expected in deep wells on the New Haven coast probably does not exceed 500 feet at most places, because of the fact that a few hundred feet below the surface water-bearing fractures in the bedrock are practically absent and there is very little circulation of ground water. The safe ratio of depth of well to distance from the shore is difficult to estimate but is placed at about 1 to 1—that is, a well 100 feet from the high-tide shore line should not be drilled more than 100 feet below sea level if any fresh water has been obtained above that depth.

On many coasts where geologic conditions are unlike those in Connecticut impervious beds seal out salt water from underlying strata containing fresh water. This is particularly true of coastal plains, such as our Atlantic Coastal Plain, where alternating sedimentary beds of different kinds dip seaward at low angles. This condition is exhibited on a small scale, in New Haven Harbor (see beyond).

Effect of special topographic and geologic conditions.

Tidal marshes:—Very few wells are sunk within the limits of tidal marshes, but from such information as was obtained the conclusion seems warranted that most of the tidal marshes contain brackish ground water. As a rule the salinity of this ground water is much less than that of sea water, because the tidal water that overflows the marshes is diluted by fresh water from streams as well as directly by rainfall. In many places the underlying ground water is further diluted by ground water from adjacent areas. In the more or less stagnant marshes, such as those of Milford, Madison, and Clinton, which receive but little inflow from streams and are separated from the sea only by low, narrow strips of land, the ground water probably is very saline. They may be compared to the sea of Haarlem, in Holland, where salt water rises nearly to the surface. (See p. 286.) In narrow tidal marshes along river estuaries the ground water is much fresher.

Bar beaches and spits.—It appears from all the evidence obtained that the ground water of bar beaches and spits is salty. Probably the water table sinks so low at low tide, because of the extreme porosity of the sand, that at high tide there is a distinct influx landward of salt water. High storm waves sometimes completely overtop the bars and spits, thus undoubtedly saturating them with salt water. On unusually high and wide spits a small amount of usable water might be obtained by shallow wells located as far as possible from the sea. However, the ground water doubtless becomes exceedingly saline at no great depth below the water table on most of these areas.

Islands.—Conditions on islands do not appear to differ materially from those on the mainland except where the available intake for ground water is exceedingly small. The nature of the land surface and of the rock composing the island are factors of importance in influencing the character and quantity of the ground-water supply. A covering of till or of stratified drift promotes absorption of rainfall and equalizes the supply of ground water reaching the water table, whereas bare rock surfaces promote run-off. It seems from all the available evidence that good water, in small quantities, may be obtained even on very small islands where there is a cover of till or stratified drift. An island having an area of an acre, or about 250 feet in diameter, usually will supply enough water for an ordinary household. The supply increases with the size of the island, though probably in considerably greater ratio, as the relative losses about the perimeter become smaller.

Effect of bedrock fractures.—Sea water enters wells that are dug or drilled in bedrock near the shore through fractures. Clapp[7] suggests that in certain contaminated wells on a peninsula in Maine the sea water enters at the side of the peninsula farthest from the wells, because the cleavage of the rocks dips from that side toward the wells. From the evidence on the New Haven coast it seems reasonably safe to assume that a high degree of fracturing in the bedrock on the shore increases the chances of sea water entering wells near by, and that the trend or inclination of fractures toward a well may also be of importance, but only as indicating the greater like-

[7] Clapp, Frederick G.: Underground waters of southern Maine, U. S. Geol. Survey Water-Supply Paper 223, p. 67, 1909.

lihood of the existence of a fracture connecting the well with the sea. There is no apparent reason why cleavage planes dipping toward a well will admit water much more rapidly than a series of connected fractures. It is difficult to evaluate the effect of fresh water fed to a well by fractures. If the supply is considerable and the water is under sufficient pressure sea water will be excluded under conditions that otherwise would readily permit it to enter the well.

Artesian conditions in New Haven Harbor.—The blanket of mud that forms the most recent deposit on the floor of New Haven Harbor and its tributary tidal marshes acts as an effective impervious stratum and excludes the salt water of the harbor and the marshes from the sands of the stratified drift beneath. The main features of the New Haven artesian system are illustrated by figure 2. The sands beneath the mud average 100 to 200 feet in thickness and are, at least for the most part, filled with fresh water. The wells of Sperry & Barnes, which are on filled land nearly 1,000 feet south of the original high-tide shore line, draw comparatively fresh water from the sand beneath the fill and the mud. In a test well of Sargent & Co., 660 feet south of the original water front, fresh water was obtained beneath the mud at a depth of 110 feet. The plants of the New Haven Gas Co. and the National Folding Box Co. use wells on the filled-in tidal marshes of Mill River and draw fresh water from sand beneath the mud. Some of these plants yield water very definitely contaminated by sea water, but this condition has resulted from excessive pumping. At all the places mentioned the water was originally drinkable and at present is only slightly brackish.

FIG. 2.

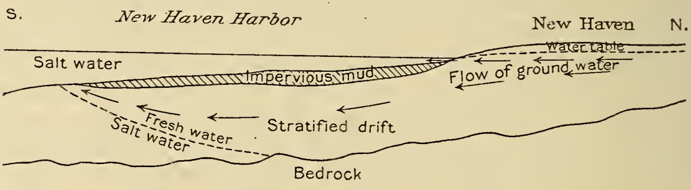


FIG. 2.—Section illustrating artesian conditions in New Haven Harbor.

Law of equilibrium between fresh and salt water.

The reason that fresh water can exist in close proximity to sea water on small islands composed of freely porous material is that it has a lower specific gravity and so rests upon the underlying salt water. The slow rate at which water percolates through the crevices in rocks and the equally slow rate of diffusion of salt through rocks prevent the rapid mingling of the fresh water with the salt water, and the continued increment from rains replaces that which is lost. The same conditions exist on mainland coasts. As a result, the fresh and salt water reach static equilibrium and assume positions which are dependent on relative specific gravities, the higher column of fresh water balancing the heavier sea water. This principle was first recognized by Badon Ghyben,[8] a Dutch captain of engineers, as the result of work done on the coast of Holland; it was later enunciated by Herzberg, apparently without knowledge of the work of Badon Ghyben. Herzberg[9] found in drilling wells on Norderney, one of the East Frisian Islands off the German coast, that the depth to salt water was roughly a function of the height of the water table above mean sea level and of the density of the water of the North Sea. Figure 3 shows the application of his theory.

Let H be the total thickness of the fresh water.
Let h be the depth of fresh water below mean sea-level.
Let t be the height of fresh water above mean sea-level.
Then $H = h + t$.

But the column of fresh water H must be balanced by a column of salt water h in order to maintain equilibrium. Wherefore, if g is the specific gravity of sea water (and if the specific gravity of fresh ground water is assumed to be 1),

$$H = h + t = hg, \text{ whence}$$

$$h = \frac{t}{g-1}$$

---

[8] Badon Ghyben, W.: Nota in verband met de voorgenomen put boring nabij Amsterdam, Tijdschrift van het Konirklijk Instituut van Ingenieurs, Instituuts jaar 1888-1889, p. 21, 's-Gravenhage. Referred to by Eugène Dubois.

[9] Herzberg, Baurat: Die Wasserversorgung einiger Nordseebäder, Jour. Gasbeleuchtung und Wasserversorgung, Jahrg. 14, München, 1901.

In any case $g - 1$ will be the difference in specific gravity between the fresh and salt water. Herzberg gives the specific gravity of the North Sea as 1.027, whence $h = 37t$.

Drillings on Norderney and other islands near by gave results varying but a few meters from those derived by the formula, but it is not clear whether the salt water encountered at the expected depth had approximately the composition of sea water or was merely too salty for use. Herzberg states, further, that the results are sometimes greatly modified by the fineness or coarseness of the sands, indicating that a factor due to porosity is involved. The theory appears to apply particularly to small islands and narrow land masses which consist of freely pervious material, especially sand, and even to these only to a certain extent. However, Herzberg's paper appeared at a time when there was great interest in coastal water supplies in Holland and Belgium, particularly at Amsterdam, and was widely quoted and much discussed by Dutch, Belgian, and French writers. The law of equilibrium between salt and fresh water is frequently referred to as the "theory of Herzberg."

Fig. 3.

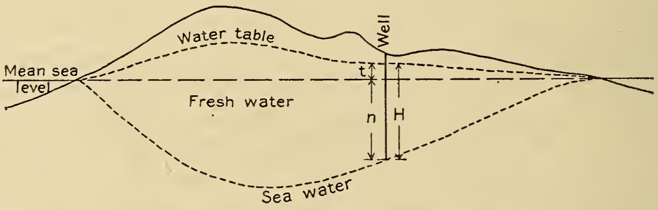


Fig. 3.—Section of the island of Norderney, showing the application of Herzberg's theory. (From Herzberg.)

Nature of the contact between fresh and salt water.

Along coasts there is a continual diffusion of salts from the sea water into the fresh ground water of the land and an actual movement of fresh ground water seaward. There must exist a transition zone in which equilibrium is established between these opposing forces. The location and nature of this zone are determined in part by several other factors, including the tides, (see p. 280), the permeability and structure of the rocks, the amount of fresh water supplied by rainfall, the density of the sea water, and perhaps the prevailing temperature. As has been shown by Herzberg and others, the depth of the contact below mean sea-level is, in uniform material, a function of the height of the water table above sea-level.

The simplest case that can be assumed for consideration is that of a small island composed of uniformly porous sand. The probable movements of ground water and the gradation from salt to fresh water on such an ideal island are illustrated in figure 4 A, which shows the approximate form of curve given by Herzberg for the island of Norderney. Imbeaux[10] states that the form of curve which he obtained experimentally closely

Fig. 4.

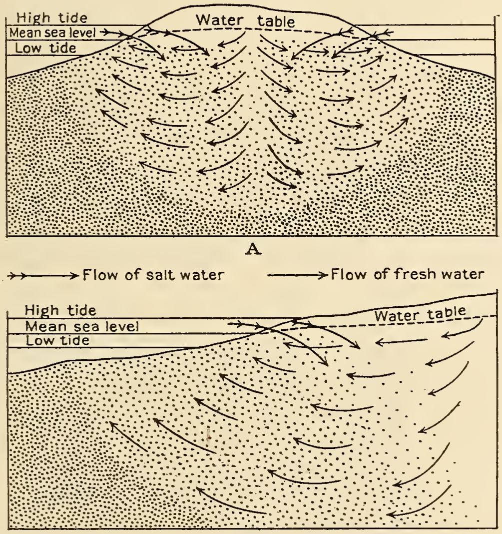


Fig. 4.—Ideal diagram showing movements of ground water and gradation into sea water along shores composed of uniformly porous sand. A, On a small island; B, on a mainland shore.

---

[10] Imbeaux, E.: Les nappes aquifères au bord de la mer; salure de leurs eaux, Bull. des séances de la Société des sciences de Nancy, sér. 3, t. 6, pp. 131-143.

approached a sinusoid. It appears that as the permeability of the rocks increases the curve flattens. Thus Sanford has described the body of fresh water above the salt water in the fractured limestones of the Florida Keys, as a "thin sheet" (see p. 279), and Lindgren[11] has found practically the same condition in the very porous basalts of Molokai. This is a very natural result, for the greater freedom of circulation permits the water table to sink lower, and the necessity for equilibrium then compels the salt water to rise higher, so that the two approach each other. On coasts composed of porous sand the conditions are probably somewhat as shown in figure 4 B. The general zone of contact slopes downward beneath the coast until it is interrupted by impervious rocks.

In Connecticut this invasion of the land by sea water terminates within a few hundred feet of the shore, owing to the fact that the underlying crystalline rocks become practically impervious within a few hundred feet of the surface. Pennink,[12] however, has demonstrated most convincingly that salt water extends for several miles inland beneath the coast of Holland and similar conditions probably exist at other places. The west coast of Holland consists of a belt of dunes about 5 miles wide and at its crest 10 to 20 meters above sea level, which separates the sea from a belt of polders.[13] The polders were created by draining the sea of Haarlem about 1850 and lie from 4 to 6 meters below sea level. In seeking to supplement the Amsterdam water supply a line of test wells was driven across this belt of dunes. Chloride determinations were made on the ground water at many different depths in these wells, and a cross section showing the actual contact between fresh water and underlying salt water was determined. (Figure 5.)[14] Certain

---

[11] Lindgren, Waldemar: The water resources of Molokai, U. S. Geol. Survey Water-Supply Paper 77, pp. 26-47. 1903.

[12] Pennink, J. M. K.: De "prise d'eau" der Amsterdamsche duin waterleiding, Tijdschrift van het Koninglijk Instituut van Ingenieurs, pp. 183-238, The Hague, 1904.

[13] In Holland and Belgium the term *polder* is applied to a tract of marshy land, lower than the sea, which has been diked and reclaimed to cultivation. —Standard Dictionary.

[14] The zero of Amsterdam shown in Fig. 5 is approximately 0.2 meter above mean sea level.

FIG. 5.

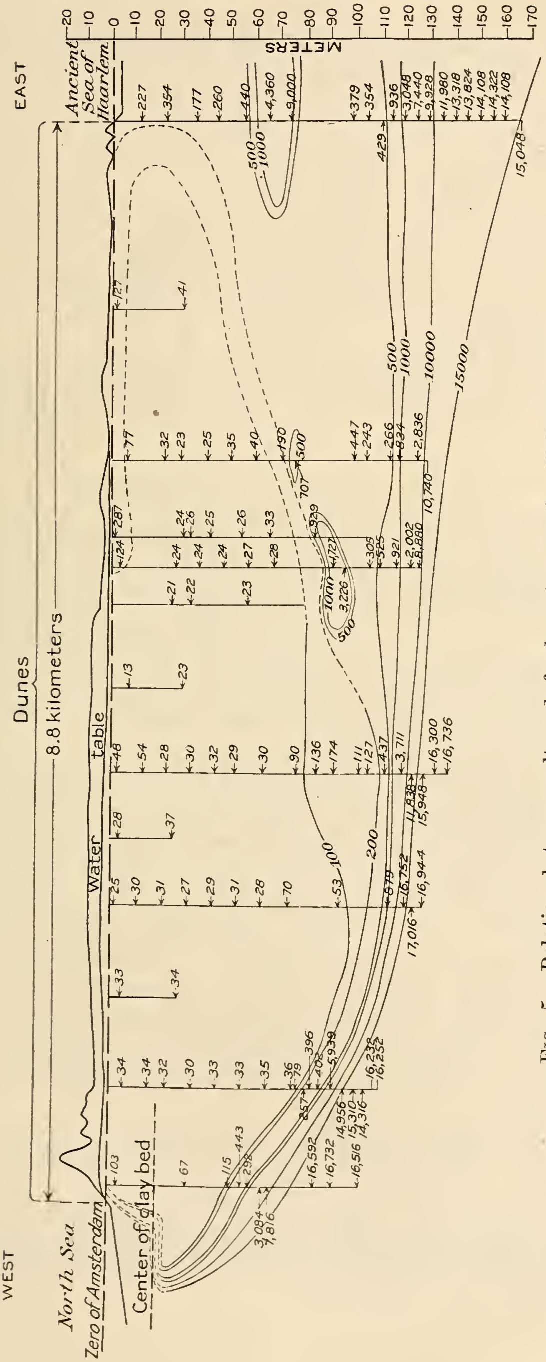


FIG. 5.—Relation between salt and fresh water on the Holland coast. (Redrawn from Pennink.)

irregularities in the distribution of salt and fresh water are easily accounted for by the local geology, but it is clear (1) that salt water actually underlies the land at a depth of 100 to 200 meters below sea level over a belt several miles in width; (2) that the depth to salt water is greatest where the land and the water table are highest; (3) that salt water rises under areas of low ground, or rather under areas having a depressed water table, such as the polder of the old sea of Haarlem. The general line of contact between salt and fresh water is very regular, however, and the zone of gradation or diffusion is surprisingly thin.

Laboratory experiments by D'Andrimont,[15] a Belgian, also gave results very much like those from Holland.

Effects of pumping on salt content.

In the work near New Haven 23 pumping plants within 500 feet of the shore were examined. The water at ten of these plants was highly contaminated with sea water, and that at three or four others was contaminated slightly. The greatest distance from the shore at which high contamination was noted was 400 feet. In general, the plants that supplied the larger amounts of water were more highly contaminated.

All the evidence regarding the effect of pumping tends to one conclusion—that if more water is removed than the contributory area supplies, the wells become salty. This statement is as true for domestic wells drawing from a small intake area as for pumping plants supplied with the underflow of a large drainage basin. Thus the Beattie dug well, which probably drains about 1 acre of sand (stratified drift) at the end of a small island, originally yielded good water, but the demands of one family, when increased by the installation of a household water system, were sufficient to overtax the well and make the water salty.

The best data regarding the limiting rate at which water may be pumped from a given contributory area

---

[15] D'Andrimont, René: Note préliminaire sur une novelle méthode pour étudier expérimentalement l'allure des nappes aquifères dans les terrains perméable en petit, Annales de la Société géologique de Belgique, t. 32, Mémoires, pp. 115-120, Liége, 1906.

are furnished by the plant of the American Steel & Wire Co. and the connected plant of the Penn. Seaboard Steel Corporation at New Haven. When these plants were engaged on war work during 1918, and the demand for water was excessive, the Penn. Seaboard Steel Corporation drew from its wells about 330,000 gallons a day or 10 million gallons per month. The water, which at first was sweet and drinkable, became very salty, evidently from salt water drawn in from the harbor. On the small plain upon which these plants are located not more than a quarter of a square mile serves as a catchment area for ground water. It appears, therefore, that the rate of pumping greatly exceeded the ability of the catchment area to supply water. The rate of 330,000 gallons a day for a quarter of a square mile is somewhat more than a million gallons a day to the square mile, a figure which is considerably above the safe draft upon a drainage basin near the sea under conditions such as prevail in Connecticut. One million gallons a day to the square mile is 20.8 inches a year, or about 45 per cent of the total annual rainfall in the New Haven region.

The effects of pumping on a large scale near the sea have been carefully studied by the Board of Water Supply for the City of New York.[16] For an intake area of 157 square miles on Long Island, where the climate is about the same as in Connecticut and where the surface formation is glacial drift, Spear estimates the safe yield at 77 million gallons a day, or very nearly half a million gallons a day to the square mile. This figure is a much closer approximation to the safe capacity of ground water reservoirs under such conditions.

The limit to which wells can safely be pumped or the depth to which the water table can safely be lowered can never be exactly determined, except by actual tests. The statement made by many writers, that if the water table is lowered below mean sea level salt water is induced to flow inland, is only partly true. An appreciable gradient, several feet to the mile, is necessary to permit ground water to flow through the rocks. Therefore, where salt water extends only a short distance beneath the coast, a

---

[16] Spear, W. E.: An additional supply of water for the city of New York from Long Island sources, New York Board of Water Supply, vol. 1, pp. 144-159. 1912.

well a mile or two inland could be pumped considerably below mean sea level before the salt water would have head enough to enter it.

Seasonal variations in salt content.

Certain wells that are contaminated with sea water exhibit a pronounced variation in salinity. The Peter Beattie dug well is on a small stratified drift plain about 200 feet in diameter at the north end of Narrows Island, (fig. 6). The well is 12 feet deep, in sand and gravel, and the water level stands at about mean sea level. The results of chloride determinations made from samples collected at different dates, covering almost a year, are given in fig. 7 and are compared with the rainfall and temperature records. The data show that there was a very great increase of saltiness in the water during June, July, and August, 1919.

Fig. 6.

Fig. 6.—Northern end of Narrows Island, Guilford, Connecticut. A well near the house yielded water with a chloride content that ranged from 83 to 609 parts per million in one year.

A factor that should not be overlooked in the study of the salinity curve of this well is the quantity of water pumped for use. In summer the quantity of water used for domestic purposes might be expected to increase somewhat. However, as the salinity of the water became

Fig. 7.

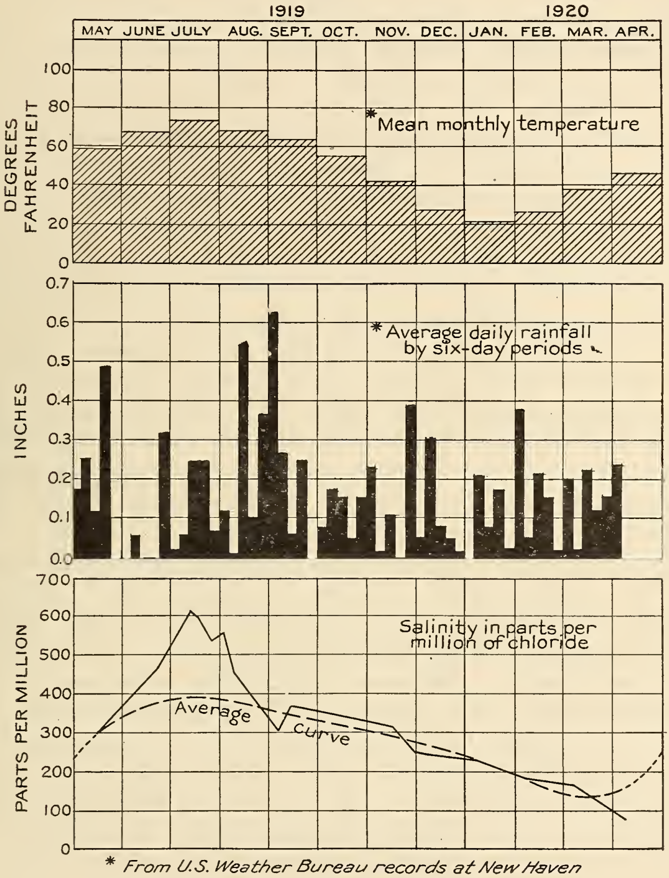


Fig. 7.—Relation of salinity to temperature and rainfall in Peter Beattie well.

greater, its use for many domestic purposes was discontinued, and water was carried from a neighboring well. The factor of use therefore does not appear to have had any appreciable influence on the degree of salinity.

The variation shows the influence of variations in precipitation and apparently also in temperature. The extremely high chloride in June and the first part of July represents the effect of a month of very light rainfall, accompanied by rising temperature. The steady decrease of chloride from July 12 to July 26 is the result of heavy, well-distributed rainfall, and the increase in the week of July 26 to August 2 coincides with a week of light rainfall. The great decrease in chloride between August 2 and September 6 is evidently the result of heavy rains, particularly on September 2 and 3, when 3.72 inches fell. The increase noted in the following week, September 6-13, apparently represents the effect of gradual rediffusion of salt after the flood of fresh ground water had subsided. Undoubtedly careful tests at more frequent intervals would show many irregularities of the curve due chiefly to the variable precipitation, but the general form would agree more or less closely with that of a yearly temperature curve, although the spring rise would lag considerably behind the rise in the temperature curve, because the frost is slow to leave the ground in spring—that is, the ground warms more slowly than the air.

The influence of temperature appears in different ways. Higher temperature increases evaporation. It also greatly increases the rate of percolation, so that ground water seeps out to sea more freely and salt water diffuses landward faster. Slichter[17] states that a change of temperature from 32° to 75° F. will practically double the power of a soil to transmit water, and that a change from 50° to 60° will increase the rate of flow 16 per cent. The influence of humidity is also a factor, and the rate of transpiration by plants is important. The island on which the well is situated supports a grove of trees and a grassy lawn, which transpire much of the precipitation in the summer season. The net result, as indicated, is a remarkable increase of salinity in summer.

Observations on two drilled wells in bedrock, although not so complete as those on the Beattie well, strengthen the evidence that certain contaminated wells are most

---

[17] Slichter, Chas. S.: Field measurements of the rate of movement of underground waters, U. S. Geol. Survey Water-Supply Paper, 140, p. 13, 1905.

salty in summer. The drilled well of Robert Mitchell, at Sachem Head, Guilford, is on a narrow point 50 feet from high tide on two sides. It is about 50 feet deep. The well was drilled for the supply of a summer cottage, but the water became so salty that the well was entirely abandoned in 1919. The following quantities of chloride, in parts per million, were found in four samples examined in 1919: May 19, 49; June 16, 94; Aug. 4, 50; Nov. 28, 31.

The water of the Anderson drilled well on Mulberry Point, Guilford, becomes salty whenever it is used. Nevertheless it is used in summer, as it is the only supply available. The quantity of water used does not vary greatly from day to day, and the results given below represent mainly natural seasonal variations in salinity. Some analyses made in 1919 showed the following quantities of chloride, in parts per million: June 16, 37; July 12, 290; July 17, 516; July 20, 446; Aug. 4, 355.

The results indicate a seasonal variation in salinity much like that in the Beattie well, though the great increase between June 16 and July 12 may be largely due to the drain upon the well. The mounting salinity early in July shows the effect of a sharp drought and subsequent decreases closely follow rains on July 16 and August 1.

Such remarkable fluctuations in salinity in ground water must be confined to small islands and isolated points where the total quantity of fresh ground water is very small and where the increment from rains reaches the sea quickly. It is quite possible, however, that at some places on mainland coasts seasonal fluctuations have an appreciable effect on the zone between salt and fresh ground water in which contamination by sea water occurs and may cause this zone to progress slightly farther inland in summer. The evident influence of temperature also suggests that in warm climates contamination is relatively greater than in cooler regions with a like amount of rainfall.

Influence of tides on ground water.

The water surface in wells near the sea is sometimes affected by tides, but the writer's observations indicate that fluctuations of this kind in sandy material are less than a few tenths of a foot. In fractured rocks, however, fluctuations of several feet may occur. The best data on tidal fluctuations in wells are given by Veatch,[18] who says that they are caused in three ways—"by transmission of pressure through open cavities or passageways affording a free communication between the wells and the ocean; by a checking of the rate of discharge of the normal ground-water flow through porous beds freely connecting with the ocean; and by a deformation of the strata due to the alternating loading and unloading of the tides." The last method accounts for the rhythmic rise and fall of flowing wells near the sea.

Experiments indicate that fluctuations in salinity in the water from wells can only very rarely be correlated directly with the rise and fall of the tides. The tidal period is too short for its immediate effect upon the salt content of ground water to be propagated in a measurable amount much beyond the limits of the low-tide and high-tide shore line. However, when wells near the sea are pumped so heavily that the water table is kept below sea level for periods of several days or more and salt water is thus enabled to flow toward the wells, the rate of this flow increases at high tide due to the increased head of salt water and a fluctuation in salinity having the periodicity of the tides is established.[19]

Undoubtedly tides are very important in maintaining the zone of brackish water that occurs along the coast. They act partly through direct infiltration of salt water at high tide (fig. 4), and partly through oscillations in the contact zone due to variations in hydrostatic pressure. These oscillations promote intermixture of fresh and salt water.

---

[18] Veatch, A. C.: Fluctuations of the water level in wells, with especial reference to Long Island, New York, U. S. Geol. Survey Water-Supply Paper **155**, p. 69. 1906.

[19] Burr, W. H., Hering, Randolph, and Freeman, J. R., Report of the commission on additional water supply for the city of New York, pp. 406-423, New York, Martin B. Brown Co., 1904.

ART. XXVIII.—*A Petrologic Study of the Cape Neddick Gabbro*; by ALFRED WANDKE.

LOCATION AND ASSOCIATED ROCKS.

The Cape Neddick gabbro, an elliptical stock, elongated northwest, measuring three fourth's by half a mile, forms the major portion of Cape Neddick, York County, Maine. The stock invades the Kittery quartzite, a fine-grained thinly bedded and vari-colored formation of steeply inclined sediments which strike about 45 degrees northeast, dip 60 degrees northwest and are presumably of Upper Carboniferous[1] age. The intrusive may then be dated tentatively as post Upper Carboniferous.

In addition to this intrusive of gabbro the shoreline portion of this part of Southwestern Maine offers a vast assemblage of dike rocks which not only illustrate most of the features associated with dike intrusion but also show contrasted types as diabases, diorites, quartz diorites, granite porphyries, tinguaites, camptonites and aplites. Within half a mile of the stock is a batholith of alkaline granite, but one of the rock varieties that make up the composite mass known as the Agamenticus complex. This complex shows in addition to a normal biotite granite, alkaline rocks such as alkaline granite, syenite and nordmarkite.

The stock rising 45 feet above tide is well exposed. A small portion of the landward half of its surface is drift-covered, whereas the seaward half is almost swept clean of debris. Excellent exposures are thus to be had not only of the contacts permitting the contact phenomena to be studied in detail, but also of the igneous mass itself which is seen to be composed of contrasting rock types in rather complex relationships.

METHOD OF EMPLACEMENT.

The debris-free contact zone, which in places is exposed two hundred feet away from the intrusive, enables one to study the mechanism of intrusion as well as the details of contact metamorphism. As is shown in fig. 1 the stock is clearly cross cutting. Although the out-

---

[1] U. S. Geol. Survey, Prof. Paper 108, p. 165, 1917.

FIG. 1.

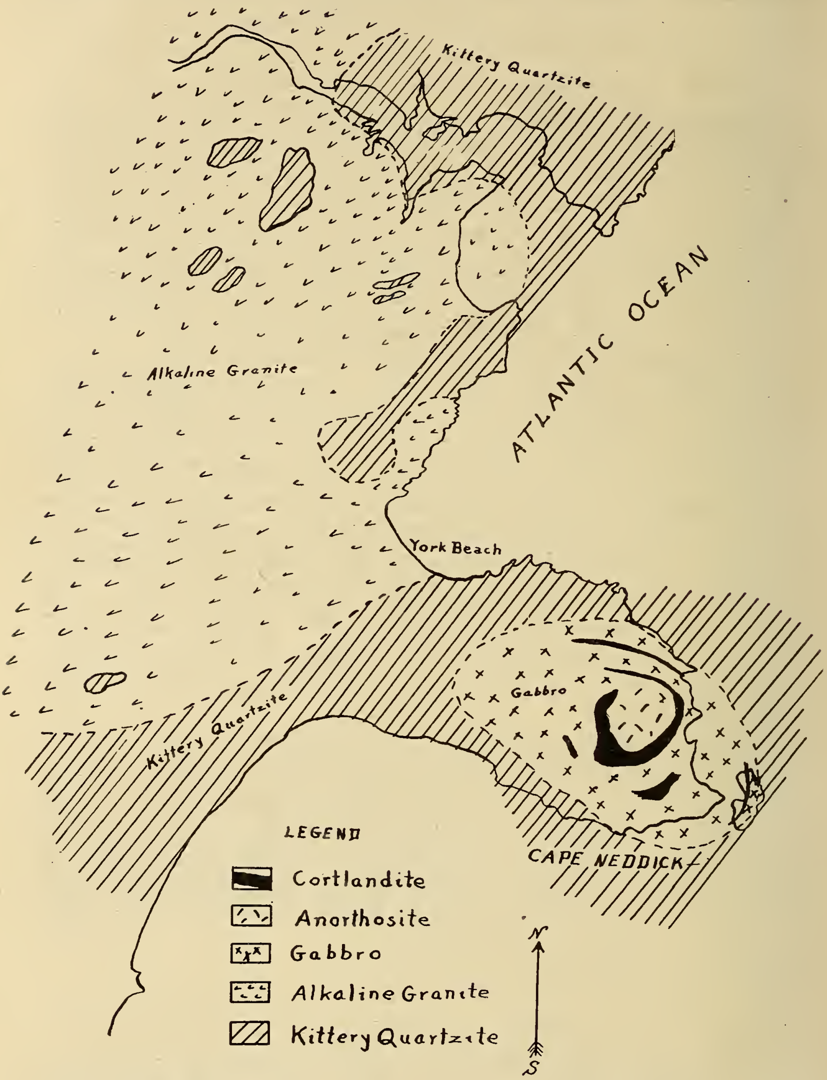


FIG. 1.—Map showing the geology of Cape Neddick and vicinity. Scale 2 inches=1 mile.

line of body is oval there is a distinct flattening of the southwestern margin along which the contact phenomena are also less intense. Along the northeastern contact a marine terrace, well exposed at low tide, shows in part how the emplacement of the gabbro was effected.

As has been mentioned, the quartzite formation strikes about 45 degrees NE. At a distance of two hundred feet from the contact this strike remains undisturbed. At about one-hundred and twenty-five feet from the contact the strike of the sediments becomes slightly flexed. Within the next twenty-five feet this flexing increases in amount and passes into gentle folding the folds becoming steeper the nearer one approaches the contact until at seventy-five feet therefrom they pass into overturned folds which in turn are broken by overthurst faults. About fifty feet from the contact the sediments that elsewhere in this region form an easily recognized lithologic unit having a remarkable persistency of strike and dip lose their identity and become a jumble of blocks of quartzite cemented by gabbro. Within five feet of the contact the sedimentary nature of some of these blocks is almost obliterated. The actual contact because of the marked alteration of the sediments is established with difficulty.

To emplace this body a force would have been required great enough to bodily thrust the enclosing rocks asunder, at the same time folding them and producing a shatter breccia. But such a lateral thrusting could not alone account for the full width of the stock. The stock is half a mile across whereas the total visible movement in the contact zone about the intrusive accounts for but a few feet of this width. In the contact zone the sediments are brecciated and blocks of quartzite are frozen in the gabbro. This would at once suggest that magmatic stoping has been operative, but stoping hardly accounts for the width of this intrusive for the expansion in volume of the last 500 feet of stoped sediments would have entirely filled the space now occupied by the gabbro. It seems, therefore, that stoping may have played but a very minor part in the emplacement.

The emplacement of this body may be accounted for if one considers that the intrusive moved upward in a zone of tension. A rupture within this zone would partially have satisfied the stresses involved and along this break magma under a high hydrostatic head may have risen. If the tensional stresses within the sediments were not entirely satisfied by the rupture it seems probable that a lateral creep of walls may have taken place aided by the hydrostatic pressure of the ascending magma. If the hydrostatic pressure of the magma and the resistance to movement of the solid walls were still unequally balanced the enclosing walls may have been thrust apart until equilibrium ensued. The field relations indicate that such a thrusting apart of the walls actually took place. After the intrusive had approximately attained its present size it may be that the contact which in the first stage had been left jagged was now smoothed off. Stoping and local assimilation, processes indicated by included blocks and marginal hybrids, evidently were responsible for this final smoothing of the contact.

PETROGRAPHY.

In speaking of this intrusive rock as a gabbro attention is called merely to the dominant marginal phase. This stock in reality shows four distinct phases: (1) a marginal or contact phase characterized by hypersthene and approximating a quartz-norite in composition; (2) gabbro; (3) and (4) two contrasting central phases, the one characterized by ferromagnesian minerals and suggesting cortlandite, the other characterized by plagioclase feldspar and best described as an anorthosite. An optical analysis by the Rosiwal method gives the following approximate mineral composition of each of these four phases:

	Contact	*Gabbro*	*Central*	
Olivine	17.89	1.50	6.76	....
Hornblende	....	10.01	21.42	.68
Pyroxene	23.53	25.00	8.23	9.43
Biotite	3.77	3.26	4.76	1.21
Plagioclase	45.50	45.60	51.85	87.10
Alkaline Feldspar	1.17	....	....	.16
Magnetite	3.62	13.82	6.79	1.55
Apatite	2.97	....	....	....
Hypersthene	2.33	....	....	....
	100.78	99.19	99.81	100.13

Contact phase.—This phase forms a peripheral zone of tough hard rock that rarely exceeds five feet in width. Inclusions of quartzite in various stages of assimilation are locally abundant. In the hand specimen the rock has a dark gray color, is fine-grained although the crystals of olivine that are abundantly sprinkled throughout the specimen may attain a maximum diameter of three millimeters. Pyroxene and plagioclase can also readily be identified. The presence of rather abundant apatite in this contact phase evidently indicates that volatile components played an active part in assimilating the engulfed quartzite, the interstitial quartz and micropegmatite being corroborative evidence of such action. Judged from its mineral composition the rock is a hybrid and resulted from the assimilation of quartzite by gabbro.

Gabbro.—The gabbro forms an interesting phase of this intrusive. In part it is developed as a normal course-grained dark colored igneous rock, but for a width of twenty-five to fifty feet from the contact phase it is strikingly banded. These bands rarely over three inches wide follow the contact, stand vertically and are due to slight fluctuations in the relative amounts of feldspar and ferromagnesian minerals. As distance away from the contact is gained this banding becomes vague and disappears, the rock then having the appearance of normal coarse-grained gabbro. In the bands the order of crystallization of the essential constituents seems to have been olivine, magnetite, plagioclase, pyroxene, hornblende, and biotite. The olivine, never abundant, occurs in grains with an anhedral outline that indicates resorption. The magnetite is irregular in outline, is commonly enclosed in the feldspar sometimes occurring as dust-like particles, and also occurs in the pyroxene surrounded by a corona of biotite. Plagioclase feldspar (Ab_2 An_3), the most abundant single constituent, was one of the first minerals to form and its period of crystallization overlapped that of the pyroxene, hornblende and biotite. It is frequently euhedral in outline, the ferromagnesian minerals being moulded about the well formed crystals. The pyroxene characteristically alters to hornblende and biotite, a change that appears to have been intermittently favored. It may well be that since they follow the pyroxene both hornblende and biotite, minerals containing hydrogen and artificially produced only in the wet way, indicate the presence of mineralizers.

The banding in igneous rocks has received considerable attention from petrographers and many examples have been described in detail. Various theories have been advanced to explain these banded rocks and it seems quite certain that different processes have been operative in different localities to produce a somewhat similar result. The entire subject has been well reviewed by Dr. F. F. Grout[2] who gives the following ways in which these banded rocks may have been produced:

1. Partial assimiliation of inclusions forming schlieren.
2. Lit par lit, or fluidal gneiss.
3. Deformation during solidification.
5. Streaked differentiation with reference to rhythmic cooling or intrusive action.
6. Successive intrusions.
    (a) Cooling separately and successively.
    (b) Cooling later, all together.
7. Heterogeneous intrusion.
8. Convection during crystallization differentiation.

At Cape Neddick where the bands are rarely over three inches wide, stand vertically, have a granitic texture, show but slight variations and can be followed for hundreds of feet about the contact, most of the above listed explanations such as 1, 2, 3, 6, and 7, can obviously be dismissed as non applicable. The facts needing explanation are the localization of the banded rock near and parallel to the contact; a vertical banding; alternation between femic and salic rock types; the alteration of pyroxene to hornblende and biotite with partial absorption of magnetite; the passage of banded gabbro into unbanded gabbro toward the center.

The narrow width of the bands and the passage from banded rock into unbanded rock would seem to rule out the possibility of successive intrusions. There remain thus as the favored hypotheses either convection during crystallization differentiation or rhythmic[3] cooling. Were it a question of explaining a banding that showed gradations from basic to more acidic rock types or vice versa then convection might have played an important part. A study shows that the bands differ only in the

[2] Journal of Geology, vol. 26, p. 439, 1919.

[3] N. V. Ussing: Geology of the Country Around Julianehaab, Greenland, p. 361, 1911.

relative amounts of light and dark constituents, any two adjacent bands throughout the banded area being seemingly like any other two adjacent bands and the two selected bands differing perhaps but little in average composition from the unbanded rock into which the banded rock grades. Some process, acting intermittently and rhythmically, for the bands are approximately of the same width in any random two-foot zone, would best account for the field relationships. It seems to the writer that the pulsatory escape of mineralizer may best be appealed to as the mechanism responsible for the banding. The steeply inclined thinly bedded sediments would have furnished excellent avenues of egress to the volatile components. These sediments, moreover, for over one-hundred feet distant from the contact are not only recrystallized but show evidence of the addition of new constituents. The abundant apatite in the contact phase as well as the marked alteration of pyroxene in the banded phase to hornblende and biotite also indicate the presence of mineralizers. The escape of the volatile components would at once upset pressure, one of the factors of temporary equilibrium. This upset in pressure would manifest itself not in a local change in equilibrium but in a change that would at once be transmitted throughout the entire magma. If now the body be thought of as crystallizing in the normal way, from the margin inward, then the change in equilibrium might make itself most apparent in this marginal zone, a banded rock being the result of recurring upsets in equilibrium.

Central phases.—The central portion of this stock is occupied by two phases showing as marked differences in composition as do any two adjacent bands of the previously described banded phase of the gabbro. The surface of this central portion, practically clear of debris, could be studied in detail and the phases mapped without exaggeration. As shown by the map the relations are almost such as to suggest that these two contrasted phases had differentiated and then the magma in the stock been given a swirl with a gigantic mixing spoon. The essential minerals of the dark phase are olivine, magnetite, pyroxene, pyrrhotite, hornblende, biotite and labradorite. The hornblende and biotite both replace the pyroxene. The biotite in addition forms about and resorbs the magnetite. The essential minerals of the light phase are labradorite, biotite, pyroxene, magnetite and hornblende, the dark minerals being accessory to the feldspar with biotite the most abundant ferromagnesian mineral. The striking feature of the thin sections of these rock types is the anhedral fragment-like habit of the silicate minerals. It is as though movement had taken place in this mass just before final complete solidification was accomplished. It is possible, therefore, that in the later stages of crystallization of this stock differentiation took place largely by the settling of crystals[4] the tendency being perhaps for the ferromagnesian and metallic minerals to sink leaving in the upper portion of the stock an accumulation of crystals consisting for the most part of feldspar. Just before complete consolidation was effected movement in this crystal mush may have taken place, the relationships as now seen being the result.

Secondary alteration.—Recent road-cuts on the Cape made available fresh specimens of the various rock phases that to the eye appear unaltered. The microscope, however, shows that the plagioclase, biotite, and olivine have undergone slight alteration. The plagioclase alters to sericite and calcite, the biotite to chlorite and calcite, the olivine to serpentine. Kaolinization of the feldspar cannot be detected nor is limonite a product of the alteration affecting either the biotite or the olivine. The changes are, therefore, ascribed to post consolidation solutions of the general nature of those which usually accompany the ores of mineral deposits. The slight amount of change produced in the rock minerals would indicate that post consolidation hypogene solutions were but sparingly present.

Contact actions.—The shearing and mashing of the enclosing sediments have already been described. The contact metamorphism of the quartzites is also well shown. Away from any intrusive the quartzites are seen to consist of quartz, with minor amounts of calcite, biotite, chlorite, plagioclase, orthoclase, and rutile. Two suites of specimens were studied from the contact zone, the one consisting of three specimens taken one-hundred-

---

[4] N. L. Bowen, Journal of Geology, vol. 27, No. 6, 1919.

fifty, fifty and one foot from the contact; the other of three specimens taken five, three and one foot from the contact. In each of the thin sections made from these specimens recrystallization of the original minerals and the addition of material are indicated by the development of feldspar, diopside, biotite, epidote, brown hornblende, calcite, magnetite, and pyrrhotite. In the specimens taken one-hundred-fifty feet from the contact the diopside and other minerals as listed above are not abundantly developed. But as the contact is approached both feldspar and diopside increase greatly in amount. The feldspar which at a distance consisted of orthoclase and albite is decidedly more basic and of larger grain near the contact.

The amount and kind of alteration of the quartzite also shows slight variations. Thus a specimen taken five feet from the southeast contact is characterized by an abundance of andesine feldspar which is replacing the quartzite. The development of the plagioclase was evidently so rapid that portions of the original quartzite were incorporated within the plagioclase, the result being grains of feldspar loaded down with inclusions. At the contact diopside is a dominant mineral and quartz, although present, occurs in decidedly less abundance than one-hundred-fifty feet from the contact. A specimen of quartzite from within the hybrid contact zone of the gabbro was also sectioned. The section shows a remarkable development of diopside which suggests that this mineral was soaked up by the quartzite as a sponge soaks up water. The presence, moreover, of hornblende, biotite, apatite, magnetite and pyrrhotite would indicate that the rock which started as a slightly argillaceous quartzite now has the composition of a quartz diorite. Thus there is a tendency for the contact phase of the sediments by the addition of material from the gabbro to approach a gabbro as far as mineral composition is concerned and to resemble the phase of the gabbro which has been altered by the assimilation of quartzite.

SUMMARY.

The striking features of this Cape Neddick locality are:

1. The intrusive apparently occupies a zone of tension the emplacement having been effected by lateral creep and by bodily thrusting apart the enclosing walls.
2. Stoping and marginal assimilation are both indicated but seem to have been rather insignificant processes during the emplacement of the gabbro.
3. The gabbro shows a banded phase that is best explained by the rhythmical reduction of pressure within the gabbro by the escape of volatile components during consolidation.
4. Differentiation by crystal settling seems indicated and the basic phase seems later to have intruded the acid phase.
5. The contact actions indicate the tendency of the quartzite near the contact to approach a quartz diorite in composition, the gabbro in turn becoming siliceous by absorbing quartzite.

Art. XXIX.—*Fossils of the Olympic Peninsula;* by William Healey Dall.

In the Transactions of the Kansas Academy of Science, volume **22**, pages 131 to 238, Mr. Albert B. Reagan described the Olympic Peninsula of Washington, discussed its geology and described and figured a number of fossils from the Clallam and Quillayute formations.[2]

At that time, paleontological literature was rarely accessible in that region, and there had been no modern discussion of the late Tertiary fossils of the Oregon-Washington area. It is not surprising therefore, that identification of the species collected was difficult, and sometimes failed in accuracy.

Fortunately Mr. Reagan turned over his types to the U. S. Geological Survey, which transmitted them to the National Museum where they are permanently preserved. In working up the fossil faunas of the later Tertiaries of the Northwest Coast, it became desirable to revise Mr. Reagan's list and supply the modern designations, comparing his material with the types of Conrad and others from the same general group. Mr. Reagan's species were figured somewhat crudely in his memoir, but the types were readily correlated with the figures, only two or three being absent from the original series.

His lists were distributed in two parts, one part specially devoted to the species of the "Clallam" formation, and the other to those of the "Quillayute" formation, so called.

So far as the material in hand goes, the two faunas do not seem to differ materially, the species being mixed at Coos Bay, but for convenience in referring to Mr. Reagan's memoir they will be separately considered here.

Fossils of the Clallam Formation.

Solemya ventricosa Conrad.

Solemya ventricosa Conrad, Report on the Geology of the U. S. Exploring Expedition p. 723, pl. 17, figs. 7, 8, 1849; Reagan, p. 174, pl. 1, fig. 1, 1909.

---

[1] Published by permission of the Director of the U. S. Geological Survey.

[2] Professional Paper 59 of the U. S. Geol. Survey was issued April 2, 1909; Mr. Reagan's memoir, Nov. 24, 1909.

Both Conrad's type and that of Mr. Reagan are poorly preserved, but there seems no reasonable doubt of their specific identity.

Nucula (Acila) conradi Meek.

Nucula divaricata Conrad, this Journal, vol. 5, p. 432, fig. 1, 1848; not of Hinds, 1843.
Nucula conradi Meek, Checklist Miocene foss. of N. Am., Nov. 1864.
Nucula (*Acila*) *castrensis* Reagan, p. 174, pl. 1, fig. 2, 1909; not of Hinds.

This species has finer sculpture than *N. castrensis* the recent species, and is not so abruptly truncate behind.

Nucula (Acila) gettysburgensis Reagan.

Nucula (*Acila*) *gettysburgensis* Reagan, p. 175, pl. 1, fig. 3, 1909.

This is a fine large species closely related to the recent Japanese *N. mirabilis* Adams and Reeve.

Yoldia reagani n. nom.

Yoldia impressa (Conrad) Reagan, p. 177, pl. 1, fig. 4, 1909; not of Conrad.

A comparison with Conrad's type shows that the latter is vertically more attenuated toward both extremities and more compressed laterally, being undoubtedly distinct from the present shell, which is closely related to *Yoldia beringiana* and *Y. monteryensis* Dall, of the recent fauna. Both of them are of greater height from base to umbones, and more inflated than the fossil.

Phacoides acutilineatus Conrad.

Lucina acutilineata Conrad, Rep. Geol. U. S. Expl. Exp., p. 725, pl. 18, figs. 2, 2*a-b*, 1849.
Phacoides acutilineata Reagan, p. 179, pl. 1, fig. 5, 1909.
Phacoides nuttallii? Conrad, Reagan, p. 179; not of Conrad.

A comparison of the specimens named by Reagan *acutilineatus* and *nuttallii* shows that they are internal casts of the former species. A fragment queried on the label as possibly *nuttallii* appears to be part of the valve of a *Protocardia.*

Thyasira bisecta Conrad.

Thyasira bisecta (Conrad) Reagan, p. 180, pl. 1, fig. 7, 1909.

This species is correctly identified.

Chione vespertina Conrad.

Cytherea vespertina Conrad, Am. Journal Sci., 1848, p. 432, fig. 9.

Venus (*Chione*) *vespertina* Reagan, p. 181, pl. 1, fig. 8, 1909.

The specimen identified by Reagan as *C. vespertina* is not in the collection.

Cyclinella ? sp.

Venus (*Chione*) *angustifrons* (Conrad) Reagan, p. 181, pl. 1, fig. 9, 1909.

This fossil is an internal cast of obliquely oval form, thin shelled, and showing a deep sharply angular pallial sinus and unusually large posterior adductor scar, suggestive of the genus *Cyclinella*. The figure is extremely inadequate.

? *Venus parapodema* Dall.

Venus (*Chione*) *mathewsoni* (Gabb) Reagan, p. 181, pl. 1, fig. 10, 1909.

The type specimen is a much dilapidated Venerid shell which may possibly belong to *V. parapodema,* but certainly cannot be identified with the *Chione.*

Chione securis Shumard.

Venus (*Chione*) *temblorensis* (Anderson) Reagan, p. 182, pl. 1, fig. 11, 1909.

Venus (*Chione*) *clallamensis* Reagan, p. 183, pl. 1, fig. 13, 1909.

The specimen named *V. clallamensis* is the internal cast of a young specimen of *C. securis.*

Antigona olympidea Reagan.

Venus (*Chione*) *olympidea* Reagan, p. 182, pl. 1, fig. 12, 1909.

The specimen thus named is remarkable for its deep lunular depression. The few particles remaining of the external layer of the shell indicate a finely reticulate sculpture. The form of the cast recalls *Venus fordi* Yates, of the recent Californian fauna.

Marcia oregonensis Conrad.

Saxidomus gibbosus (Gabb) Reagan, p. 184, pl. 2, fig. 14, 1909.

The identification is correct, but Gabb's name is a synonym of Conrad's *Cytherea oregonensis,* 1848.

Macoma calcarea Gmelin.

Tellina albaria (Conrad) Reagan, p. 184, pl. 2, fig. 15, 1909.

The type is a specimen of Gmelin's species which is abundant in these deposits, and is quite distinct from *albaria.*

Tellina arctata (Conrad) var. *juana* Reagan.

Tellina arctata (Conrad) Reagan, p. 186, pl. 2, figs. 16, 16 *a.*, 1909.

Tellina arctata, var. *juana* Reagan, p. 186, pl. 2, fig. 17, 1909.

The specimens are all internal casts of which that designated as variety *juana* is closest to Conrad's type of *arctata.* It is probable that the differences all lie within the range of individual variation.

Tellina oregonensis Conrad.

Tellina clallamensis Reagan, p. 186, pl. 2, fig. 18, 1909.

The type specimen is a defective internal cast, apparently referable to Conrad's species.

Spisula albaria Conrad.

Mactra gibbsana (Meek) Reagan, p. 187, pl. 2, figs. 19 *a-b.*, 1909.

This specimen, an internal cast, seems referable to an adolescent *Spisula albaria.*

Panope abrupta Conrad.

Panopea generosa (Gould) Reagan, p. 188, pl. 3, fig. 20, 1909.

The specimen exhibits both valves, one imperfect the other intact. The draughtsman has selected the imperfect one for figuring. The perfect valve agrees exactly with Conrad's type of *Mya* (= *Panope*) *abrupta.*

Teredo sp. indet.

Teredo sp. Reagan, p. 188, pl. 3, fig. 21, 1909.

The specimen is a mass of small nearly straight tubes, apparently of *Teredo,* with a diameter at the aperture of about a millimeter and a half.

Xylotrya ? substriata Conrad.

Teredo bulbosa Reagan, p. 189, pl. 3, fig. 22, 1909.

This is identical with Conrad's species. The "bulbs" are the proximal ends of adult tubes formed when the borer has completed its growth.

Dentalium ? substriatum Conrad.

Dentalium substriatum (Conrad) Reagan, p. 189, pl. 3, fig. 23, 1909.

The type consists of short pieces from the anterior end of a large thin *Dentalium,* showing only incremental sculpture. The specific identification is uncertain.

Olivella pedroana Conrad.

Olivella pedroana (Conrad) Reagan, p. 189, pl. 3, fig. 24, 1909.

This is a young shell, but seems to be correctly identified.

? *Buccinum clallamensis* Reagan.

Pisiana clallamensis Reagan, p. 190, pl. 3, fig. 25, 1909.

The specimens are internal casts, probably of a species of *Buccinum*. A good species but certainly not a *Pisania.*

? *Chrysodomus postplanatus* Dall.

Chrysodomus gettysburgensis Reagan, p. 190, pl. 3, fig. 26, 1909.

An unidentifiable very defective internal cast, most nearly resembling the Astoria species.

Nucella lima Martyn, var. ?

Purpura canaliculata (Duclos) Reagan, p. 192, pl. 3, fig. 27, 1909.

The figured specimen is a small individual closely related to if not identical with *N. lima* Martyn. Another specimen not figured but similarly labelled is *Nucella precursor* Dall, described from the Astoria horizon at Coos Bay.

Neverita ? *inezana* Conrad.

Polynices (*Neverita*) *recluziana* (Petit) Reagan, p. 193, pl. 3, fig. 28, 1909.

These are all decorticated specimens and their identification cannot be positive, but they agree fairly well with Conrad's species. They are quite distinct from the *P. recluziana.* The *Polynices saxea* Conrad, mentioned on p. 193, is not among the specimens received.

Amauropsis ? *oregonensis* Dall.

Polynices (*Lunatia*) *olympidea* Reagan, p. 194, pl. 3, fig. 29, 1909.

This is also decorticated, it seems close to the *Amauropsis,* but appears to have been a much heavier shell.

Sinum scopulosum Conrad.

Sigaretus scopulosus (Conrad) Reagan, p. 194, pl. 3, fig. 30, 1909.

This is correctly identified.

Trochita inornata Gabb.

Trochita inornata (Gabb) Reagan, p. 195, pl. 3, fig. 31, 1909.

This is an imperfect internal cast, but probably belongs to Gabb's species.

Eudolium petrosum Conrad.

Dolium petrosum (Conrad) Reagan, p. 195, pl. 3, fig. 32, 1909.

This is correctly identified.

Eudolium biliratum Conrad.

Dolium biliratum (Conrad) Reagan, p. 196, pl. 3, fig. 33, 1909.

This is a badly crushed internal cast, but is probably Conrad's species.

FOSSILS OF THE QUILLAYUTE FORMATION.

Yoldia (Cnesterium) oregona Shumard.

Yoldia cooperi (Gabb) Reagan, p. 206, pl. 4, fig. 34, 1909.

This is not the recent *Y. cooperi* Gabb, though closely allied.

Cardium coosense Dall.

Cardium meekianum (Gabb) Reagan, p. 206, pl. 4, fig. 35, 1909.

The type specimen comprises an internal cast of both valves of what appears to be a young shell of *C. coosense;* but among the miscellaneous duplicate material which came with the types, I find a fragment which may be referable to the true *C. meekianum.*

Cardium corbis Martyn.

Cardium corbis (Martyn) Reagan, p. 207, pl. 4, fig. 36, 1909.

The internal cast which served as Reagan's type, appears to have been correctly identified.

Mactra (Spisula) arnoldi n. nom.

Tivela crassatelloides (Conrad) Reagan, p. 208, pl. 4, figs. 37 *a.*, 37 *b.*, 37 *c.*, 1909.

Mactra albaria Arnold, Bull. U. S. Geol. Survey, No. **398**, pl. 41, fig. 4, 1910; not of Conrad.

The heavy valve referred to *Tivela* by Reagan, belongs to the Mactroid shell figured by Arnold under the name of *Albaria,* but which is much more elevated and triangular than the true *albaria.* Specimens of *albaria* are rare in Reagan's material, though he has identified one as *M. falcata* Gould.

Chione staleyi Gabb.

Dosinia staleyi Gabb, Pal. Cal., vol. 2, p. 24, 1866.
Tapes staleyi Gabb, Pal. Cal., vol. 2, part 2, pl. 7, fig. 42, 1868; Reagan, p. 209, pl. 4, fig. 38 *c.* only, 1909.

The specimens figured as number 38 *a.* and 38 *b.*, are defective individuals of *Chione securis* Shumard.

Macoma inquinata Deshayes.

Macoma inquinata (Deshayes) Reagan, p. 209, pl. 4, fig. 39, 1902.

Compared with specimens of the recent *Macoma inquinata* var. *arnheimi* Dall, this rather imperfect individual agrees fairly well. It is shorter and less acuminate behind than the typical *inquinata.*

Tagelus sp.

Tagelus californicus (Conrad) Reagan, p. 211, pl. 4, fig. 40, 1909.

The type is a fragment probably belonging to the genus, but insufficient to identify specifically.

Mactra (Spisula ?) precursor Dall.

Mactra californica (Conrad) Reagan, p. 211, pl. 4, fig. 41, 1909.

This is the internal cast of a large species whose form is analogous to that of *M. nasuta* Gould, though not identical. It is numerous in the duplicate material, but has little in common with the *M. californica* which is a small species.

Mulinia olympica n. nom.

Mactra exoleta (Gray) Reagan, p. 212, pl. 4, figs. 42 *a.*, 1909.
Mactra hemphilli (Dall) Reagan, p. 212, pl. 4, fig. 43, 1909.

Though the hinge is not visible, this appears to be a small *Mulinia*, in no way related to *M. exoleta.* The hinge figured at 42 *b.*, belongs to a different species. Figure 43 depicts a slightly larger specimen. It has no resemblance to the recent *M. hemphilli* or *exoleta.*

Mactra (Spisula) albaria Conrad.

Mactra (*Spisula*) *falcata* (Gould) Reagan, p. 213, pl. 5, fig. 44, 1909.

This is the only typical specimen of *M. albaria* among Reagan's types. The specimens doubtfully to *M. falcata* on p. 214, and figure on plate 5, figures 45 *a.* to 45 *c.*, are defective immature specimens of *M. arnoldi.*

Mya intermedia Dall.

Mya truncata (Lin.) Reagan, p. 214, pl. 5, fig. 46, 1909.

This is doubtless the same as the recent Alaskan species, though the specimens are rather defective, but it is certainly not the *M. truncata.*

? *Cylichna alba* Brown.

Cylichna alba (Brown) Reagan, pl. 5, fig. 47, 1909.

The type specimen has both ends broken off and the aperture invisible, but the remains have the aspect of a *Cylichna.*

Antiplanes perversa Gabb.

Pleurotoma perversa (Gabb) Reagan, p. 215, pl. 5, fig. 48, 1909.

This appears to be correctly identified, though the specimen is slightly stouter than the average recent specimen.

Lora sp.

Bela sanctae-monicae (Arnold) Reagan, p. 217, pl. 5, figs. 49 *a-b.*, 1909.

A fragment of the last whorl of a species of *Lora,* sculptured like Arnold's species, but really unidentifiable.

Lora miona Dall.

Bela fidicula (Gould) Reagan, p. 217, pl. 5, fig. 50, 1909.

Analogous to but not identical with *L. fidicula,* the specimen being well preserved, is confidently identified with the recent species.

Buccinum ? tenebrosum Hancock.

Buccinum bogachieli Reagan, p. 218, pl. 5, figs. 51 *a-b.*, 1909.

The portions of the type specimen not concealed by the matrix are well preserved, and agree closely with the same portions of *B. tenebrosum.*

Cymatium (Linatella) pacificum Dall.

Chrysodomus giganteus Reagan, p. 218, pl. 5, fig. 42, 1909.
Chrysodomus stantoni Reagan, l. c., fig. 53.

The sculpture gives this shell a superficial resemblance to such species as *Chrysodomus liratus,* but there is no doubt of its identity with the Coos Bay shell. Figure 53 is based on a decorticated specimen of the same species.

Chrysodomus imperialis Dall.

Neptunea maxfieldi Reagan, p. 219, pl. 6, fig. 54, 1909.

This has been well figured both in Professional Paper 59, and by Arnold in U. S. Geological Survey Bulletin 398.

Liomesus ? sulculatus Dall.

Monoceros engonatum (Conrad) Reagan, p. 220, pl. 6, fig. 55, 1909.

The specimens are too imperfect basally to be certain that they belong to *Liomesus*. The *Trophon* species cited on page 220, is not among the specimens received.

Nucella sp.

Purpura crispata (Chemnitz) Reagan, p. 121, pl. 6, fig. 57, 1909.

This is hardly identifiable, owing to its defective condition, but is probably a *Nucella* allied to *M. lamellosa* Gmellin.

The specimen identified by Reagan as *Purpura lapillus* is not in the collection, but was certainly not the Atlantic species.

Nucella (? var.) *quillayutea* Reagan.

Purpura lapillus var. *quillayutea* Reagan, p. 221, pl. 6, figs. 57 *a-b.*, 1909.

This is closely related to *Nucella lamellosa*, but is sufficiently distinct from any of the recent forms to constitute a good variety if not a species.

Strombiformis washingtoni Reagan.

Eulima washingtoni Reagan, p. 223, pl. 6, fig. 60, 1909.
Eulima smithi Reagan, l. c., fig. 61, 1909.

This is a good and rather remarkable species of Melanelloid type. The aperture not being accessible, the genus is not positively determined, but the shell resembles *Strombiformis riversi* Bartsch, from the Pliocene of Santa Monica.

The difference noted by Reagan between his two species is due to the fact that one specimen is decorticated.

Gyrineum mediocre Dall.

Ranella marshalli Reagan, p. 222, pl. 6, fig. 62, 1909.

The type specimen is identical with that from Coos Bay.

Natica (Cryptonatica) consors Dall.

Natica (*Cryptonatica*) *clausa* (Broderip) Reagan, p. 224, pl. 6, fig. 63, 1909.

This is the smaller common *Natica* of these beds.

Polinices (Lunatia) galianoi Dall.

Polynices (*Lunatia*) *lewisii* (Gould) Reagan, p. 225, pl. 6, fig. 64, 1909.

This is the common larger species of this horizon. It does not reach the size of *L. lewisii,* and has a different contour.

Purpura foliata Martyn.

Aporrhais (*Arrhoges*) *quillayutensis* Reagan, p. 226, pl. 6, fig. 65, 1909.

This is a cast with some remains of the shell adhering and is closely related to if not identical with *Purpura foliata* Martyn, better known as *Cerostoma foliatum.*

ART. XXX.—*A Mid-Devonian Callixylon;* by C. J. HYLANDER.

In the paleobotanical collections of Yale University there have long been some unstudied sections of a Devonian wood from Eighteen Mile Creek, New York. These sections were made by Dr. Wieland about 1900, from material collected by O. C. Marsh in 1860. They bear numbers 240, 241, and 242. Since this wood consists merely in siliceous fragments containing much residual carbon, and is otherwise poorly preserved, the structure is difficult to make out. Only the transverse and radial longitudinal sections are diagnostic. The tangential section failed, cutting a region of especially poor preservation, with oblique compression.

Nevertheless, a new species of Zalessky's genus CALLIXYLON (7)[1] is indicated, and attention to the plants rather than associated vertebrates must bring to light better material of the original stem type, supposedly a foot or more in diameter. If so, further sectioning must disclose the better conserved areas as in various other instances of petrified stems. Accordingly, it has been considered worth while to give the description which follows. The value of these notes rests in the fact also, that the fine type from the Indiana Black Shale, CALLIXYLON OWENI (6), is at hand for close comparison and renders less doubtful features that otherwise would be obscure. The camera lucida figures here reproduced are accurate to scale, and are not restored, but actual drawings of the areas they show.

Generic Position.

The grouping of the radial pits in discontinuous masses undoubtedly puts the wood of these sections into the genus *Callixylon.* Other characters also are those of typical Cordaitean wood, as described by Penhallow (5), or Elkins & Wieland (3). In regard to the specimens and their inclusion in Zalessky's genus, Dr. Wieland has the following to say:

---

[1] For Literature references see the end of this paper.

"Seward in his great textbook (vol. III p. 292) says of the reference of the Indiana black shale Cordaite to CALLIXYLON—'Miss Elkins and Dr. Wieland refer some upper Devonian wood from Indiana characterized by a grouping of the circular or elliptical bordered pits in the radial walls of the tracheids similar to those in CALLIXYLON TRIFILIEVI, which they include together with the middle Devonian species of CORDAITES NEWBERRYI in Zalessky's genus. Though these two American species are comparable in the discontinuous arrangement of the tracheal pits with the Russian type, the latter is characterized by primary xylem strands, a feature not recognized in the American stems; it would seem, then, undesirable to adopt the designation CALLIXYLON in preference to DADOXYLON unless there is evidence as to similar characteristics in the primary xylem.'

Is this either a guide to convenient usage or a logical conclusion? It is not well to lay stress on the precise position in the middle or upper Devonian for any of these forms, since their time range is only inferable. The interesting and decisive point is that in middle to later Devonian time there was a cosmopolitan group of Cordaites with the grouped pits, and such forms are known in a typical instance to have the old cryptogamic wood. The probability is that all have it. But if any of the species referred to CALLIXYLON with reservations well within the recognized usages of Paleobotany, were later found to lack cryptogamic wood, then a new genus would be indicated, perhaps a new family. Moreover, mere reference to *Dadoxylon* would settle nothing, where these recurrently variant forms are concerned. With or without the cryptogamic wood, there would still remain the chance that the leaf or floral characters varied strongly from the forms primarily designated as *Dadoxylon.* Like so many of the genera of Paleobotany, *Dadoxylon* is now more a group name than a genus in the purely botanical sense. And similarly *Callixylon,* in the first instance a needed generic distinction, must share the same fate of ultimate and convenient inclusiveness. Only thus may we avoid the use of over-many generic names in our descriptions and groupings of ancient plants. The other alternative must be genera of mainly one sole species.

These more or less silicified bits of lignitic wood must have attracted the attention of Marsh while searching in the limestone which thinly covers the Hamilton, and carries both fish and plant remains. They would thus be from near the close of the mid-Devonian. But the horizon might be in the Hamilton shale, or higher in the black shale of the Portage, also carrying plants. The bits were marked by Marsh as from the Hamilton group.

This Cordaite is not likely to be as old as the Paleopitys Milleri of the Old Red of Scotland;[2] and, incidentally, even the wood-cuts of the latter given by Hugh Miller in the 'Testimony of the Rocks,' fig. 3, permit fair judgment of the main features. It is seen that the pitting is of the Dadoxylon type (2 to 3-seriate), and the rays thin (uniseriate), as Miller discerned.

'The fossil botanist on taking leave of the lower Carboniferous beds, quits the dry land and puts out to sea.' So wrote the stylist of Cromarty over seventy years ago; and while not intended in the very severest literal sense, the epigram was long justified. But new methods of study and new discoveries have broadened the paleobotanic horizon, and helped to give material once thought inadequate, high value as evidence of structure, or distribution, or both. Perhaps no further answer is needed to any question why the fossil tree type here described was not earlier taken up."

Structure.

The tracheids of the sections cited are mostly rectangular in cross-section, and vary much in size. The average is thirty-five to forty-five microns across, in this respect differing sharply from the larger tracheids of Callixylon Oweni (3), which run from forty-five to sixty microns across. The walls appear thick, from three to five microns. In radial longitudinal section, the tracheids show the chief characteristic of the genus—the bordered pits of the radial walls, aligned in discontinuous groups. As in Callixylon Oweni (3), the pits are circular or irregularly elliptical in outline, and occur in a varying number of vertical rows, from one to three (in rare instances, four). These vertical rows of pits are rather closely set, without compression to marked hexagonal form, in the groups as aligned in radial bands that correspond to the bands of pit groups on the neighboring tracheid. Only in a few places in the Eighteen Mile Creek material is the grouping of the pits fully visible over any great area; the best area of preservation is shown in fig. 2. These features can of course only appear to advantage where there is little compression and the section cuts closely to the true radial wood lines.

---

[2] McNab, W. R.: On the Structure of a Lignite from the Old Red Sandstone; Trans. Bot. Soc. of Edinburgh, vol. 10, p. 312.

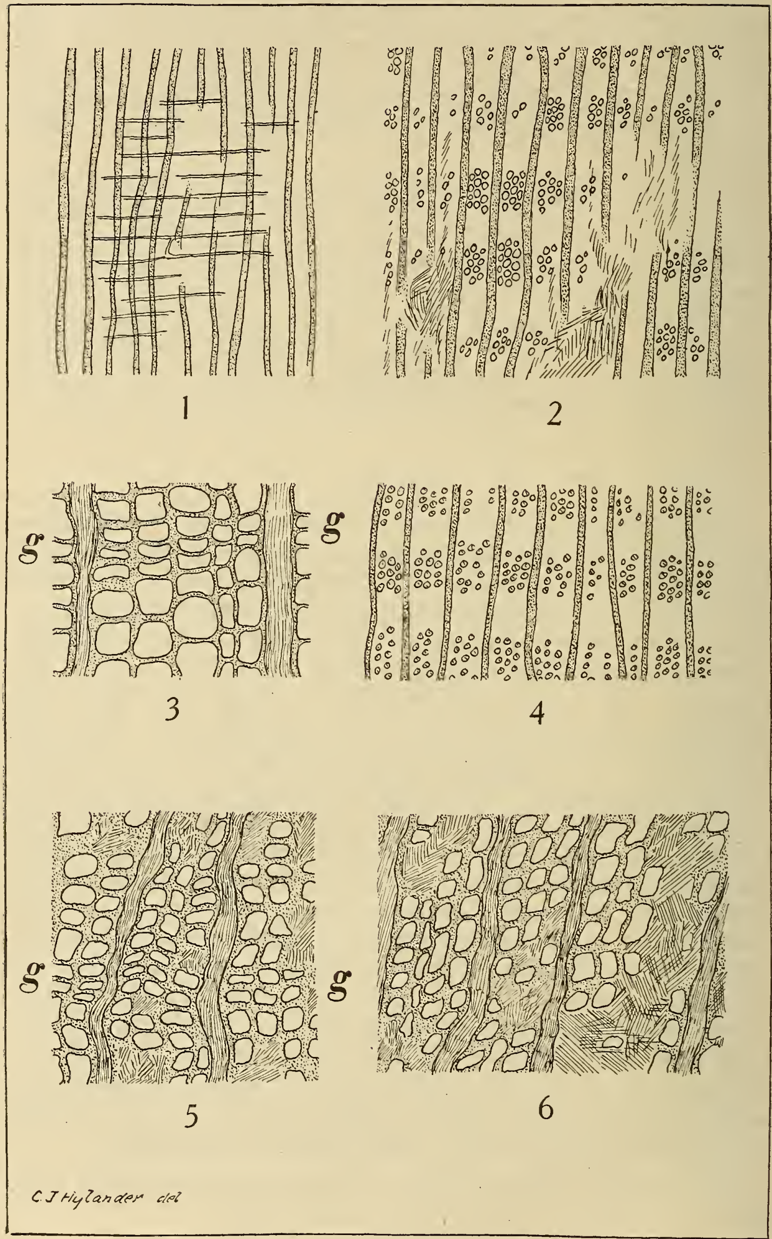


Fig. 1–6. Explanation opposite.

In the transverse section, the wood rays appear unusually wide, compared with the tracheids. They are also of considerable depth, varying from ten to fully twenty cells deep. In only one instance, in the radial longitudinal section, could the end of a ray cell be distinguished, and that is shown in fig. 1. The ray cells appear to be about the same size as those of CALLIXYLON OWENI. The cell-width of the rays is not visible in the imperfect tangential section, but the rays must be in part two-cells wide, as in *C. Oweni.* Wieland (6, p. 123) notes that in Araucarioxylon stems the wood rays are never more than two cells wide, although rays three and four cells wide are not infrequent in the older Cordaites.

The growth ring (fig. 5), as also in *C. Oweni* (fig. 3), is a significant feature of this wood, which may have been widespread in the mid-Devonian. Such growth rings are not present in the Russian *Callixylon;* nevertheless it is likely that the feature is more or less general in *Callixylon,* and it occurs in various other typical American Cordaites. Miss Goldring finds it in a Carboniferous Cordaite as far south as southern Texas (4). These ancient rings are not thought to indicate as sharp a seasonal change as the rings in Dicotyledonous plants. But on the other hand, little attention has been given to the fact that in old and simpler types of wood, growth rings do not become a feature of the wood structure. The simpler type of growth ring occurs in both Mesozoic and recent Cycads, and Chamberlain (1) has now observed it in a Monocotyl. Accentuation of growth ring is mainly correlated with the more marked tracheidal and ray differention of mid to later Mesozoic time.

EXPLANATION OF FIGURES 1-6. (All figures enlarged 100.)

CALLIXYLON MARSHII, sp. nov.

FIG. 1. Radial long. section showing approximate height of wood ray.

FIG. 2. Radial long. section showing the aligned grouping of the radial pits.

FIG. 5. Transverse section showing growth ring and average appearance of tracheids in one of the less compressed areas.

FIG. 6. Transverse section showing typical wood and conservation.

CALLIXYLON OWENI, Elkins & Wieland.

FIG. 3. Transverse section, showing growth ring and larger and well preserved tracheids. [Tracheid ends probably aligned.]

FIG. 4. Radial long. section, showing radial grouping of pits, for comparison with fig. 2.

Specific Characters.

Comparison of the type sections of Callixylon Oweni with those of the present Eighteen Mile Creek wood sections, reveals specific variation. There are the same discontinuous pit groups and obscure growth rings, but the tracheids are of a consistently smaller size not accounted for by compression or accidental variations, and the wood rays are relatively broader. Therefore, there need be no doubt in naming it after its finder of sixty years ago, who later became so famous as an indefatigable collector and paleontologist.

Callixylon Marshii sp. nov. Tracheids 35-45μ in diameter, walls 3-5μ thick, radial pits of the bordered crossed slit type, arranged in from one to three vertical rows in discontinuous groups of few to 12 or 13 pits to the grouping, groupings radially aligned; wood rays few to 20 cells deep, two cells wide, conspicuously broad in cross section; growth ring of primitive type present but difficult to see. Horizon, upper mid-Devonian of New York. Type locality, Eighteen Mile Creek, New York.

The following comparison is added for convenience: Trans. Sect.—Diameter of tracheids: C. Marshii, 35-40μ; C. Newberryi, 44-55μ; C. Oweni, 45-60μ. Thickness of walls: C. Marshii, 3-5μ; C. Newberryi, 6μ; C. Oweni, 5μ. Growth rings absent in C. Newberryi, also C. Trifilievi, present in the other two species. Radial long. Sect. Pit groups: 3-13 in C. Marshii, 6-13 in C. Newberryi, and 3-40 in C. Oweni. Pit diameter: 9.3μ in C. Newberryi, 8-10μ in C. Marshii, and 10-11μ in C. Oweni. Tang. Sect. Height of rays: C. Marshii, 1-20; C. Newberryi, medium height; C. Oweni, 1-40. Thickness of rays: C. Marshii, at least 2-seriate; C. Newberryi, 3-seriate rarely; C. Oweni, 2-seriate.

Thus it is seen that the C. Marshii is closer to C. Newberryi (2) than to C. Oweni. And this is an interesting point since the C. Newberryi is given from the mid-Devonian of Ohio. Neither of these forms can be confused with the forms called *Dadoxylon Ouangondianum* and *D. Halli* (2), from the mid-Devonian of New York. These are distinct as forms with four and five pit rows, the adpressed pits, and broad wood rays. They are mentioned merely because figured by Dawson along with the

C. Newberryi (2). A form Ormoxylon (2) is given with three pit rows, as having very narrow wood rays one cell thick, but this is more likely a typical *Dadoxylon*.

Literature cited.

[1] Chamberlain, C. J.: Growth Rings in a Monocotyl, Bot. Gaz., 72, 293-304. Text fig. 1-16, 1921.

[2] Dawson, J. W.: Fossil Plants of the Devonian and Upper Silurian of Canada, 92 pp., 20 pls., Geol. Surv., Canada. Montreal, 1871.

[3] Elkins, M. G., & Wieland, G. R.: Cordaitean Wood from the Indiana Black Shale, this Journal, 38: 65-78. pl. 1, 2, 1914.

[4] Goldring, W.: Annual Rings of Growth in Carboniferous Wood, Bot. Gaz., 72, 326-330, 1921.

[5] Penhallow, D. P.: Notes on the North American Species of Dadoxylon, Trans. Roy. Soc. Canada, 6, IV, 61, 1900.

[6] Wieland, G. R.: Flora Liasica de la Mixteca Alta, Inst. Geol. Mex., Bol. 31, 1914.

[7] Zalessky, M. D.: Etude sur l'anatomie du Dadoxylon Tchihatcheffi Göppert sp. Mem. du Comite Geol. Nouvelle Ser. Liv. 68, pp. 18-29, Pls. I-IV, St. Petersburg, 1911.

Osborn Botanical Laboratory,
Yale University.

SCIENTIFIC INTELLIGENCE.

I Chemistry and Physics.

1. *A Revision of the Atomic Weight of Beryllium: The Analysis of Beryllium Chloride.*—O. Honigschmid and L. Birkenbach call attention to the circumstance that the atomic weight of this metal, usually called glucinum in this country, is of much theoretical interest in connection with the study of the structure of atoms. For instance, according to the idea of Rydberg, as it has the even atomic number 4, its atom should consist of two helium atoms with 8 as its atomic weight, instead of about 9 as now accepted, or it might be composed of two isotopes of the values 8 to 12. Another view is that the atom is composed of two heliums and one hydrogen, making 9 the value. The fact observed by Strutt that beryl contains appreciable quantities of enclosed helium, indicating radioactive transformation, which is not known to be the case with any other minerals except those containing thorium or uranium, adds interest to the problem of this atomic weight.

The present investigators have made a very careful analysis of beryllium chloride, using the most refined modern methods and have obtained remarkably closely agreeing results with an average of 9.018. This is 1% lower than 9.1, the value accepted by the International Committee. The authors have pointed out a very probable source of error in previous determinations where the oxide was weighed in the fact that this powder is capable of absorbing atmospheric air to an appreciable extent. The fact that this atomic weight appears to be so close to the whole number 9 is of much interest.—*Berichte,* 55, 4. H. L. W.

2. *Experimental Attempts to Decompose Tungsten at High Temperatures.*—Gerald L. Wendt and Clarence B. Irion have considered the circumstances that atomic disintegration by radioactivity has been recognized for 20 years, that this decomposition has been artificially produced recently by Rutherford by the impact of α-particles on light atoms, that there is astronomical evidence that the heavier atoms do not exist at the temperatures of the hottest stars, and that Anderson, two or three years ago, devised a method of exploding wires at temperatures above 20,000°, well above that attributed to the hot stars, a method which has become valuable in spectroscopy. They have, therefore, carried out the explosion of fine tungsten wires within strong glass bulbs, so that the gaseous products of the explosions could be collected for analysis. A powerful electric current, usually of about 30,000 volts, which passed suddenly across a spark-gap, was used to cause the explosions. These were made either in a vacuum, or in carbon dioxide. The greatest precautions were

employed to exclude impurities from the bulbs. The principal feature of the results is that helium appears to be produced by these explosions of tungsten. Several lines in the spectra of the resulting gases were not identified, but it appeared that hydrogen was not formed. In the 21 recorded explosions in the presence of carbon dioxide, the residues after the absorption of the latter were remarkably variable, but about 20 cc. of the total gas thus obtained was accidentally lost before it was analyzed. This report is merely a preliminary one. The senior author has been obliged to suspend work for a year or more on account of ill-health, and the authors regret the somewhat sensational report of their work in the public press last March.—*Jour. Amer. Chem. Soc.* **44**, 1887. H. L. W.

3. *A Micro-Method for the Determination of Molecular Weights in a Melting-Point Apparatus.*—Nearly all of the organic solvents show only a few degrees of depression in their melting points from the presence of one gram-molecule per kilogram of dissolved substance, but KARL RAST has found in camphor a solvent that is distinguished by such an extraodinarily high depression that it presents the possibility of using a thermometer graduated in whole degrees, instead of the Beckmann thermometer, in determining molecular weights, and in permitting the use of the simple capillary-tube melting-point apparatus for the purpose. The freezing-point depression of camphor amounts to 40° for a normal solution (gram-molecules per kilogram), and since camphor is a solvent which will dissolve many organic substances in normal quantity, and almost all in ½ or ¼ normal amounts, the depressions can be accurately measured. The method is very simple. A few milligrams of the substance are fused with 10 to 20 parts of camphor in a small clean test-tube, and after solidification a portion is used for a melting-point determination. The original article should be consulted in regard to certain details. It appears that this simple method will be very useful to organic chemists.—*Berichte* **55**, 1051.

H. L. W.

4. *Women in Chemistry: A Study of Professional Opportunities.* By THE BUREAU OF VOCATIONAL INFORMATION. 8vo, pp. 273. New York City, 1922. (To be obtained from the above-mentioned Bureau, 2 West 43d St. Price, postpaid, paper-bound $1.10, cloth-bound $1.60.)

This report has been issued under the auspices of a large and distinguished advisory council which includes the presidents of the prominent colleges for women in this country. Information has been obtained directly from, and indirectly concerning, hundreds of women chemists, while a great many officials of scientific, educational and industrial institutions have contributed their experiences and opinions in regard to the matter.

The study of the subject has been an exceedingly extensive and thorough one, and the results are reported in a very excellent manner. There is a very elaborate classification of the different positions in chemistry, showing the varied character and wide scope of the work. The prejudices to be met by women, the training requirements, salaries, means of obtaining positions, and many other topics connected with chemical work are well discussed.

The book is to be highly recommended for the perusal of women students who are attracted by the study of chemistry and are considering making a specialty of the subject. It is an excellent book also for those who give advice to such students, and it may be added that young men who are prospective chemists can find in it much valuable information in regard to chemical positions. H. L. W.

5. *Spectrum of Aurora.*—In making the extended series of photographs of all light of the night sky reported in this journal **3**, 476, 1922, Lord Raleigh was fortunate in securing spectra of the aurora which show more detail than has been obtained in any previous photographs, but, except for the aurora line 5578 of unknown origin, the whole spectrum is accounted for by three groups of bands in the blue, the violet, and the ultra violet which have been proved by Bossekop to be negative nitrogen bands.

As the origin of this phenomenon has never been fully explained Rayleigh's study and attempt to reproduce these bands artificially are worth reporting.

A large tube through which a stream of rarefied nitrogen could be passed was prepared and arranged so that the various features of the cathode discharge could be isolated and their spectra separately photographed. The sources of light were four. (1) The pencil of cathode rays, which could be easily deflected by a weak magnetic field. (2) The undeflected or so-called "retrograde" rays which may be designated as atomic rays in distinction from (1) which are electronic. (3) The negative glow. (4) The so-called dark space which really emits some light and is only dark by comparison.

It was found that the relative intensities within the blue and violet groups of bands vary with the different kinds of excitation and that this difference was most conspicuous within the blue group. The point under examination was to determine which mode of excitation most closely approximated the relative intensity of these bands in the auroral spectrum. It was found that these intensities in the cathode rays, the negative glow and the dark space gave no approximation to the auroral conditions but the atomic ray spectrum did exhibit about the same intensity ratios as the spectrum of the aurora.

Numerous experiments on variation of pressure were tried as well as observations on the capillary spectrum-tube of ordinary form, at low pressure, but in no case does the development of the negative bands by cathode rays imitate the aurora as well as the atomic rays. As far as it goes this tends to support the idea that the aurora arises from rays from the sun of an atomic nature but our author has never been able to secure experimentally quite so simple a spectrum as that of the aurora. The negative nitrogen bands are accompanied by other details such as bands of the positive group or by the line 3995. Traces of hydrogen also are always present in the spectrum, the source of this gas evidently being the material of the electrodes.

It has been presumed on theoretical grounds that the upper air in which the aurora occurs is rich in helium and hydrogen but neither the present nor previous photographs show any traces of these gases in the spectrum of the aurora. The only alternatives are either that these gases are absent or that the conditions of excitation are not such as to develop their spectrum. As to hydrogen, all laboratory experience shows that any kind of electric discharge through air will reveal the smallest trace of hydrogen by its spectrum. The difficulty of explaining the absence of helium lines is not so great but it is still serious. On the diffusion theory the composition of the atmosphere well below the measured height of the auroral discharge should be at least five volumes of helium to one of nitrogen. If these figures are accepted it is very difficult on the hypothesis of atomic ray excitation to explain the absence of both the helium and the nitrogen lines from the spectrum. On the hypothesis of cathode ray excitation the helium lines might be vanishingly feeble but a new difficulty appears, namely that the intensity distribution in the nitrogen band spectrum of the aurora is not that characteristic of cathode rays but rather of atomic rays. The author dismisses the matter with the suggestion that the .true mode of excitation may be something entirely different from either.—*Proc. Roy. Soc.*, **101**, 114, 1922. F. E. B.

6. *Suspended Impurity in the Air.*—Some of the methods hitherto used for the trapping and examination of suspended impurities in the air are the following: (a) The filter-paper method, in which a given volume of air is filtered through white paper leaving a smudge upon it. From the darkening of the paper some estimate of the amount of impurity present is afforded by comparison with a properly constructed scale of shades. It is applicable only to the case of dark colored particles and their quantitative estimation is difficult as the amounts collected are hardly weighable. It has the further drawback that the sediment thus entangled in the meshes of the paper cannot be subjected to microscopic examination.

(b) The condensation method. When air not too dry and containing foreign particles is suddenly expanded condensation occurs about these particles which subsequently settle down in drops of moisture upon a glass floor where they may be counted. As water is known to condense on ions as well as upon dust particles the results obtained by this method cannot be very exact.

(c) The soluble filter method. When soluble filters such as collodion-wool or sugar are used the filter may be dissolved and the number of trapped particles in a small measured volume of the solution counted. The difficulty with this method is that the suspended particles may themselves be soluble, or particles which were aggregates would tend to subdivide. (c) The spray method. The air may be drawn through a spray and the capture counted or weighed after evaporating the water. As it is extremely difficult to wet dry dust this method cannot be considered very efficient.

It is to be noted that while all these methods tell something as to the matter deposited the relation as to the amount actually in suspension is rather uncertain. An improved method devised by Dr. J. S. Owens is free from many of the above objections. He has found that when a very small jet of air properly humidified is made to impinge at a high velocity upon a surface such as a microscope cover glass, the foreign particles adhere to the glass and a record is obtained which may be removed, examined, and counted microscopically. By varying the conditions of the experiment he was able to select the form of the orifice, the velocity of the air and arrangement of apparatus which gave the most satisfactory results. Also by subjecting a specimen of air to dust extraction in successive cells a very definite knowledge of the efficiency of the apparatus was secured. For the details the reader will naturally refer to the original paper which also contains an extended record of observations made at Norfolk, England, and a discussion of the probable sources of contamination. This investigation was carried out for the Advisory Committee on Atmospheric Pollution.—*Proc. Roy. Soc.,* **101**, 18, 1922.

F. E. B.

7. *The Principles of Geometry;* by H. F. Baker, vol. I, pp. VIII, 183. Cambridge, 1922 (Cambridge University Press).—The purpose of the author is to place the reader in touch with the main ideas dominant in contemporary geometry, or at least for those parts which precede the theory of higher plane curves and irrational surfaces. The present volume is entitled *Foundations* and is devoted to the indispensable logical preliminaries. Its method, however, is very different from the usual text book of geometry, on the one hand, and the work of the logical rigorist, on the other, in which the fundamental conceptions are analysed into a sufficient and final number of axioms. Adopting the view that a Science grows up from the desire to bring the results of

observations or the relations of a class of facts which appear to be connected under as few general propositions as possible, if it is found necessary to introduce abstract entities transcending the actual observations, the author is of the opinion that the degree of abstractness which may be usefully and safely applied is a matter for judgment and choice.

In particular the consideration of distance and congruence are rejected as fundamental ideas but in effect they are replaced by a theory of related ranges. Although the plan soon leads into the exposition of non-Euclidean geometry, the author believes that many students of the class who look forward to becoming engineers or physicists will find the course stimulating and easy.

Subsequent volumes will deal on the basis of results obtained in this volume, with conics, quadric surfaces, cubic curves in space, cubic surfaces and certain quartic surfaces. F. E. B.

II. MISCELLANEOUS SCIENTIFIC INTELLIGENCE.

1. *Smell, Taste, and allied Senses in the Vertebrates;* by G. H. PARKER. Pp. 192, with 37 figures. Philadelphia and London, 1922 (J. B. Lippincott Company).—This new volume in the series of monographs on experimental biology by American writers explains without unnecessary technicalities the structure, physiology, embryological development, and evolution of the chemical sense organs, or chemoreceptors, of man and the other vertebrate animals. The subject is treated from a comparative standpoint, the conditions found in man being first discussed, followed by an account of the homologous structures in the other groups of animals. The final chapter explains the interrelations of all the chemical senses and compares the chemoreceptors with the receptors for mechanical and radiant energy. At the end of each chapter is a brief bibliography of the more important literature on the subject.

The book brings together the results of recent studies on these complex sense organs, some of the most important of which have come from the author's own investigations, and makes the information so comprehensible that even the general reader can now gain a clear conception of the nature of some of the sensations which he has daily experienced but little understood. W. R. C.

2. *Science and Human Affairs from the Viewpoint of Biology;* by WINTERTON C. CURTIS. Pp. vii, 330. New York, 1922 (Harcourt, Brace and Company).—The author follows the history of the scientific method from the earliest times and shows how human progress has always been associated with advances in natural science. And this is particularly true of biological science, by means of which man has come to know about himself, his origin, his developmental history, his physical, physiological

and psychical peculiarities, with the gradual emancipation of mankind from persecution and superstition.

The second part of the book treats of the cell doctrine, organic evolution, and current problems and methods of zoological science, showing the profound influence which recent biological discoveries are having upon the philosophy of the everyday life of all classes of the people.

In the third part into which the subject is conveniently divided the importance of science in the solution of our present social problems is discussed and the dependence of the material and spiritual welfare of the race on continued scientific research is emphasized. The author holds that the cure for the present widespread social unrest and the solution of the complex problems in this reconstructive period will rest upon the recognition of nature's laws as the guiding principle in the ordering of all human affairs.

The book is thoughtful and scholarly, well arranged and pleasingly written; its reading will give one a more dignified view of science as applied to human welfare, with suggestions as to how he may aid in social progress. W. R. C.

3. *The Biology of the Sea-shore;* by F. W. Flattely and C. L. Walton, with an introduction by J. Arthur Thomson. Pp. xvi, 336, with 16 plates and 23 text-figures. New York, 1922 (The Macmillan Company).—The first two decades of the present century may be looked upon as the period of experimental biology, when the most important discoveries have been made in the laboratory. More and more, however, in recent years there has been a return to out-of-doors nature and a reawakened interest in old-fashioned natural history, now refined and dignified by the term "ecology."

This book is one of the first in several years to deal with the associations of organisms found along the shores of the seas, but the subject is treated in a much broader way than would have been possible without the knowledge gained by the intensive laboratory studies of past years.

How the hundreds of species of animals and plants to be found in even a limited area between tide-marks are associated together, how their distribution is determined by the physical characteristics of the shore, how the animals are provided with means for attack and defense, how they may regenerate their missing parts after injury or spontaneous fragmentation, how some forms are dependent upon others for food and protection, the wonderful adaptations for locomotion of the various types for securing food, for respiration under different conditions, their nervous organization and behavior, their reproduction and growth, their influence on the human welfare—these are the interesting topics discussed in so entertaining a manner that one is tempted to hurry to the shore and verify the stated facts by first-hand observation. W. R. C.

4. *New Meteoric Iron from Kentucky;* G. P. MERRILL (Communicated).—The National Museum has received from Professor A. M. Miller of the University of Kentucky an heretofore unrecorded 15 lb. mass of meteoric iron found while plowing in a field near Glascow in that state. The iron (an octahedrite) is much oxidized and evidently has lain long in the soil. There is no record of its fall. This is the eleventh iron meteorite thus far found within the state limits.

OBITUARY.

DR. ROLLIN D. SALISBURY, professor of geography and geology in the University of Chicago and dean of the Ogden Graduate School of Science, died on August 15 at the age of sixty-four years. He was graduated at Beloit College in 1881 receiving the degree of Ph.B., and later those of A.M. and LL.D. He was also professor of geology at the same institution, from 1884 to 1891. In 1891-92 he was professor in the University of Wisconsin, since which time he has been connected with the University of Chicago. His chief interest was early in glacial geology and subsequently more particularly in geography. In glaciology he was connected with the Geological Survey of New Jersey and the United States Geological Survey. A work in which he took an important part, in association with Professor T. C. Chamberlin, was the Geology published in three volumes (1904 and 1906). The first volume (654 pp.) dealt with Geologic Processes and their results; the second and third (692 and 624 pp.) with Earth History.

In his special subjects Professor Salisbury stood in the front as a thinker, investigator and teacher. His death robs the University of Chicago and the science of the country of a man of rare gifts and attainments, and an especially effective teacher.

DR. G. H. COX, recently geologist for the Josey Oil Company, and for a number of years professor of geology at the Missouri School of Mines, was killed in an automobile accident near Bristow, Oklahoma, on August 20.

CONTENTS.

Page

SCIENTIFIC INTELLIGENCE.

VOL. IV NOVEMBER, 1922

Established by **BENJAMIN SILLIMAN** in 1818.

THE
AMERICAN
JOURNAL OF SCIENCE.

EDITOR: EDWARD S. DANA.

ASSOCIATE EDITORS

PROFESSORS WILLIAM M. DAVIS AND REGINALD A. DALY,
OF CAMBRIDGE,

PROFESSORS HORACE L. WELLS, CHARLES SCHUCHERT,
HERBERT E. GREGORY, WESLEY R. COE AND
FREDERICK E. BEACH, OF NEW HAVEN,

PROFESSOR EDWARD W. BERRY, OF BALTIMORE,
DRS. FREDERICK L. RANSOME AND WILLIAM BOWIE,
OF WASHINGTON.

FIFTH SERIES

VOL. IV—[WHOLE NUMBER, CCIV].

No. 23—NOVEMBER, 1922.

NEW HAVEN, CONNECTICUT.
1922.

THE TUTTLE, MOREHOUSE & TAYLOR CO., PRINTERS, 123 TEMPLE STREET.

Published monthly. Six dollars per year, in advance. $6.40 to countries in the Postal Union; $6.25 to Canada. Single numbers 50 cents; No. 271, one dollar.

Entered as second-class matter at the Post Office at New Haven, Conn., under the Act of March 3, 1879.

WILEY BOOKS

The Works of

G. MONTAGUE BUTLER, E.M.,

Dean, College of Mines and Engineering,
University of Arizona.

Geometrical Crystallography

Gives the reader the ability to recognize crystal forms and especially systems at sight, and with the use of few, if any, instruments.

155 pages. 4 by 6¾. 107 figures. Cloth, $1.50.

A Pocket Handbook of Minerals.

Gives all the details needed to identify most of the minerals which mining men, students, or collectors are apt to encounter. The emphasis is always placed upon characteristic physical features.

311 pages. 4 by 6¾. 89 figures. Flexible binding, $3.00.

Pocket Handbook of Blowpipe Analysis.

Complete directions are presented for the determination of the composition of minerals.

80 pages. 4½ by 6¾. Cloth, $1.25.

Crystallography, Minerals and Analysis, Complete.

A handy combination of the three above books in one volume.

546 pages. 4 by 6¾. 196 figures. Flexible binding, $4.00.

HAYES' Handbook for Field Geologists.

Third Edition, Thoroughly Revised and Rearranged, by **SIDNEY PAIGE.**

A well-known educator says, of this book: "This work has been used by me and my students in geological surveying since its first appearance. . . . Dr. Paige has happily preserved with improvements the quality and the design of the original work."

166 pages. 4½ by 6¾. 20 figures. Flexible binding, $2.50.

JOHN WILEY & SONS, Inc.

432 Fourth Avenue
New York

London
CHAPMAN & HALL, Ltd.

Montreal, Quebec
Renouf Publishing Company

AJS 11.22

THE

AMERICAN JOURNAL OF SCIENCE

[FIFTH SERIES.]

Art. XXXI.—*The Silicates of Strontium and Barium*; by Pentti Eskola.

Contents.

Introduction.

Among the compounds of the alkaline earth metals (calcium, strontium, and barium), the sulphates and carbonates are common as minerals. In the case of the silicates, however, we find those of calcium common, but natural silicates of strontium and barium are few in number, complicated in composition, and of rare occurrence. Considering the existence of isomorphous carbonates, sulphates, and other compounds of these three elements, the non-occurrence of analogous silicates seems striking and suggests experimental investigation to answer the questions: Do strontium and barium under experimental conditions form such compounds as are known in the case of calcium? And, if they do, what are their properties and relations to the calcium silicates?

The calcium silicates which form from dry melts have been studied, but very little is known about the strontium and barium silicates. G. Stein[1] prepared some silicates and determined their melting points as follows: $SrSiO_3$, 1287°; $BaSiO_3$, 1368.5°; Sr_2SiO_4, 1593°. R. Wallace[2]

---

[1] G. Stein, Z. anorg. Chem., 55, 159, 1907.
[2] R. Wallace, Z. anorg. Chem., 63, 1, 1909.

carried out thermal investigations by the cooling curve method on the binary systems of the metasilicates of sodium and lithium with those of strontium and barium. He gives the melting point of $SrSiO_3$, 1529° and of $BaSiO_3$, 1490°. All his melting diagrams resulted in the type of complete solid solutions with a minimum. P. Lebedew,[3] for the system $BaSiO_3$-$CaSiO_3$, also found a melting curve of the complete solid solution type with the melting point of $BaSiO_3$ at 1438° and a minimum at about 1000°. Smolensky,[4] who studied the system $BaSiO_3$-$BaTiO_3$, found the melting point of $BaSiO_3$ at 1470°.

All these results were obtained by the cooling-curve method, using carbon crucibles and porcelain tubes to protect the thermo-elements. No quantitative optical or other physical diagnostics for the crystalline phases were given. In the absence of such characteristics, and in view of the poor agreement of the results, the melting diagrams merely based upon cooling curves are subject to large corrections and often entirely erroneous. The melting point determinations are, in fact, all considerably too low.

Very accurate determinations were carried out by Jaeger and Van Klooster,[5] who found the melting point of $SrSiO_3$, 1578 ± 1°, and of $BaSiO_3$, 1604 ± 0.5°. They, also, emphasize the unreliability of the cooling-curve method and illustrate this by experimental evidence. They determined further some physical constants of the compounds named. Their results will be mentioned later.

The entire field of the physical chemistry of the strontium and barium silicates being open, the first task was to investigate the two binary systems SrO-SiO_2 and BaO-SiO_2. Among the further problems, those regarding the relations of the metasilicates to the well-known wollastonite minerals seemed to me most interesting and were chosen for study. For still further comparison with corresponding calcium compounds I tried to synthesize the strontium and barium compounds analogous to two important lime silicate minerals, diopside and anorthite.

---

[3] P. Lebedew, Z. anorg. Chem., 70, 301, 1911.

[4] S. Smolensky, Z. anorg. Chem., 73, 293, 1912.

[5] F. M. Jaeger and H. S. Van Klooster, Proc. Kon. Akad. Amsterdam, 6, XVIII, 896, 1915.

Methods of Working.

The mixtures were made up of pure quartz, specially prepared calcium carbonate, barium carbonate "Squibb's reagent" and strontium carbonate from "Baker's analyzed chemicals." These substances were dried at 150° C before weighing, and mixed together, melted if possible, chilled and crushed, then reheated and ground twice more.

The equilibrium relations were ascertained almost exclusively by the quenching method. Heating curves were run in some cases for the purpose of checking the temperature measurements.

The temperatures were determined by potentiometer and a Pt-PtRh thermoelement calibrated against the melting points of diopside and anorthite. The temperatures, for the most part, are not far from the diopside-point, so that the calibration against diopside, together with the temperature limits taken in the quenchings, show the actual degree of accuracy of the work. Therefore those calibrations are stated below.

Diopside, melting point 1391.5°, in the standard scale corresponds to 14230 microvolts.

Date (1921)	Crystals μv	Melt μv	Correction	The systems under investigation
6 April	14100	14150	+ 105	$SrO-SiO_2$
28 April	14110	14130	+ 105	
11 May	14120	14130	+ 105	$BaO-SiO_2$ and $SrSiO_3-CaSiO_3$
17 June	14090	14110	+ 130	$BaSiO_3-CaSiO_3$
26 June[a]	14310	14330	— 90	
30 June	14310	14330	— 90	
5 August	14290	14310	— 70	
22 August	14270	14290	— 50	

[a] New thermoelement.

In the determination of the refractive indices I had the advantage of using the improved immersion method as worked out by Merwin.[6] This method involves an improvement in accuracy as well as in completeness, making it possible to determine at the same time dispersion as well as refractive indices. One determines directly, using a monochromatic illuminator, the wave-lengths for which the refractive indices to be measured

---

[6] E. Posnjak and H. E. Merwin, The ternary system $Fe_2O_3-SO_3-H_2O$, J. Am. Chem. Soc., 44, 1965, 1922.

match those of two or more members in the set of refractive liquids. The dispersions of the whole series of liquids used having been determined and expressed graphically, it now remains simply to locate, on the diagram, the points determined and to read the refractive index for any wave-length desired. The values obtained in favorable substances are dependable in the third decimal place, provided due care is taken for variations in the temperature.

In the present work the indices of refraction are given for four wave-lengths corresponding with the spectral line F($\lambda = 486\mu\mu$), Tl($\lambda = 535\mu\mu$), D($= 589\mu\mu$) and C($\lambda = 656\mu\mu$). In the actual determinations wave-lengths between 500 and 625 were commonly used, therefore the values for F and C may sometimes have an uncertainty of ± 0.001 or a little more, due to enlargement of the errors in extrapolation.

The System SrO-SiO_2.

The results of a thermal study of this system are given in table I.

TABLE I.

Composition wt. per cent		Temperature	Time	Resulting phases
SrO	SiO_2	°C.	minutes	
		Liquidus of cristobalite		
40	60	1636	15	Glass
40	60	1600	60	Glass and cristobalite
		Eutectic tridymite-$SrSiO_3$		
53.82	46.18	1368	30	Glass
53.82	46.18	1361	60	Glass and a little tridymite
53.82	46.18	1356	60	Tridymite, $SrO.SiO_2$, trace of glass
50	50	1363	25	$SrO.SiO_2$ and glass
		Liquidus of $SrO.SiO_2$		
50	50	1430	30	Glass
50	50	1420	60	Glass and $SrO.SiO_2$
60	40	1571	60	Glass
60	40	1552	45	Glass and $SrO.SiO_2$
		Melting point of $SrO.SiO_2$		
63.22	36.78[a]	1584	15	Glass
63.22	36.78	1580	15	$SrO.SiO_2$ and glass
63.22	36.78	1575	15	$SrO.SiO_2$ only

Eutectic $SrO.SiO_2$-$2SrO.SiO_2$

65	35	1554	15	Glass
65	35	1546	30	Glass and $SrO.SiO_2$
65	35	1538	15	$SrO.SiO_2$ and $2SrO.SiO_2$
67	33	1544	15	$SrO.SiO_2$ and $2SrO.SiO_2$

Liquidus of $2SrO.SiO_2$

67	33	1617	15	Glass
67	33	1600	15	Glass and $2SrO.SiO_2$
72	28	1628	15	Glass and $2SrO.SiO_2$
77.46	22.54b	1634	5	Sr_2SiO_4 only

a = $SrO.SiO_2$
b = $2SrO.SiO_2$

The equilibrium diagram (fig. 1) is based on the above results; the melting point of cristobalite has been placed at 1710°, according to the determinations of Ferguson and Merwin,[7] and the inversion point cristobalite-tridymite at 1470° according to Fenner.[8]

The liquidus curve of the silica minerals has the same general shape as formerly found in all the other binary systems with silica as one component: starting from the eutectic point first a very steep rise a little above 1600°.

The eutectic tridymite-$SrO.SiO_2$.—I prepared incidentally a mixture of 46.18 per cent SrO and 53.82 per cent SiO_2, corresponding to the proportion $SrO.2SiO_2$, to find out whether there was any disilicate of strontium, analogous to the barium disilicate known formerly. The result was negative, and this happened to be almost exactly the eutectic composition. The tridymite liquidus lying only about five degrees above the solidus, the eutectic composition can be located with a fair degree of accuracy at 46.5 per cent SrO and 53.5 per cent SiO_2. The temperature is 1358 ± 4°.

Strontium metasilicate, $SrO.SiO_2$.—Strontium metasilicate was found in only one form which shows a very close resemblance to α-$CaSiO_3$, or pseudowollastonite. Its melting point was determined as 1580 ± 4°, in agreement with Jaeger and Van Klooster's result, 1578 ± 1°. It is apparently of dihexagonal pyramidal symmetry, uniaxial and positive, and its characteristic habit is thick-tabular parallel to (0001). There is a fairly good basal cleavage.

---

[7] J. B. Ferguson and H. E. Merwin, this Journal, 46, 417, 1918.
[8] C. N. Fenner, this Journal, 36, 337, 1913.

FIG. 1.

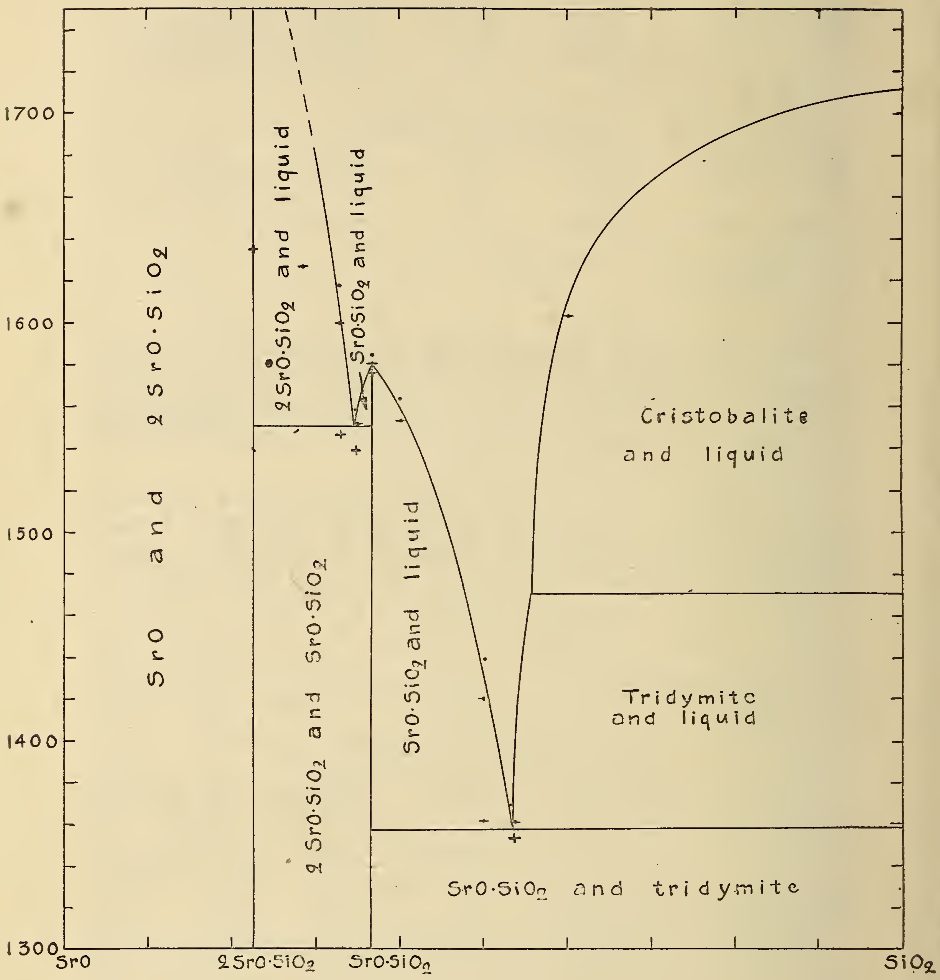


FIG. 1.—Temperature-concentration diagram of the binary system SrO-SiO$_2$.

The density, at 30°, determined with a pycnometer, is 3.650. This is calculated as real density, compared with water at 4° and making correction for the buoyancy of air. Jaeger and Van Klooster[9] found $d_4=3.652$ at 25.1°, in good agreement with that found by me which gives $d_4=3.653$.

---

[9] Loc. cit.

The refractive indices were determined in granular crystals obtained by cooling a pure melt. They were found to be:

	α	γ
F	1.606	1.646
Tl	1.602	1.641
D	1.599	1.637
C	1.596	1.634

These values were repeatedly checked and are correct in the third decimal place. Jaeger and Van Klooster give less exact values: $n_1 = 1.590 \pm 0.003$, and $n_2 = 1.620 \pm 0.003$.

α-$CaO.SiO_2$ has[10] $\alpha(D) = 1.610$; $\beta(D) = 1.611$; $\gamma(D) = 1.654$.

In the apparent uniaxial positive character and hexagonal tabular habit the strontium metasilicate is similar to α-$CaO.SiO_2$ and, as stated later, they form a continuous series of solid solutions. It would seem necessary, therefore, that they should be closely isomorphous. Now Wright[11] has proved α-$CaO.SiO_2$ to be really monoclinic, showing, in plates perpendicular to the optic normal, a polysynthetic twinning along the basal plane. The optic axial angle, though small, is not quite 0°.

Much care was taken to find out whether the strontium metasilicate shows a similar deviation from hexagonal symmetry, but no such phenomena were noticed, although apparent twinning was observed in the mix crystals of $SrO.SiO_2$ and $CaO.SiO_2$ (cf. below).

Euhedral crystals of $SrO.SiO_2$ were obtained from a strontium chloride melt with an excess of silica (cf. below). They are all thick tabular and apparently dihexagonal pyramidal (hemimorphic), one end being terminated only by the basal plane (fig. 2), sometimes with additional narrow pyramid faces, while the other end regularly shows well developed pyramids, usually combinations of two, three, or four simple forms. The pyramid faces are striated parallel to the edge with the basal plane. The greater part of the crystals are twinned on the base (fig. 3).

As the crystals are perfectly hexagonal in aspect and

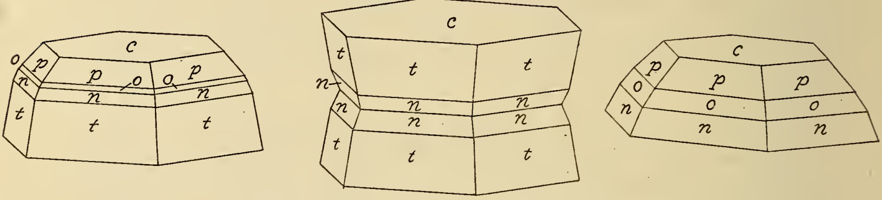
---

[10] G. A. Rankin and F. E. Wright: The ternary system CaO-Al_2O_3-SiO_2, this Journal, 39, 1, 1915.

[11] E. T. Allen, W. P. White, and F. E. Wright: On wollastonite and pseudowollastonite,—polymorphic forms of calcium metasilicate, this Journal, 21, 89, 1906.

the measurements failed to reveal any deviation from hexagonal symmetry, I shall provisionally describe them as hexagonal, although the isomorphism with the calcium metasilicate makes it probable that the strontium metasilicate is pseudohexagonal and really monoclinic, in that case belonging to the domatic, or monoclinic hemihedral class.

Fig. 2. Fig. 3. Fig. 4.



Figs. 2, 3, 4.—Crystals of $SrO.SiO_2$.

In examining these crystals with a binocular microscope one was found that was larger (about 0.5 mm in diameter) and better than the rest, but it was incomplete, having only faces in two pyramidal zones developed. These zones were identical, each combined of three different pyramids, $p(10\bar{1}1)$, $o(4045)$ and $n(20\bar{2}1)$ (fig. 4). While searching for evidence of monoclinic symmetry I measured a number of crystals, but unfortunately they were too imperfect to prove anything positively. Often the pyramidal faces were quite curved in their zones so that the signals appeared as lines instead of points. All the forms observed in the best crystals were, however, also identified in other crystals, and some of them at the same time in three pyramidal zones. A further form $t\ (50\bar{5}1)$ was found to be very common.

The following data are based on the best crystal, except for the last named form *t*.

The crystals separating from silicate melts and embedded in glass usually were bipyramidal in habit, with large basal planes, and thinner than those obtained from the chloride melt.

In summarizing the evidence regarding the crystal form of $SrO.SiO_2$, we may state that, from its solid solubility and apparent isomorphism with α-$CaO.SiO_2$, it might be expected to be monoclinic, but actually the crystals agree so closely with the dihexagonal pyramidal

	ρ			ϕ	
	Observed		Calculated	Observed	Calculated
	Limits	Average			
c (0001)	—— ——	——	0° 0′	— —	— —
p $(10\bar{1}1)$	49° 10′ — 49° 55′	49° 32′	49° 32′	30° 10′	30° —
o $(49\bar{4}5)$	55° 50′ — 56° 2′	55° 56′	55° 41′	— —	— —
n $(20\bar{2}1)$	66° 32° — 66° 55′	66° 44′	66° 55′	— —	— —
t $(50\bar{5}1)$	78° 20′ — 80° 50′	79° 17′	80° 20′	— —	— —

Axial ratio $a : c = 0.98$

symmetry that, judging only from the characters of the rather poor crystals available, it should belong to this class.

Another question that arose from the similarity to α-$CaO.SiO_2$ was whether $SrO.SiO_2$ would also appear in more than one form. Several experiments were made to settle this question.

$SrO.SiO_2$-glass was held one hour at 1020°. The result was a crystallized mass showing radiating scaly crystals, uniaxial, positive, $\omega = 1.600 \pm 0.003$, $\epsilon = 1.640 \pm 0.003$. It is consequently identical with the crystals separating from the melt.

The same result was achieved when the glass was held 4 hours at 950°.

$SrO.SiO_2$ was melted together with $SrCl_2$ in a Fletcher furnace and allowed to cool very slowly. After dissolving the chloride in water to which finally was added a little HCl to decompose the chloro-silicate that had formed, the result was the same form of $SrO.SiO_2$ as before.

The last-named experiment was modified so that the $SrO.SiO_2$-$SrCl_2$-melt was left in the platinum resistance furnace over night at about 1000°. The product was not metasilicate at all, but strontium orthosilicate, which was identified by its refringence and characteristic twinning.

Now, imitating the method that Allen and White[12] found most effective in changing pseudowollastonite into wollastonite, I prepared strontium vanadate, $Sr(VO_3)_2$, and melted one gram of this with two grams of $SrO.SiO_2$. The mixture was held over night at about 900°. After washing away the vanadate, the mass consisted of the

---

[12] E. T. Allen and W. P. White, this Journal, 21, 89, 1906.

same form of $SrO.SiO_2$, as rounded crystal grains and with no euhedral forms.

To prevent the formation of orthosilicate in the strontium chloride melt I finally heated $SrO.SiO_2$ with $SrCl_2$ and a considerable excess of silica, added in the form of coarse quartz grains, which dissolved rapidly in the melt above a gas burner. This mixture, held over night at about 1000°, gave well-developed crystals of the same form of $SrO.SiO_2$. The identity, as in all the other cases, was ascertained by determination of the refractive indices.

Thus all the experiments failed to show any other form of $SrO.SiO_2$ than the one similar to the pseudowollastonite.[13]

The eutectic $SrO.SiO_2$-$2SrO.SiO_2$ was located at 65.5 per cent SrO, as is apparent from the diagram (fig. 1). The steep slope of the liquidus curves at both sides is remarkable. While in the 65 per cent SrO mixture the primary phase is $SrO.SiO_2$, it is $2SrO.SiO_2$ in the 67 per cent SrO mixture, and the liquidus has risen 60° above the eutectic temperature, 1545°.

The existence of $3SrO.2SiO_2$ *not proved.*—The primary phase in all the mixtures between the eutectic at 65.5 per cent SrO and $2SrO.SiO_2$ is strontium orthosilicate. The following experiments were carried out in order to establish whether there might be formed the compound $3SrO.2SiO_2$, analogous to $3CaO.2SiO_2$, known from the studies on the calcium silicates.

Strontium carbonate and quartz powder in the proportion required to form $3SrO.2SiO_2$ (72 per cent SrO), well mixed together, were held 2 hours at 1475° and quenched. The product consisted of $SrO.SiO_2$ and $2SrO.SiO_2$. Another time the charge was allowed to cool slowly. The result was the same.

The same mixture was heated 16 hours at 1150°. It was now so fine-grained and poorly individualized, that it could not be decided whether there were one or two phases present. Neither $SrO.SiO_2$ nor $2SrO.SiO_2$ could be identified.

---

[13] Jaeger and Van Klooster (op. cit., p. 903) heated 0.5 g. of pure $SrO.SiO_2$ with 1 or 2 g. of sodium tungstate at 860° during 72 hours and always obtained the same form as by direct crystallization from a melt, whether they had started with crystals or with glass.

Strontium orthosilicate, $2SrO.SiO_2$.—The melting point of $2SrO.SiO_2$ is far above the range of the platinum resistance furnace.

In a search for several polymorphic forms of this compound I heated a preparation of crystalline $2SrO.SiO_2$ at different temperatures: 5 minutes at 1634°, 2 hours at 1415°, 1300°, and 990° respectively. The result was always the same form, well characterized by its refringence and twinning. It was also obtained from a $SrCl_2$ melt at about 1000° (cf. above, p. 339). Nor did the substance change when allowed to cool very slowly. The phenomenon of "dusting" in the case of $2CaO.SiO_2$ apparently has no analog here.

For the determination of the optical properties the preparation quenched from 1634° was used, with the following results.

	α	β	γ
F	1.740	1.744	1.766
Tl	1.7325	1.737	1.760
D	1.7275	1.732	1.756
C	1.722	1.727	1.752

The crystals are optically positive with $2E = 58°$ approximately, or $2\ V = 32°30'$.

In many of the crystals a twinning was observed, often repeated (fig. 5). In sections normal to γ, the acute bisectrix, the trace of the axial plane forms, with the composition planes of the twinning lamellæ, angles of 17°. Thus, if the crystal system is monoclinic, the plane of the optic axes is normal to the plane of symmetry.

The repeatedly twinned crystals, in their outlines, often display the habit of orthorhombic crystals, and when the lamellæ are very narrow they have apparent straight extinction.

---

[14] Free strontium oxide attacks platinum on heating. Every mixture does so as soon as it contains an excess, however small, of SrO over $2SrO.SiO_2$, while the more acid mixtures may be heated in platinum crucibles without any danger. The phenomenon appears as a blackening of the surface of the platinum and of the charge. This black substance is soluble in HCl, forming chloroplatinic acid.

A probable explanation is that the strontium oxide dissociates at high temperatures, either into metallic strontium or into a strontium suboxide which forms an alloy with platinum. This may be connected with the fact that the strontium oxide is somewhat volatile.

Both the dissociation and the volatilization are, however, very slight at the temperatures of the platinum resistance furnace. 0.300 g. SrO, wrapped in platinum foil and held 4 hours at 1580°, lost only 0.0017 g. in weight.

Strontium oxide, SrO[14].—All the mixtures which contained more SrO than $2SrO.SiO_2$, resulted in two phases, $2SrO.SiO_2$ and SrO, when heated at high temperatures. In these mixtures the strontium oxide could always be identified from its isotropic character and high index of refraction.

Fig. 5.

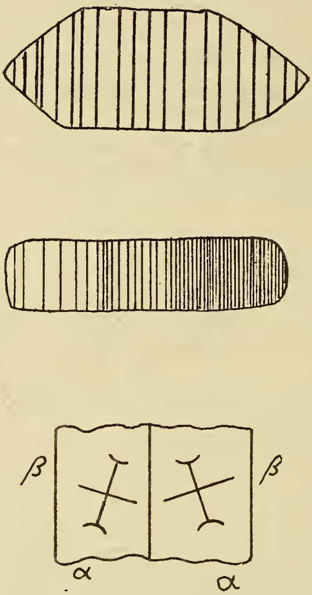


Fig. 5.—Crystals of $2SrO.SiO_2$.

Pure SrO was prepared in two ways, from strontium carbonate and from strontium nitrate. In the first case it forms minute rounded, though clear grains. When these were held 4 hours at 1580° they reacted slowly with water and even with HCl. From nitrate the oxide may be obtained as large clear crystals showing a perfect cubic cleavage.[15]

The determination of the index of refraction was very difficult, because the oxide instantly reacts with the high refractive liquids containing iodine. It was found to be somewhat higher than 1.86 for all the colors and may be very roughly estimated at 1.87.

[15] See also G. Brügelmann, Z. anorg. Chem., 10, 415, 1895.

The specific gravity has been determined by Brügelmann (loc. cit.) as 4.750.

According to H. Moissan,[16] strontium oxide melts more easily than calcium oxide, but nothing more is known about its melting temperature.

Wyckoff[17] has determined, by Debye and Scherrer's method, the crystal structures of CaO, SrO, BaO and mixtures of CaO with SrO and BaO, respectively, in samples prepared by me. His results have interest for us in so far as they prove SrO to be perfectly isomorphous with and to form a series of solid solutions with CaO.

The System BaO-SiO_2.

The quenching experiments pertaining to the system $BaO.SiO_2$ are described in table II.

TABLE II.

Composition wt. per cent						
Oxides		Compounds				
BaO	SiO_2	$BaO.2SiO_2$	$2BaO.3SiO_2$	Temperature °C	Time minutes	Resulting phases
				Liquidus of tridymite		
40	60			1551	90	Glass and tridymite
45	55			1472	120	Glass
45	55			1447	90	Glass and tridymite
				Eutectic tridymite-$BaO.2SiO_2$		
45	55			1372	135	Tridymite and $BaO.2SiO_2$
47.5	52.5			1390	120	Glass
47.5	52.5			1377	60	Glass and tridymite
47.5	52.5			1373	120	$BaO.2SiO_2$ and tridymite
50	50			1398	120	Glass
50	50			1385	60	Crystals and glass
50	50			1369	120	Tridymite and $BaO.2SiO_2$
				Melting point of $BaO.2SiO_2$		
55.98	44.02[a]			1425	90	Glass
55.98	44.02			1421	30	Glass
55.98	44.02			1419	60	$BaO.2SiO_2$ (with some glass)
				Liquidus of the solid solutions $BaO.2SiO_2$-$2BaO.3SiO_2$		
58	42	71	29	1441	60	Glass
58	42	71	29	1435	60	Glass
58	42	71	29	1432	60	Glass and mix crystals
60	40	42	58	1448	60	Glass
60	40	42	58	1443	60	Glass and mix crystals
61.25	38.75	23.9	76.1	1451	60	Glass
61.25	38.75	23.9	76.1	1448	60	Glass and mix crystals

[16] H. Moissan, Ann. Chem. Phys., (7) 4, 136, 1895.

[17] Ralph W. G. Wyckoff, unpublished data.

Solidus of the solid solutions $BaO.2SiO_2$-$2BaO.3SiO_2$						
58	42	71	29	1418	60	Crystals
58	42	71	29	1424	60	Mix crystals with little glass
60	40	42	58	1435	60	Mix crystals and glass
60	40	42	58	1431	60	Mix crystals
61.25	38.75	23.9	76.1	1443	60	Mix crystals and glass
61.25	38.75	23.9	76.1	1440	60	Mix crystals and glass
61.25	38.75	23.9	76.1	1438	60	Mix crystals
Melting point of $2BaO.3SiO_2$.						
62.90	37.10*b*			1451	60	Glass
62.90	37.10			1451	30	Glass
62.90	37.10			1448	30	Glass and $2BaO.3SiO_2$
Eutectic $2BaO.3SiO_2$-$BaO.SiO_2$						
65	35			1439	15	Glass
65	35			1435	30	$BaO.SiO_2$ and $2BaO.3SiO_2$ with a little glass.
65	35			1431	30	$BaO.SiO_2$ and $2BaO.3SiO_2$.
Eutectic $BaO.SiO_2$-$2BaO.SiO_2$						
75	25			1556	15	$2BaO.SiO_2$ and glass.
75	25			1546	15	$2BaO.SiO_2$ and $BaO.SiO_2$

a = $BaO.2SiO_2$ *b* = $2BaO.3SiO_2$

From these determinations results the equilibrium diagram fig. 6. A part of it is given on a larger scale in fig. 7.

The liquidus curves of cristobalite and tridymite in this binary system were, by means of a few quenchings, shown to have the same general character as in the system SrO-SiO_2, and were not investigated any more closely.

The eutectic tridymite-$BaO.2SiO_2$.—The mixture containing 47.5 per cent BaO was found to be very close to the eutectic composition, and on the tridymite side of it. The eutectic composition was placed at 47 per cent BaO, 53 per cent SiO_2 and the temperature at 1374°.

Barium disilicate, $BaO.2SiO_2$, has previously been studied by N. L. Bowen.[18] Crystals of this composition were found in optical glass of the variety known as "barium crown." They had the shape of platy elongated hexagons (fig. 8*a*), about 3 mm long, 2 mm wide,

---

[18] N. L. Bowen: Crystals of barium disilicate in optical glass. J. Wash. Acad. Sci., 8, 265, 1918. Cf. also N. L. Bowen: Devitrification of glass, J. Am. Ceram. Soc., 2, 261, 1919.

FIG. 6.

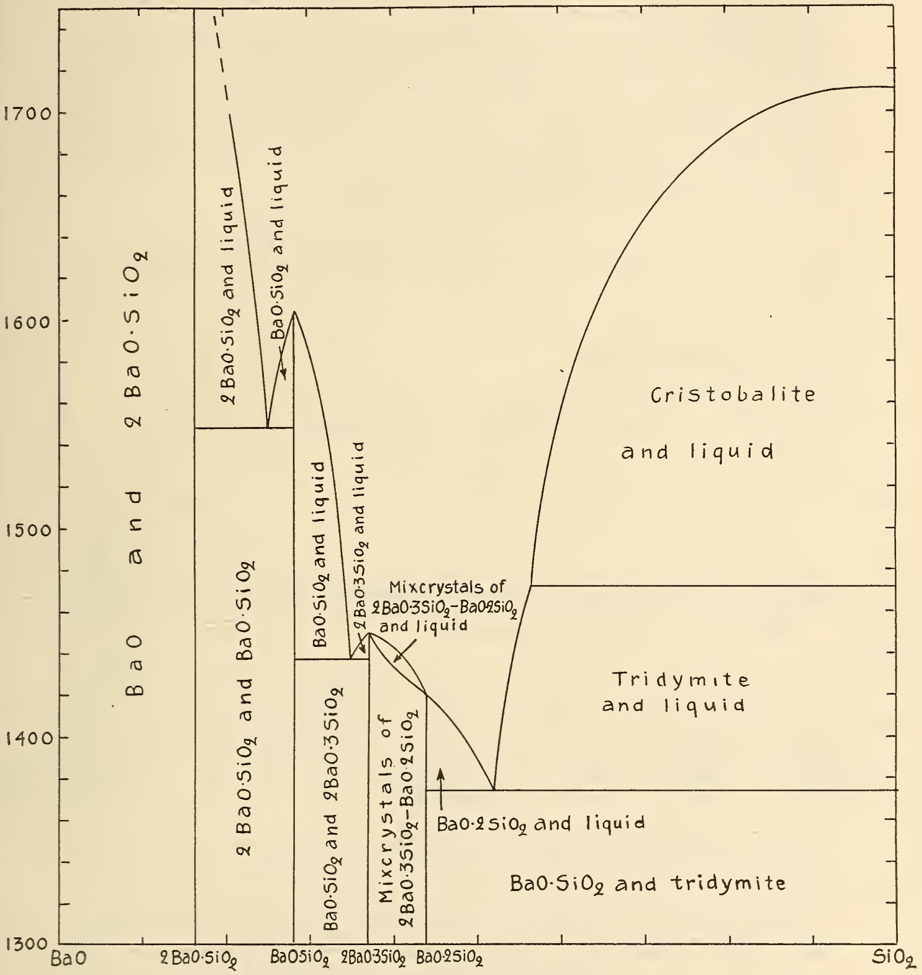


FIG. 6.—Temperature-concentration diagram of the binary system BaO-SiO_2.

and only 0.03 mm thick. The terminal angles were approximately 100° and the lateral angles 130°. The crystals are orthorhombic, the negative acute bisectrix being parallel to the elongation, and the plane of the optic axes parallel to the platy development, which is a good cleavage. $2V\,\alpha = 70^\circ$ approximately $\gamma = 1.613$; $\alpha = 1.595$.

In pure crystals obtained by cooling a melt of the composition $BaO.2SiO_2$ were found: $\gamma = 1.617$ and $\alpha = 1.598$. The melting point was determined by the heating curve method at 1426°C. Bowen suggests that the slightly lower values of the indices of refraction of the crystals in the optical glass may represent a real difference and that when formed in the glass they take a small amount of alkaline disilicates into solid solution.

FIG. 7.

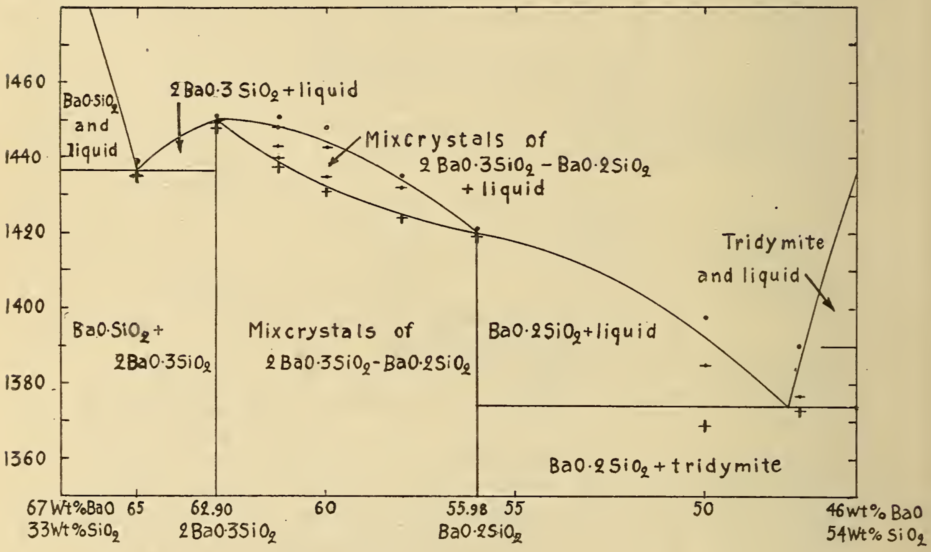


FIG. 7.—Part of the binary system $BaO\text{-}SiO_2$ showing the melting of the mix crystals of barium disilicate and dibarium trisilicate.

I prepared crystals of $BaO.2SiO_2$ from a $BaCl_2$-melt, and also obtained well-formed crystals embedded in Ba-silicate glass from a mixture containing 50 per cent BaO, held at 1385°. In both cases the crystals were bounded only by the three orthorhombic pinacoids, were very much elongated in the direction of α and had almost square cross sections (fig. 8*b* and 8*c*). There are notable cleavages in all the pinacoidal directions, but by far the most perfect is the one parallel to $\alpha\beta$, so that when crystalline masses of this substance, as for example, that obtained by cooling of the pure melt, are ground, there are formed almost exclusively scaly cleavage splinters normal to γ.

Fig. 8.
a. b. c.

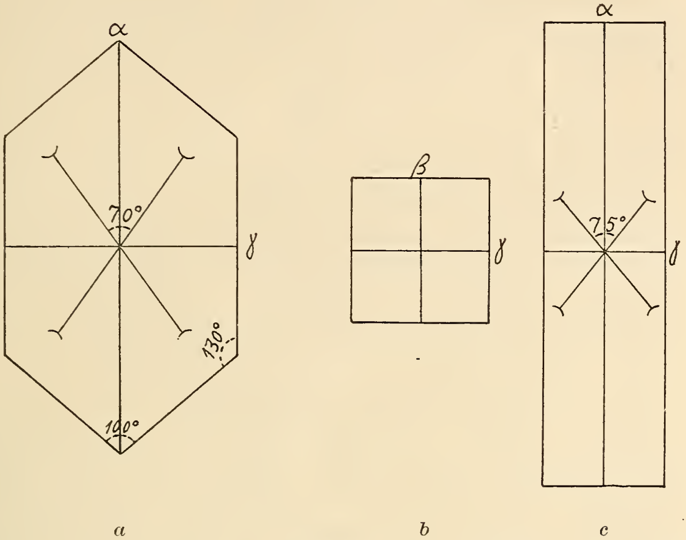


Fig. 8.—Optical orientation in crystals of barium disilicate: $\alpha =$ crystals in optical glass after N. L. Bowen; *b* and *c* = crystals from $BaCl_2$-flux, and as formed in barium silicate melt.

Thus these crystals are, in their habit, considerably different from those in the barium crown glass, as described by Bowen. In other ways my crystals agree well with the characteristics given by Bowen.

The indices of refraction are as follows:

$$\alpha(D) = 1.597;\ \beta(D) = 1.612;\ \gamma(D) = 1.621$$

As appears from these values, also confirmed by direct observation, the optical character is negative and the axial angle approximately 75°. A calculation from the indices of refraction gives $2V = 74°45'$.

The density, determined with the pycnometer, was found to be 3.73.

The melting point of pure $BaO.2SiO_2$, according to my measurements, is 1420 ± 4°.

There was no indication that the barium disilicate takes silica in solid solution; the crystals obtained from the mixture containing 50 per cent SiO_2 showed exactly the same optical properties as those from the pure melt. On the other hand it forms a remarkable solid solution series with another less acid silicate.

Solid solutions of barium disilicate, $BaO.2SiO_2$ *and dibarium trisilicate,* $2BaO.3SiO_2$.—My first observations pointing to the existence of solid solutions in the system BaO-SiO_2 were made with the mixture containing 60 per cent BaO. It was found to give only one kind of crystals very similar but not identical with those of $BaO.2SiO_2$. Furthermore I found that the crystals, when formed in a solid state (below the solidus) had lower refractive indices than they had when formed in the presence of a liquid phase (above the solidus). These observations made it probable that there exists a solid solution series without a maximum or minimum. In the course of the work this proved to be the case, the other end member of the series being the compound $2BaO.3SiO_2$.

The gradual change in the physical properties will appear from the following description.

Mixture 29 per cent $2BaO.3SiO_2$-71 per cent $BaO.2SiO_2$ gives crystals which agree fairly well with the pure disilicate. Among the three pinacoidal cleavages the one parallel to $\alpha\beta$ is most perfect. The optical character, however, is distinctly positive, with $2V = 70°$ approximately.

Density = 3.80.

The crystals of the composition 58 per cent $2BaO.3SiO_2$-42 per cent $BaO.2SiO_2$ show a different habit, being usually somewhat elongated along β. The cleavage parallel to $\beta\gamma$ is most perfect. Cleavage along $\alpha\beta$ also is good and that parallel to $\alpha\gamma$ distinct. Many crystals are composition twins along a prismatic face in the zone of α. The angle between β and the twinning plane is about 30°, or between β in both individuals about 60°. The optical character is positive and the axial angle quite small. I determined $2E = 44°$, or $2V = 27°$.

Crystals of the composition 76.1 $2BaO.3SiO_2$-33.9 $BaO.2SiO_2$ are equant grains, not elongated. Cleavage along $\beta\gamma$ is best, next to it that along $\alpha\beta$, while that parallel to $\alpha\gamma$ was hardly observed at all. The same prismatic twinning with the twinning plane parallel to α and inclined 30° to β was observed frequently, and is sometimes polysynthetic. The axial character is positive and the axial angle larger than in the former. I measured $2E = 56°$ or $2V = 33°30'$.

The mix crystals containing 94.2 per cent $2BaO.3SiO_2$ are in all their characters closely similar to the former ones.

The variation of the refractive indices in this solid solution series appears from table III and from fig. 9.

As may be seen from fig. 9, the indices of refraction, in the series of crystals between $BaO.2SiO_2$ and 2BaO.

FIG. 9.

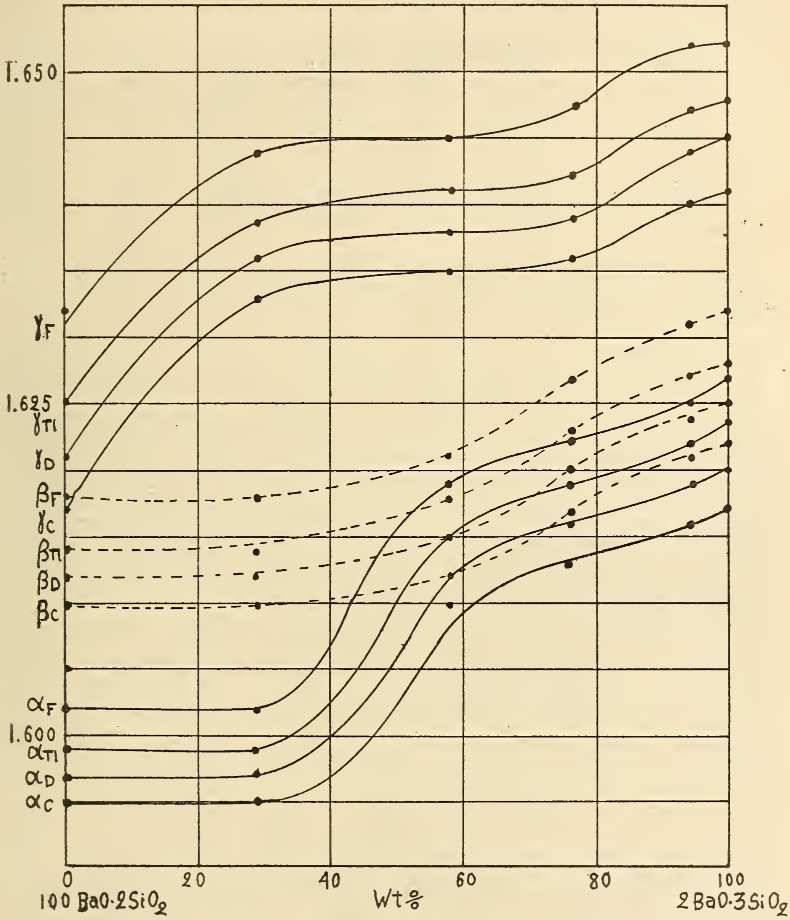


FIG. 9.—Variation of the indices of refraction in the series of mix crystals of barium disilicate and dibarium trisilicate.

$3SiO_2$, change gradually along with the composition, and all of them increase towards the latter end member, but their intermediate relations and hence the optic axial angles have rather complicated variations.

TABLE III.

Wt. % $2BaO.3SiO_2$	0	29	58	76.1	94.2	100
Wt. % $BaO.2SiO_2$	100	71	42	23.9	5.8	0
α(F)	1.602	1.602	1.619	1.622	1.625	1.627
α(Tl)	1.599	1.599	1.615	1.619	1.622	1.623
α(D)	1.597	1.597	1.612	1.616	1.619	1.620
α(C)	1.595	1.595	1.610	1.613	1.616	1.617
β(F)	1.617	1.618	1.621	1.627	1.631	1.632
β(Tl)	1.614	1.614	1.618	1.623	1.627	1.628
β(D)	1.612	1.612	1.615	1.620	1.624	1.625
β(C)	1.610	1.610	1.612	1.617	1.621	1.622
γ(F)	1.632	1.644	1.645	1.647	1.652	1.652
γ(Tl)	1.625	1.639	1.641	1.642	1.647	1.648
γ(D)	1.621	1.636	1.638	1.639	1.644	1.645
γ(C)	1.618	1.633	1.635	1.636	1.640	1.641
Density[a]	3.73	3.80	....	....	....	3.93

[a] The determinations of density in this series were made on only 0.5 g. of substance and are therefore less accurate than in the other cases.

It might seem probable, from the diagram, that α and β should exchange rôles at about 65 per cent $2BaO.3SiO_2$. Drawn thus, the curves for β would be nearly straight lines. I have not, however, drawn the curves across each other because it was found that the twinning along a prismatic face occurs in the same relation to the three main optical directions, in the two mixtures containing 58 and 76 per cent $2BaO.3SiO_2$. This indicates that the indices α and β have not exchanged rôles.

Dibarium trisilicate, $2BaO.3SiO_2$.—This pure compound was observed only in the form of a granular mass and I did not see any crystalline forms. It does not seem to have any disposition for prismatic or scaly development, the grains being rounded and equant. The only cleavage that appears perfect is that along $\beta\gamma$ while the two other pinacoidal cleavages are poorly developed.

The twinning and composition plane in the zone of α and inclined 30° from β forms polysynthetic lamellæ. In many cases just a few such lamellæ occur and they are so narrow that they appear as what is often called parting planes.

The indices of refraction (cf. table 3) are as follows:

$$\alpha(D) = 1.620;\quad \beta(D) = 1.625;\quad \gamma(D) = 1.645.$$

The optical character is positive and the axial angle is of about the same size as in diopside, or $2V = 58°$. A calculation from the indices of refraction gives 2V = 53° 30′. The density was found to be 3.93.

In summary, it appears that the two silicates $BaO.2SiO_2$ and $2BaO.3SiO_2$ are very perfectly isomorphous, have orthorhombic symmetry and pinacoidal cleavages. Their relations bear some resemblance to the plagioclase feldspar series. The melting diagrams of the solid solution series are quite similar, cleavage variations are similar. The variation of the refractive indices and optic axial angles is irregular in the plagioclases, though in a smaller degree than we have found here.

Very rarely do two compounds of the same element so different in chemical constitution form so perfect an isomorphous series.

Eutectic $2BaO.3SiO_2$-$BaO.SiO_2$.—The mixture of 60 per cent BaO and 40 per cent silica was found to have very exactly the eutectic composition between the barium metasilicate and the dibarium trisilicate, as appears from the fact that a melt of this composition gives the two crystalline phases simultaneously.

Barium metasilicate, $BaO.SiO_2$.—In the BaO-SiO_2 mixtures in wihch $BaO.SiO_2$ is a primary phase, this compound was found in the form of rounded globules or short rods with rounded ends. The latter show a negative elongation and parallel extinction. In glasses composed of mixtures of barium and calcium silicates (in the system $CaO.SiO_2$-$BaO.SiO_2$) it was frequently observed as small crystallites looking like short needles sharpened on both ends. These always show a parallel extinction and negative elongation. There is a well developed cleavage parallel to $\alpha\beta$. Grains placed parallel to this plane show the axial figures, with $2E = 50°$ approximately, or $2V = 29°$. Dispersion of the optic axes is strong: $\rho > \nu$. Birefringence is very weak. Grains parallel to $\beta\gamma$, showing the trace of the good cleavage along $\alpha\beta$, display abnormal blue interference colors. The indices of refraction were determined as follows:

	α	β	γ
F	1.682	1.684	1.688
Tl	1.677	1.678	1.682
D	1.673	1.674	1.678
C	1.669	1.670	1.673

The density at 4° was determined to be 4.399.

The melting point of $BaO.SiO_2$ is, according to Jaeger and Van Klooster, 1604 ± 0.5°.

To find out whether the barium metasilicate could be inverted into some other form I heated a sample of the crystallized compound, first alone and a second time with one-fifth of its weight $Ba(VO_3)_2$, over night at about 1100°. No change took place.[19]

Eutectic $BaO.SiO_2$-$2BaO.SiO_2$.—A mixture of these compounds, containing 75 per cent BaO, gave at 1546° crystals of both kinds, but at 1556° only crystals of $2BaO.SiO_2$ and glass. From this it may be concluded that there is a eutectic at about 74.5 per cent BaO with a melting point of 1551 ± 6°.

No other compounds except the two named above occur in this part of the system.

Barium orthosilicate, $2BaO.SiO_2$.—Barium orthosilicate appears as a granular mass of rounded grains and does not show any cleavages or twinning. The melting point is higher than that of platinum.

$$\alpha(D) = 1.810 \pm 0.005; \ \gamma(D) = 1.830 \pm 0.005.$$

Barium oxide, BaO.—Mixtures of barium orthosilicate and barium oxide were not studied more closely. The fact that all the mixtures containing an excess of BaO over the orthosilicate ratio attack platinum, seems to prove that they contain free BaO.[20]

Coarsely crystalline barium oxide was prepared from barium nitrate by heating slowly in a graphite crucible. It was obtained in clear translucent crystals showing cubic cleavage.

The refractive index is very high, but difficult to determine; the substance absorbs moisture from the air almost immediately when exposed and also attacks the high-refractive media (in this case mixtures of sulphur and selenium). I found (in red light):

$$n = 2.16 \pm 0.05.$$

Brügelmann has determined the specific gravity of barium oxide as 5.722.

---

[19] Jaeger and Van Klooster (loc. cit.) were not more successful in their attempt to effect a change by heating 0.5 g. barium metasilicate with 1 g. sodium tungstate at 860° for 72 hours.

[20] Barium oxide attacks the platinum in the same way as strontium oxide, but still more strongly.

The System $CaO.SiO_2$-$SrO.SiO_2$

The quenches made to establish the melting diagram of mixtures of the metasilicates of calcium and strontium are recorded in table IV.

TABLE IV.

Composition wt. per cent							
Oxides			Silicates		Temperature °C	Time minutes	Resulting phases
CaO	SrO	SiO_2	$CaO.SiO_2$	$SrO.SiO_2$			
36.13	15.81	48.06	75	25	1495	15	Glass
36.13	15.81	48.06	75	25	1485	15	Mix crystals
30.11	23.71	46.18	62.5	37.5	1482	15	Mix crystals and glass
30.11	23.71	46.18	62.5	37.5	1474	15	Mix crystals
24.09	31.61	44.30	50	50	1482	15	Glass
24.09	31.61	44.30	50	50	1478	15	Glass and mix crystals
24.09	31.61	44.30	50	50	1474	15	Mix crystals
21.08	35.56	43.36	43.75	56.25	1477	15	Glass
21.08	35.56	43.36	43.75	56.25	1472	15	Mix crystals
12.05	47.41	40.54	25	75	1511	15	Glass
12.05	47.41	40.54	25	75	1507	15	Glass and mix crystals
12.05	47.41	40.54	25	75	1500	15	Mix crystals and glass
12.05	47.41	40.54	25	75	1496	15	Mix crystals

As these data, together with the optical study of the mix crystals obtained, seemed fully to establish the general character of the melting diagram (fig. 10), it was considered unnecessary to determine the curve in more detail. Assuming as the melting point[21] of α-$CaO.SiO_2$, 1540°, and of $SrO.SiO_2$, 1578° (cf. above, p. 335), we get the diagram reproduced in fig. 10.

FIG. 10.

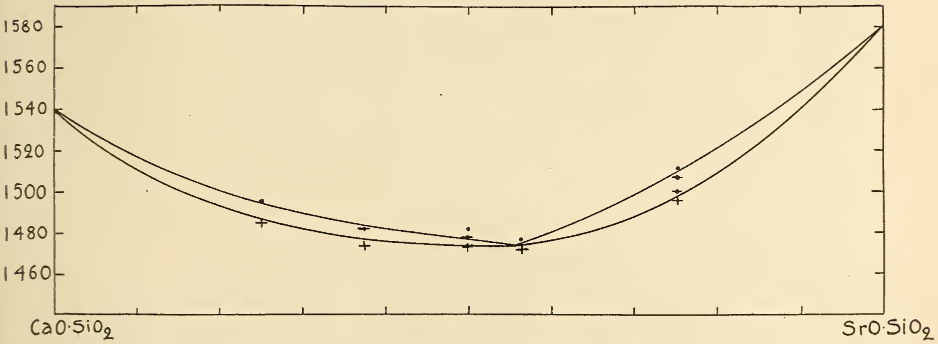


FIG. 10.—Temperature-concentration diagram of the binary system $CaO.SiO_2$-$SrO.SiO_2$ showing a complete series of mix crystals with a minimum.

---

[21] G. A. Rankin and F. E. Wright, this Journal (4) 39, 1, 1915.

The minimum melting temperature in this series was found to be 1474 ± 3° at the composition 44 per cent $CaO.SiO_2$–56 per cent $SrO.SiO_2$.

The mix crystals were found to be crystallographically very like α-$CaO.SiO_2$. Considerable care was taken to find out whether they show that twinning on the base which, in the case of pseudowollastonite, indicates monoclinic symmetry.

In α-$CaO.SiO_2$ I found frequently polysynthetic twinning along the basal plane, as described by Wright (loc. cit.). In mix crystals with 12.5 per cent $SrO.SiO_2$ the twinning was no less clear; in one case I measured an extinction angle of 3°. In the mixture with 25 per cent $SrO.SiO_2$ twinning was clearly observed, while, in mixtures with 37.5 per cent, 56.25 per cent and 62.5 per cent SrO the extinction angles were apparently so small that the twinning lamellæ, though occasionally positively identified, always appeared extremely faint. In a preparation with 75 per cent $SrO.SiO_2$ the occurrence of faint twinning along the base was still clearly observed. In the pure $SrO.SiO_2$ I did not succeed in finding definite twinning appearing as oblique extinction, in spite of much search.

In summary, therefore, it may be stated that all the crystals containing calcium and strontium metasilicates in solid solutions are pseudohexagonal and really monoclinic. In the pure strontium metasilicate, although it may belong to the same class of symmetry as the mix crystals, no deviation from hexagonal symmetry was observed (cf. p. 337).

The indices of refraction for the solid solution series were determined with the following results.

TABLE V.

Wt. % $CaO.SiO_2$	100	75	50	43.75	25	0
Wt. % $SrO.SiO_2$	0	25	50	56.25	75	100
α(F)	1.618	1.617	1.614	1.612	1.609	1.606
α(Tl)	1.614	1.612	1.609	1.608	1.605	1.602
α(D)	1.610	1.608	1.606	1.6045	1.602	1.599
α(C)	1.607	1.604	1.602	1.6015	1.599	1.596
γ(F)	1.663					1.646
γ(Tl)	1.667					1.641
γ(D)	1.654	1.651	1.646	....	1.642	1.637
γ(C)	1.649					1.634

The same is expressed in the diagrams (fig. 11) in which is also shown the variation in the index of refraction in the strontium and calcium metasilicate glass.

Fig. 11.

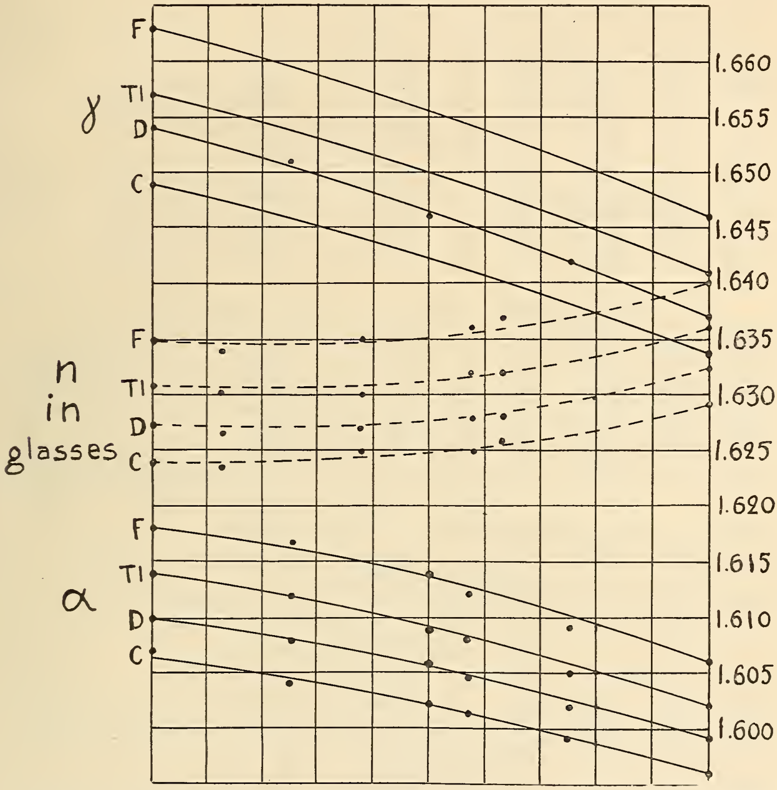


Fig. 11.—Variation of the indices of refraction in the mix crystal series $CaO.SiO_2$-$SrO.SiO_2$.

The System $CaO.SiO_2$-$BaO.SiO_2$.

While strontium and calcium metasilicates give a complete series of solid solutions and apparently are perfectly isomorphous, barium metasilicate does not mix at all with calcium metasilicate. Instead of this there occurs a double compound, $2CaO.BaO.3SiO_2$, which, however, has no true melting point, but breaks up into α-$CaO.SiO_2$ and liquid. Those quenches which yielded important results are quoted below in table VI.

TABLE VI.

Composition wt. per cent							
Oxides			Silicates		Temperature	Time minutes	Resulting Phases
CaO	BaO	SiO_2	CaO. SiO_2	BaO_2 SiO_2	°C		
Liquidus of α-$CaO.SiO_2$							
36.13	17.95	45.92	75	25	1466	15	Glass
36.13	17.95	45.92	75	25	1457	15	Glass and α-$CaO.SiO_2$
36.13	17.95	45.92	75	25	1441	15	Glass and α-$CaO.SiO_2$
36.13	17.95	45.92	75	25	1344	15	α-$CaSiO_3$ and glass
28.90	28.71	42.38	60	40	1394	15	Glass
28.90	28.71	42.38	60	40	1380	15	Glass and α-$CaO.SiO_2$
24.09	35.89	40.02	50	50	1342	15	Glass
24.09	35.89	40.02	50	50	1330	15	Glass and α-$CaO.SiO_2$
24.09	35.89	40.02	50	50	1326	15	Glass and α-$CaO.SiO_2$
24.09	35.89	40.02	50	50	1325	25	Glass and α-$CaO.SiO_2$
Invariant point α–$CaO.SiO_2$–$2CaO.BaO.3SiO_2$–liquid.							
24.09	35.89	40.02	50	50	1321	15	Glass and α-$CaO.SiO_2$
24.09	35.89	40.02	50	50	1319	15	Glass and $2CaO.BaO.3SiO_2$
24.09	35.89	40.02	50	50	1317	15	Glass and $2CaO.BaO.3SiO_2$
24.09	35.89	40.02	50	50	1300	15	Glass and $2CaO.BaO.3SiO_2$
22.88	37.69	39.43	47.5	52.5	1323	15	Glass
22.88	37.69	39.43	47.5	52.5	1321	15	Glass and $2CaO.BaO.3SiO_2$
22.88	37.69	39.43	47.5	52.5	1314	15	Glass and $2CaO.BaO.3SiO_2$
Decomposition of $2CaO.BaO.3SiO_2$							
25.13	34.32	40.54	52.18 $= 2CaO.BaO.3SiO_2$	47.82	1320	30	α-$CaO.SiO_2$ and glass
25.13	34.32	40.54	52.18	47.82	1315	20	$2CaO.BaO.3SiO_2$ only
Liquidus of $2CaO.BaO.3SiO_2$.							
21.68	39.48	38.84	45	55	1321	30	Glass
21.68	39.48	38.84	45	55	1316	30	Glass and $2CaO.BaO.3SiO_2$
21.68	39.48	38.84	45	55	1301	30	Glass and $2CaO.BaO.3SiO_2$
16.99	46.47	36.54	35.26 $(BaO.CaO.2SiO_2)$	64.74	1306	20	Glass
16.99	46.47	36.54	35.26	64.74	1300	20	Glass and $2CaO.BaO.3SiO_2$
16.99	46.47	36.54	35.26	64.74	1294	20	Glass and $2CaO.BaO.3SiO_2$
16.38	47.37	36.25	34	66	1293	20	Glass and $2CaO.BaO.3SiO_2$
16.38	47.37	36.25	34	66	1290	20	Glass and $2CaO.BaO.3SiO_2$
15.66	48.45	35.89	32.5	67.5	1289	15	Glass and $2CaO.BaO.3SiO_2$
15.42	48.81	35.77	32	68	1290	15	Glass
15.42	48.81	35.77	32	68	1284	25	Glass and $2CaO.BaO.3SiO_2$
14.45	50.25	35.30	30	70	1280	20	Glass
14.45	50.25	35.30	30	70	1276	20	Glass and $2CaO.BaO.3SiO_2$
14.45	50.25	35.30	30	70	1274	20	Glass and $2CaO.BaO.3SiO_2$
Eutectic $2CaO.BaO.3SiO_2$–$BaO.SiO_2$							
16.99	46.47	36.54	35.26	64.74	1273		$2CaO.BaO.3SiO_2$ and glass
16.99	46.47	36.54	35.26	64.74	1271		$2CaO.BaO.3SiO_2$ and glass
16.99	46.47	36.54	35.26	64.74	1265		$2CaO.BaO.3SiO_2$ and $BaO.SiO_2$

14.45	50.25	35.30	30	70	1270	$2CaO.BaO.3SiO_2$ and glass
14.45	50.25	35.30	30	70	1268	$2CaO.BaO.3SiO_2$ and $BaO.SiO_2$
13.25	52.04	34.71	27.5	72.5	1274	Glass
13.25	52.04	34.71	27.5	72.5	1271	Glass
13.25	52.04	34.71	27.5	72.5	1268	$2CaO.BaO.3SiO_2$ and $BaO.SiO_2$
12.05	53.83	34.12	25	75	1275	$BaO.SiO_2$ and glass
12.05	53.83	34.12	25	75	1267	$BaO.SiO_2$ and $2CaO.BaO.3SiO_2$
9.63	57.42	32.95	20	80	1267	$BaO.SiO_2$ and $2CaO.BaO.3SiO_2$

Liquidus of $BaO.SiO_2$

12.05	53.83	34.12	25	75	1300	Glass
12.05	53.83	34.12	25	75	1292	Glass and $BaO.SiO_2$
9.63	57.42	32.95	20	80	1367	Glass and $BaO.SiO_2$

The melting diagram resulting from these facts is given in fig. 12.

The liquidus curve of α-$CaO.SiO_2$ was followed to 50 per cent $BaO.SiO_2$. The α-$CaO.SiO_2$ which always separated in the form of thin crystals tabular parallel to the basal plane did not seem to take any $BaO.SiO_2$ in solid solution, as the crystals in all cases showed the indices of refraction characteristic of pure pseudowollastonite: $\alpha(D) = 1.609 \pm 0.002$; $\gamma(D) = 1.652 \pm 0.002$.

Dicalcium barium silicate, $2CaO.BaO.3SiO_2$.—When the mixture composed of 50 per cent $BaO.SiO_2$ and 50 per cent $CaO.SiO_2$ was allowed to crystallize on cooling, it formed a coarsely crystalline, fibrous mass, almost like natural wollastonite. The fibers were speckled with minute crystals of another substance ($BaO.SiO_2$). Supposing the fibrous crystals to have the composition $2CaO.BaO.3SiO_2$ I prepared such a mixture, which was now found to crystallize as homogeneous crystals and on heating to break up at 1320 ± 4° into α-$CaSiO_2$ and liquid.

The crystals are uniaxial and negative, probably hexagonal, and have good cleavages in their prismatic zone. A crystallizing mass develops negatively elongated fibers.

The indices of refraction were determined as follows:

	ω	ϵ
F	1.690	1.678
Tl	1.685	1.672
D	1.681	1.668
C	1.677	1.664

Fig. 12.

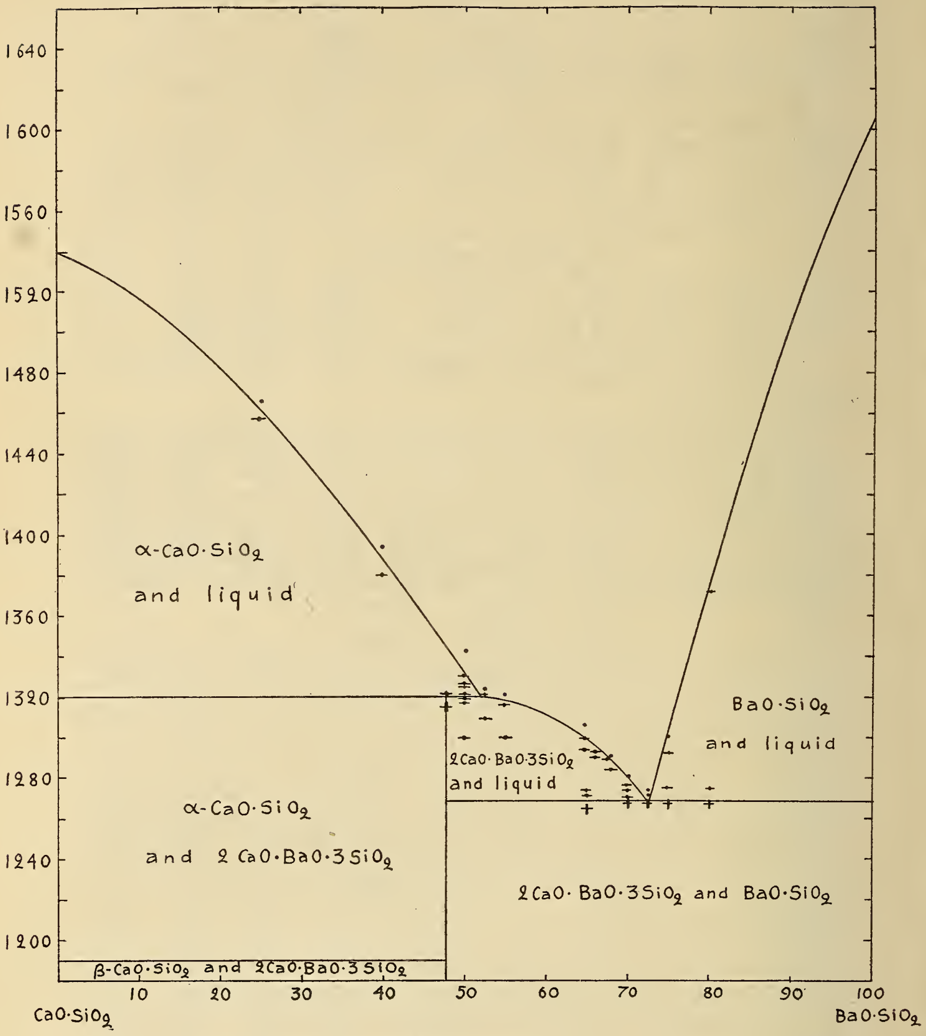


Fig. 12.—Temperature-concentration diagram of the binary system $CaO.SiO_2$-$BaO.SiO_2$.

As it was thought possible that there could exist solid solutions between the double compound and $BaO.SiO_2$, I determined the refractive indices of the exceedingly small crystals in preparations with 55 and 60 per cent

$BaO.SiO_2$. I found in both cases $\omega(D) = 1.683 \pm 0.003$; $\epsilon(D) = 1.669 \pm 0.003$. The results are not significantly different from those of the pure compound.

The invariant point $CaO.SiO_2$-$2CaO.BaO.3SiO_2$-melt.—In a mixture containing 50 per cent of $CaO.SiO_2$ and as much $BaO.SiO_2$ the crystals of $2CaO.BaO.3SiO_2$ break up into α-$CaO.SiO_2$ and liquid before melting entirely. In another mixture with 47.5 per cent $CaO.SiO_2$ the last crystals before complete melting consist of the double compound. The invariant point therefore is between these limits, and the course of both liquidus curves meeting there indicates it to be at 52 per cent $BaO.SiO_2$ and 48 per cent $CaO.SiO_2$, with the temperature of complete melting $1320 \pm 4°$.

The liquidus of $2CaO.BaO.3SiO_2$ has, from the invariant point, a regular course towards a eutectic. I followed its course very closely, because it was suspected that another double compound, $CaO.BaO.2SiO_2$, might possibly form here, its composition corresponding to 35.26 weight per cent $CaO.SiO_2$ and 64.74 weight per cent $BaO.SiO_2$. But no such compound could be isolated, and the corresponding mixture crystallized within an interval of 32° into a very fine mixture of $BaO.SiO_2$ and $2CaO.BaO.3SiO_2$.

The liquidus of $BaO.SiO_2$ was determined, with only a few quenches, to have a steep course towards the high melting point of the barium metasilicate.

The crystals of this compound in melts containing 75 to 80 per cent $BaO.SiO_2$ were not equant grains as in the system $BaO.SiO_2$, but needle-like, sharp at both ends. As they have formed at much lower temperatures than the crystals in BaO-SiO_2 melts, it may be possible that they represent another form of $BaO.SiO_2$. The refractive indices, however, so far as they could be determined, were identical, and experiments carried out to establish the transformation expected failed, even when mineralizers were applied (cf. p. 352).

The Properties of the Glasses.

The physical properties of representative glasses studied in the present work are tabulated below.

TABLE VII.

Glasses in the system $SrO–SiO_2$.

Wt. % SrO	46.2	50	60	63.2	67
Wt.% SiO_2	53.8	50	40	36.8	33
Formula	$SrO.2SiO_2$	—	—	$SrO.SiO_2$	—
n(F)	1.591	1.598	1.632	1.640	1.652
n(Tl)	1.587	1.595	1.627	1.636	1.648
n(D)	1.584	1.5915	1.624	1.632	1.644
n(C)	1.581	1.589	1.621	1.629	1.641
Density	3.201	—	—	3.537[a]	—

[a] Calculated from the value of specific gravity, $d(4°) = 3.540$, given by Jaeger and Van Klooster, op. cit. 902.

TABLE VIII.

Glasses in the system $BaO–SiO_2$.

Wt. % BaO	45	50	56	65
Wt. % SiO_2	55	50	44	35
Formula	—	—	$BaO.2SiO_2$	
n(F)	1.576	1.593	1.617	1.653
n(Tl)	1.571	1.589	1.612	1.648
n(D)	1.5665	1.585	1.6085	1.645
n(C)	1.5635	1.582	1.605	1.641
Density	—	3.441	—	—

FIGS. 13, 14.

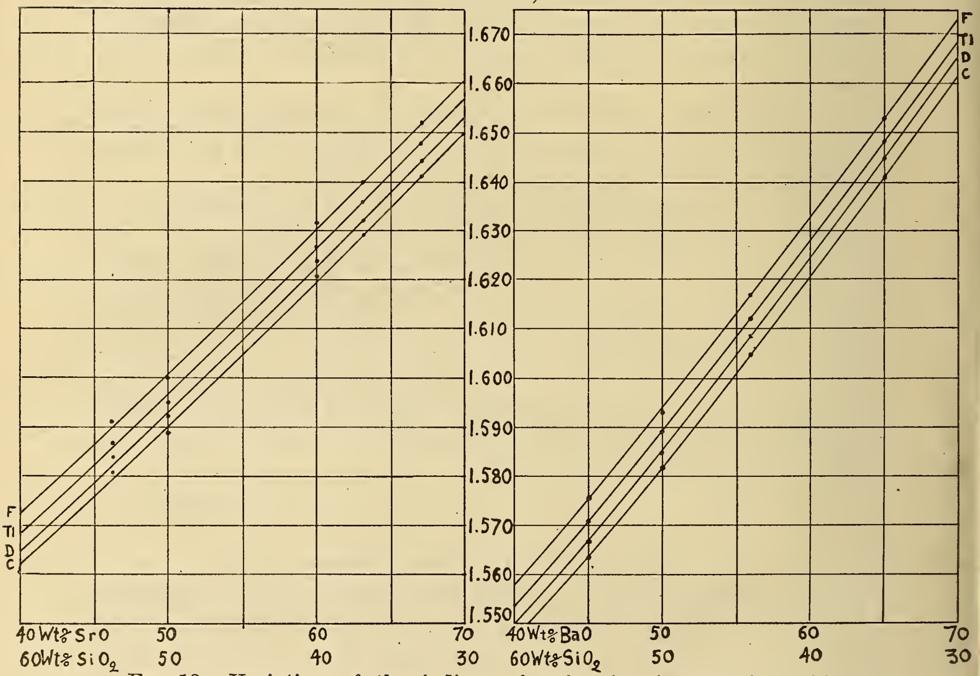


FIG. 13.—Variation of the indices of refraction in strontium silicate glasses.

FIG. 14.—Variation of the indices of refraction in barium silicate glasses.

Figs. 13 and 14 are diagrams of the variations in the refractive indices of glasses of the systems SrO SiO_2 and BaO-SiO_2 showing also the dispersions.

FIG. 15.

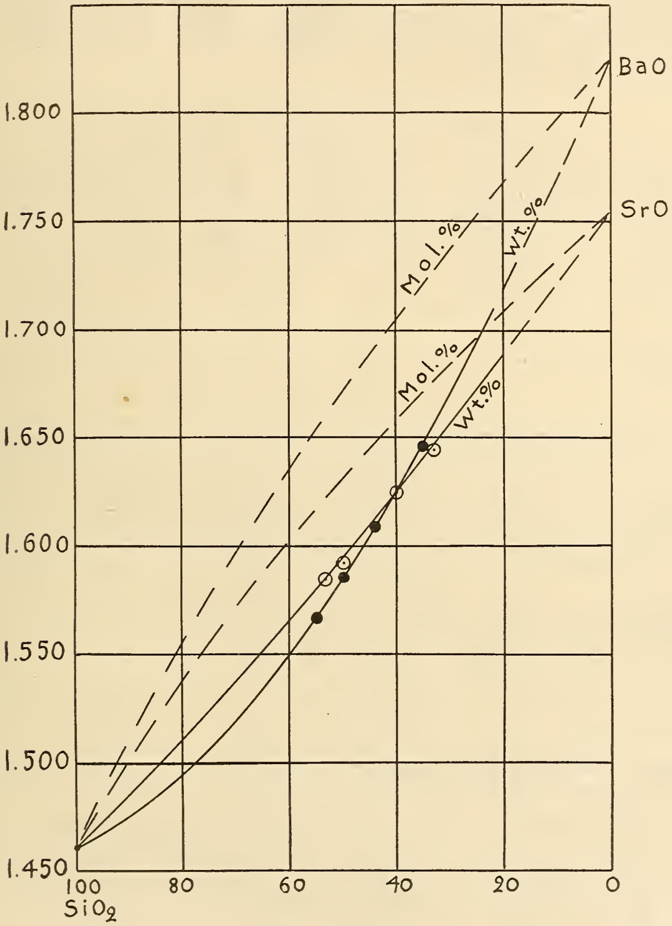


FIG. 15.—Variation of the index of refraction in strontium and barium silicate glasses.

Fig. 15 represents the same for the sodium light. The curves are drawn as far as the point corresponding to the index of refraction of silica glass and extrapolated up to the points of the hypothetical refractive indices of barium and strontium oxide glasses. In this part the curves, of course, can not give the values of the indices very exactly, while those of the acid end should be fairly accurate, and the data given here may be, in the case of the barium silicate, of some practical interest to the manufacturer of optical glasses.

In tables IX and X are given the determinations of refractive indices of glasses in the systems $CaO.SiO_2$-$SrO.SiO_2$ and $CaO.SiO_2$-$BaO.SiO_2$. The same is expressed in fig. 16.

FIG. 16.

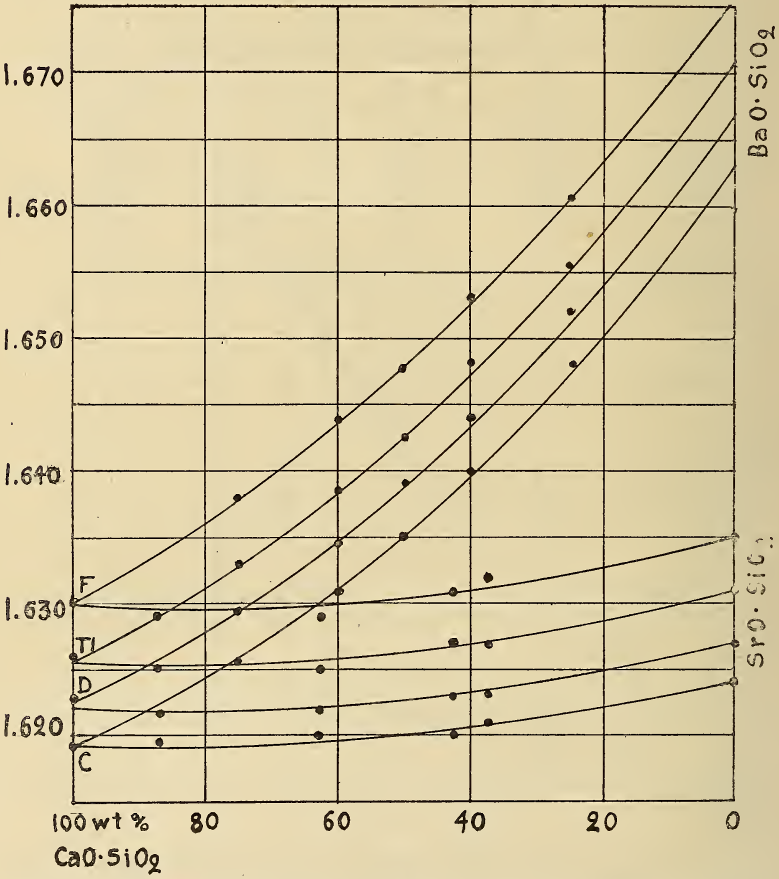


FIG. 16.—Variation of the indices of refraction in glasses of $CaO.SiO_2$. $SrO.SiO_2$ and $CaO.SiO_2$-$BaO.SiO_2$.

TABLE IX.

Glasses in the system $CaO.SiO_2$–$SrO.SiO_2$.

Wt.% $CaO.SiO_2$	100	87.5	62.5	43.75	37.5	0
Wt. % $SrO.SiO_2$	0	12.5	37.5	56.25	62.5	100
n(F)	1.635	1.634	1.634	1.636	1.637	1.640
n(Tl)	1.631	1.630	1.630	1.633	1.632	1.636
n(D)	1.628	1.6265	1.627	1.628	1.628	1.632
n(C)	1.625	1.6245	1.625	1.625	1.626	1.629

TABLE X.

Glasses in the system $CaO.SiO_2$–$BaO.SiO_2$.

Wt. % $CaO.SiO_2$	100	75	60	50	40	25	0
Wt. % $BaO.SiO_2$	0	25	40	50	60	75	100[a]
n(F)	1.635	1.643	1.649	1.6525	1.658	1.6655	(1.681)
n(Tl)	1.631	1.638	1.6435	1.647	1.653	1.6605	(1.675)
n(D)	1.628	1.6345	1.6395	1.644	1.649	1.657	(1.672)
n(C)	1.625	1.6305	1.636	1.640	1.645	1.653	(1.668)
Density					3.633		

[a] Extrapolated.

Absence of Diopside Analogs.

A few experiments were made to ascertain whether strontium and barium metasilicates form double compounds with magnesium metasilicate, analogous to diopside, the calcium compound, $CaO.MgO.2SiO_2$. Mixtures corresponding to these proportions were prepared and quenched from different temperatures.

A mixture corresponding to $SrO.MgO.2SiO_2$ gave only glass at temperatures above 1320 and, at temperatures down to about 1200°, glass and crystals that from their optical properties may have consisted of clinoenstatite. Another mixture of the composition $2SrO.MgO.3SiO_2$ gave $SrO.SiO_2$ as a primary phase. It therefore seems that the metasilicates of strontium and magnesium do not form any double compound at all. At any rate, there is no compound $SrO.MgO.2SiO_2$, analogous to diopside.

Furthermore, I made a mixture of 25 weight per cent $SrO.MgO.2SiO_2$ and 75 weight per cent $CaO.MgO.2SiO_2$, heated it above 1400° and let it cool slowly. The product contained diopside, showing $\alpha(D) = 1.665 \pm 0.002$; $\beta(D) = 1.675 \pm 0.003$; $\gamma(D) = 1.695 \pm 0.002$ and $2V = 60°$. These properties agree perfectly with those of pure diopside and consequently the crystals do not contain any strontium compound as isomorphous mixture. This conclusion, however, is not very dependable, as our experience is that strontium replacing calcium changes the optical properties of crystals very little. More weighty evidence proving positively that the amount of the strontium compound entering into solid solution in the diopside must be very small, is that the product consisted of more than one phase, the other phases besides the diopside being present as a fine crystalline mass.

The preparation of the composition $BaO.MgO.2SiO_2$, on cooling from a melt heated not above 1370°, also gave several phases, and no double compound analogous to diopside was formed.

This negative result is very remarkable, especially in the case of strontium, which in other ways showed such close similarity with calcium.

The Strontium and Barium Feldspars.

Former investigations.—From melts of the corresponding oxides Fouqué and Michel-Lévy[22] believed they had prepared strontium, barium, and lead analogs of anorthite, oligoclase and labradorite.

Their different "feldspars" had the following specific gravities:

	Sr	Ba	Pb
Oligoclase	1.619	2.906	3.196
Labradorite	2.862	3.333	3.609
Anorthite	3.043	3.573	4.093

The products were not well crystallized and their crystal system could not be determined with certainty. The barium feldspar, $BaAl_2Si_2O_8$, always formed microlites showing parallel extinction with negative elongation, and the crystals, being usually rectangular in cross section, seemed to be orthorhombic. Later investigation by E. Dittler,[23] on artificial barium feldspar, confirmed this result and also established it to be biaxial. Ginsberg,[24]

---

[22] F. Fouqué et A. Michel Lévy: Sur la production artificielle de feldspaths à base de baryte, de strontia et de plomb, correspondant à l'oligoclase, à labradore et a l'anorthite; études des propriétés optiques des ces mineraux, Bull. soc. min. France 3, 124. 1880.

[23] E. Dittler, Tscherm. Min. Petr. Mitt., 30, 122, 1911.

[24] A. S. Ginsberg, Ann. de l'Inst. Polytech. Pierre le Grand à Pétrograde, 1915, XXIII.

however, states that crystals of $BaAl_2Si_2O_8$ obtained by cooling of the pure melt were uniaxial, positive, and he regards this form as presenting a nephelite analog.

There is some evidence to the effect that some amount of lime, in plagioclase feldspars, may be replaced by baryta without changing the triclinic symmetry. Descloizeaux[25] found this to be the case in a natural feldspar from unknown locality, whose optical and crystallographic properties were similar to those of labradorite, while its composition resembled that of oligoclase more closely, with 7.30 BaO, 1.83 CaO, 7.45 Na_2O, and 0.83 K_2O. Ginsberg[26] investigated the binary system $CaAl_2Si_2O_8$-$BaAl_2Si_2O_8$ in artificial products and found that the triclinic anorthite may take up limited amounts of barium feldspar in solid solution, whereby the optic axial angle diminishes. The hexagonal $BaAl_2Si_2O_8$, on the other hand, may take up some lime feldspar.[27]

The relation of barium feldspar and orthoclase is far better known. Penfield[28] described barium-bearing orthoclase from Blue Hill, Delaware County, Pennsylvania. Later Sjögren[29] and Strandmark[30] studied the barium feldspar, or celsian, from Jakobsberg, Sweden, and proved it to have the composition $BaO.Al_2O_3.2SiO_2$. The latter establishes its monoclinic symmetry and crystallographic similarity to adularia. The crystals are usually elongated parallel to $\dot{c}$. The angle $\alpha \wedge \dot{c} = 3°1'$ in the acute angle β. $\alpha = 1.5835$; $\beta = 1.5886$; $\gamma = 1.5941$. Sp. g. 3.37. Strandmark also proved that the hyalophanes are isomorphous mixtures of celsian and orthoclase.

Rock analyses including determinations of BaO and SrO commonly show small amounts of both of these oxides. As Washington[31] has pointed out, the highest amount of both of these oxides have been found in certain highly potassic rocks of Wyoming, showing up to 1.10 per cent BaO and 0.30 per cent SrO. A study of the analyses published in Washington's Tables[32] shows that

---

[25] A. Descloizeaux, Tscherm. Min. Petr. Mitt., 7, 99, 1877.

[26] A. S. Ginsberg, loc. cit.

[27] The thermal work of Ginsberg was done by the cooling curve method and is subject to criticism (cf. p. 332).

[28] S. L. Penfield, this Journal, 36, 326, 1888.

[29] Hj. Sjögren, Geol. Fören., Förh., 17, 578, 1895.

[30] J. F. Strandmark, Geol. Fören. Förh. 25, 289, 1903; 26, 97, 1903.

[31] H. S. Washington, J. Franklin Inst., 190, 767, 1920.

[32] H. S. Washington, U. S. Geol. Surv., Prof. Paper 99, 1917.

the ratio of the percentages of BaO and SrO corresponds, to a considerable degree, with the ratio of the percentages of K_2O and CaO, so that it may be presumed that strontia is present in the plagioclase and baryta in the potash feldspar. A chemical investigation of the feldspars from the rocks in question might prove this to be true.

In the present study it was not intended to make any exhaustive experimental investigation of the strontium and barium feldspars, but a few experiments were made to elucidate their behavior.

As both the compounds, $SrO.Al_2O_3.2SiO_2$ and $BaO.Al_2O_3.2SiO_2$, were found to have very high melting points (far above 1700°) and to crystallize but poorly when the pure mixtures of the respective oxides were heated up, I applied the vanadate flux method to produce better crystals. In both cases the feldspar mixtures were powdered with about 1/3 of their masses of $Sr(VO_3)_2$ and $Ba(VO_3)_2$, respectively, and kept over night at about 1400°. The vanadates were then washed out with very dilute cold HCl.

Artificial barium feldspar, $BaO.Al_2O_3.2SiO_2$.—The barium feldspar thus obtained formed minute crystals, not more than 0.05 mm in length. They were elongated parallel to α and tabular parallel to $\alpha\gamma$, so that most crystals placed themselves on that plane and, in convergent light, showed the trace of the optical normal. The terminal faces show an apparent bilateral symmetry, like orthorhombic domes and, as the extinction is almost always parallel so far as can be determined, the crystals give entirely the appearance of orthorhombic symmetry, in agreement with the earlier results of Fouqué and Michel-Lévy, and of Dittler. I found, however, that this is only apparent and due to the fact that most of the crystals are Carlsbad contact twins, so that light has to pass through the two individuals with opposite extinction angles, the individuals being tabular parallel to 010, which is also the composition plane. The other forms are (110), which is the zone of elongation, and (001) and (101). In simple crystals, or in outstanding simple parts of the twins, there may be observed extinction angles of two or three degrees, and the optical orientation is thus: $\beta \parallel b$; $\alpha \wedge c = 3°$. Basal cleavage is not very well developed, though its trace may be seen occasionally. All these characters agree with those found in natural celsian. No evidence was found of the existence of a nephelite analog, a hexagonal form of $BaAl_2Si_2O_8$ described by Ginsberg.

The indices of refraction indicate a negative character. They were determined as follows and are compared with Strandmark's result on the natural celsian:

	α(D)	β(D)	γ(D)
Artificial barium feldspar[33]	1.587±0.002	1.593±0.002	1.600±0.002
Natural celsian	1.5835	1.5886	1.5941

The differences in the indices of refraction are somewhat greater than the probable errors, but not more than may be accounted for by the fact that the natural celsian carries a few tenths of a per cent of alkalies and lime.

Artificial strontium feldspar, $SrO.Al_2O_3.2SiO_2$.—The strontium feldspar obtained from the vanadate flux formed a crystalline mass showing radiating fibrous development but no well-formed crystals. No twinning could be discerned. Therefore nothing can be said about its crystallographic characters. The indices of refraction, however, were readily determined and are stated below, compared with those of anorthite.

	α(D)	β(D)	γ(D)
$SrO.Al_2O_3.2SiO_2$	1.574±0.002	1.582±0.002	1.586±0.002
$CaO.Al_2O_3.2SiO_2$	1.576	1.584	1.588

It was thus found that the strontium feldspar is, in its optical properties, exactly like the calcium feldspar within the limits of the possible errors. This is not very surprising in itself, as we have found in some cases the indices of refraction of the strontium compounds somewhat lower and in other cases somewhat higher than those of the calcium compounds.

A mixture of 50 weight per cent $SrO.Al_2O_3.2SiO_2$ and 50 weight per cent $CaO.Al_2O_3.2SiO_2$ was prepared and heated at about 1500°. It formed clear homogeneous-looking grains whose indices of refraction agreed with those of anorthite. It did not melt at this temperature and it is therefore probable that the strontium feldspar forms a complete series of solid solutions with anorthite.

---

[33] $\alpha(F) = 1.593$; $\alpha(Tl) = 1.590$; $\alpha(D) = 1.587$; $\alpha(G) = 1.585$

Some General Considerations Regarding the Relations of the Alkaline Earth Compounds.

With the exception of some rare titanosilicates, the only natural anhydrous silicates of barium known are barium feldspar, or celsian, $BaAl_2Si_2O_8$, notable for its isomorphism with potash feldspar, barylite, $Ba_4Al_4Si_7O_{24}$, and taramellite, $Ba_4Fe''Fe'''_4Si_{10}O_{31}$. Hydrated silicates are more numerous, mostly belonging to the zeolite group, namely: brewsterite, $H_4(Sr,Ba,Ca)Al_2Si_6O_{18} + 3H_2O$, harmotome, $H_2(K_2,Ba)Al_2Si_5O_{15} + 4H_2O$, edingtonite, $BaAl_2Si_3O_{10} + 3H_2O$ and wellsite $(Ba,Sr,Ca,K_2)Al_2Si_3O_{10} + 3H_2O$. Micas sometimes contain appreciable amounts of barium.

No strontium silicates are known as minerals, though this element, in smaller quantities, is contained in some rock-forming feldspars, probably plagioclases (cf. p. 365), and in hancockite, a lead-epidote, and in zeolite minerals heulandite, $H_4(Ca,Sr)Al_2Si_6O_{18} + 3H_2O$, and wellsite and brewsterite, named above.

The present study adds some information concerning the isomorphous relations of a number of other silicates of strontium and barium. Thus the compound $BaO.2SiO_2$ which was suggested by Bowen (loc. cit.) to be isomorphous with the potassium disilicate studied by Morey and Fenner,[34] has now been found to be also isomorphous with $2BaO.3SiO_2$. A strontium metasilicate was found to be isomorphous with a form of calcium metasilicate, and a strontium orthosilicate is probably isomorphous with either the α or the β form of calcium orthosilicate. A strontium feldspar was found to be probably isomorphous with the lime feldspar, anorthite, which is also isomorphous with a soda feldspar.

Now taking into account all the compounds of the alkaline earths, silicates as well as others, we may discriminate, according to their isomorphous relations to compounds of other elements, at least four different classes:

(1) Calcium, strontium, and barium compounds isomorphous with each other (all or two of them) and also isomorphous with lead compounds. Examples: The tetrahedral-pentagondodecahedral nitrates of Ca(?), Sr, Ba, and Pb. The orthorhombic carbonates, aragonite, strontianite, witherite, and cerussite. The sulphates,

---

[34] G. W. Morey and C. N. Fenner, J. Am. Chem. Soc., 36, 215, 1914.

celestite, barite, and anglesite, form an isomorphous series which excludes calcium sulphate. Among silicates we note the group of hancockite and epidote, and we have now found that the metasilicates form an isomorphous series to which belong only the calcium and strontium, but not the barium metasilicate.[35]

(2) Calcium and strontium (also barium?) compounds isomorphous with each other and also isomorphous with sodium compounds. Example: Anorthite and strontium anorthite.

(3) Barium compounds isomorphous with potassium compounds. Example: Barium disilicate. Among the natural silicates named above, celsian and harmotome are representatives of this class.

(4) Calcium compounds isomorphous with corresponding compounds of magnesium, ferrous iron and a number of other elements, but not with those of barium or strontium. Example: The rhombohedral carbonates, calcite, magnesite, siderite, etc.

It seems to be a rule that in the compounds in which the lime may possibly be replaced by magnesia and ferrous oxide, it can not be replaced by strontia or baryta. Thus it was found in the present work that there are no strontium or barium compounds analogous to diopside, $CaO.MgO.2SiO_2$.

Accordingly we find, in nature, strontium and barium compounds forming mix crystals with lime and alkali minerals, but not with ferromagnesian, although the latter may contain calcium. In other words, these elements are likely to be found in salic rather than in femic rocks, a circumstance that is really very striking in their distribution in the igneous rocks.

The authors of the so-called quantitative classification of igneous rocks make a distinction between salic and femic lime. Now these terms gain added significance, as we find that only the salic but not the femic lime may be replaced by strontia.

It may be of interest, for the sake of comparison, to present together some important properties of the members of some well known simple compounds of the three alkaline earth metals.

---

[35] Bourgeois (Ann. chim. phys., 29, 445, 1883) records a lead metasilicate of a similar appearance to those of calcium and strontium.

		Mol. vol.	$(\alpha+\beta+\gamma)/3$
Carbonates:	Aragonite	34.01	1.632
	Strontianite	39.87	1.615
	Witherite	45.82	1.627
Sulphates:	Anhydrite	45.99	1.586
	Celestite	46.18	1.626
	Barite	51.96	1.641
Metasilicates:	β-$CaO.SiO_2$	40.09[36]	1.625
	α-$CaO.SiO_2$	40.11[36]	1.625
	$SrO.SiO_2$	44.91	1.612
	$BaO.SiO_2$	48.57	1.675

The carbonate series exemplifies the rule found to hold good in many other instances that the molecular volumes, in an isomorphous series, increase regularly with the atomic weights of the substituted elements. Compounds which are not isomorphous often show a discrepancy in their molecular volumes, as for example anhydrite in its relation to celestite and barite.

The metasilicate series, in the regular increase of the molecular volumes with the atomic weight, behaves more like an isomorphous series, although we know that barium metasilicate is not isomorphous with the others. Our knowledge of the solid solubility relations of the carbonate and sulphate series is too incomplete to allow any closer comparison.

In the refringence one can hardly see any regular relation. The barium compounds have mostly the highest indices of refraction, but the carbonates make an exception, aragonite having higher indices than witherite. Among the strontium compounds some have higher and others lower indices than the corresponding calcium compounds, without any apparent regularity.

Schaefer[37] carried out a thermal study of the binary systems $CaCl_2$-$SrCl_2$ and $CaCl_2$-$BaCl_2$. He found, in the former case, a complete solid solubility with a minimum in the melting curve, while the latter do not mix at all, but

---

[36] These values have been obtained by computing the specific gravities at 25°, compared with water at 25°, as found by Allen and White (this Journal, 21, 103, 1906), for α-$CaO.SiO_2$ 2.912 and β-$CaO.SiO_2$ 2.214, in terms of density, i. e. comparing with water at 4° and making the correction for the buoyancy of air. Thus, for *α-$CaO.SiO_2$*, $d = 2.901$ and, for β-$CaO.SiO$, $d = 2.903$.

[37] Walter Schaefer, Neues Jahrb. Min. Geol., **1**, 15, 1914.

form a double compound $CaCl_2.BaCl_2$ which shows an incongruent melting, breaking up into crystals of $BaCl_2$ and liquid. These relations are in all particulars, except in the molecular proportion of the double compound, strictly analogous to those of α-$CaO.SiO_2$ to the metasilicates of strontium and barium.

In the lime-silica system there occur the basic silicates $3CaO.SiO_2$ and $3CaO.2SiO_2$ the analogs of which were not found in the systems strontia-silica or baryta-silica. The last-named system, on the other hand, is the only one in which occur silicates more acid than the metasilicate, namely, $2BaO.3SiO_2$ and $BaO.2SiO_2$. Among the alkali metals, in a similar way, the one having the lowest atomic weight (lithium) forms the most basic silicates and those with higher atomic weights (potassium, etc.) more acid silicates.

Summary.

Fig. 17 gives a synoptical view of the melting diagrams for the three binary systems CaO-SiO_2, SrO-SiO_2, and BaO-SiO_2. To make the diagrams really comparable they are all expressed in terms of molecular percentages.

The compositions and melting or decomposition points of the compounds and eutectics, etc. in the three systems are listed in table XI. Table XII gives all the important properties determined for the strontium and barium silicates.

In the system SrO-SiO_2 the following compounds were found: SrO, $2SrO.SiO_2$, $SrO.SiO_2$ and SiO_2. With the exception of silica each of them was found in one form only, although the temperature of formation of the strontium silicates was varied from the melting points down to about 900°.

Especial interest was taken in the strontium metasilicate, $SrO.SiO_2$, which was found to be closely isomorphous and optically very similar to α-$CaO.SiO_2$. It therefore probably belongs to the monoclinic crystal system, but its crystals agree so closely with the hexagonal system that, judging only from its own properties, it would seem to belong to this system. The crystals are apparently hemimorphic and might belong to the dihexagonal pyramidal or, if they are monoclinic, to the monoclinic domatic class.

FIG. 17.

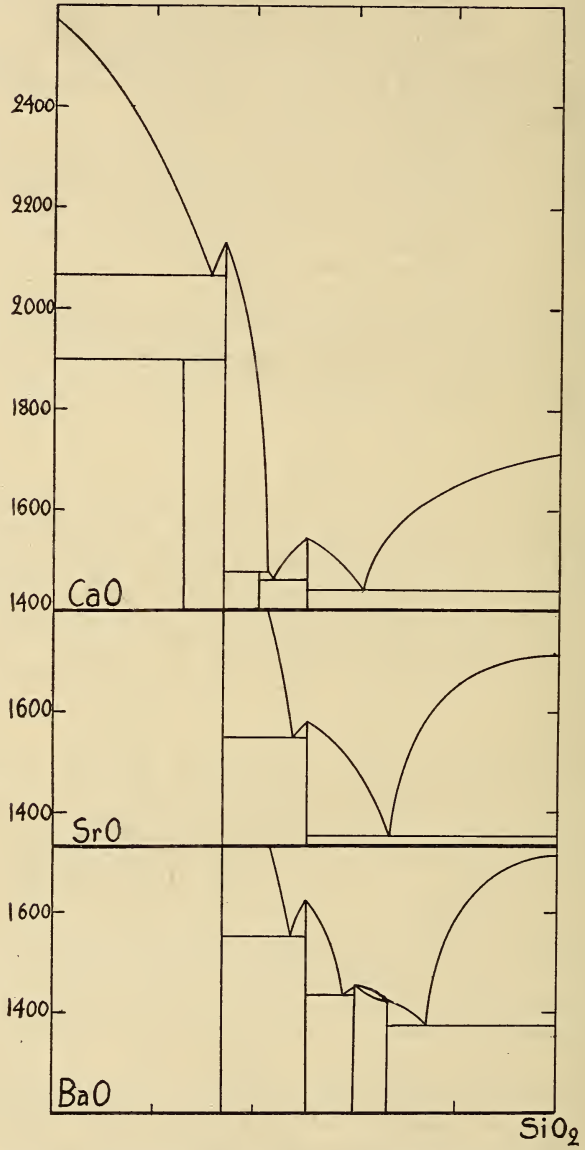


FIG. 17.—Synopsis of the binary systems BaO-SiO_2 SrO-SiO_2, and CaO-SiO_2 in mol. %.

TABLE XI.

Compositions and temperatures in the systems
CaO—Si_2, SrO_2, and BaO—SiO_2.

	Wt. %		Mol. %		Temperature °C	Character of change
	CaO	SiO_2	CaO	SiO_2		
Eutectic cristobalite (?)-α–$CaO.SiO_2$	37.0	63.0	38.7	61.3	1436	Melting
α–$CaO.SiO_2$	48.2	51.8	50	50	1540	Melting
Eutectic α-$CaO.SiO_2$-$3CaO.2SiO_2$	54.5	45.5	56.3	43.7	1455	Melting
$3CaO.2SiO_2$	58.2	41.8	60	40	1475	Decomposition
Invar. pt. $3CaO.2SiO_2$–$2CaO.SiO_2$	55.5	44.5	57.3	42.7	1475	Melting
$2CaO.SiO_2$	65.0	35.0	66.7	33.3	2130	Melting
$3CaO.SiO_2$	73.6	26.4	75	25	1900	Decomposition
Eutectic $2CaO.SiO_2$–CaO	67.5	32.5	69.1	30.9	2065	Melting
CaO	100	—	100	—	2570	Melting
	SrO	SiO_2	SrO	SiO_2		
Eutectic tridymite-$SrO.SiO_2$	46.5	53.5	33.6	66.4	1358	Melting
$SrO.SiO_2$	63.2	36.8	50	50	1578	Melting
Eutectic $SrO.SiO_2$–$2SrO.SiO_2$	65.5	34.5	52.5	47.5	1545	Melting
$2SrO.SiO_2$	77.5	22.5	66.7	33.3		
Eutectic $2SrO.SiO_2$–SrO	—	—				
SrO	100	—	100	—		
	BaO	SiO_2	BaO	SiO_2		
Eutectic tridymite-$BaO.2SiO_2$	47	53	25.9	74.1	1374	Melting
$BaO.2SiO_2$	56	44	33.3	66.7	1420	Melting
$2BaO.3SiO_2$	62.9	37.1	40	60	1450	Melting
Eutectic $2BaO.3SiO_2$–$BaO.SiO_2$	65	35	57.8	42.2	1437	Melting
$BaO.SiO_2$	71.8	28.2	50	50	1604	Melting
Eutectic $BaO.SiO_2$–$2BaO.SiO_2$	74.5	25.5	53.5	46.5	1551	Melting
$2BaO.SiO_2$	83.6	16.4	66.7	33.3		
Eutectic $2BaO.SiO_2$–BaO	—	—	—	—		
BaO	100	—	100	—		

In the system BaO-SiO_2 the compounds BaO, $2BaO.SiO_2$, $BaO.SiO_2$, $2BaO.3SiO_2$, $BaO.2SiO_2$, and SiO_2 have been found.

Of these compounds the dibarium trisilicate, $2BaO.3SiO_2$, and the barium disilicate, $BaO.2SiO_2$, showed very remarkable behavior, being isomorphous, of orthorhombic symmetry, and forming a complete series of solid solutions. The melting diagram of this series belongs to Bakhuis Roozeboom's type 1, without maximum or

TABLE XII. Physical properties of the strontium and barium silicates and oxides.

Composition	System and habit	α	β	γ	2 V Dispersion	Cleavage	Density	Remarks
SrO	Isometric	....	1.87	....	....	[100] perfect	4.750[a]	
$2SrO.SiO_2$	Monocl. ?	1.727	1.732	1.756	32°30′	......	....	Twinned on [100]
$SrO.SiO_2$	Pseudo (?) dihexagonal pyramidal tabular (0001)	1.599 $=\omega$		1.637 $=\varepsilon$	0°	good ⊥ c	3.650	Complete series of solid solutions with α-$CaO.SiO_2$
BaO	Isometric	....	2.16	....	....	[100] perfect	5.722[a]	
$2BaO.SiO_2$	Granular	1.810	....	1.830	?	no	....	
$BaO.SiO_2$	Orthorhombic granular or needles	1.673	1.674	1.678	29° strong $\rho > v$	good $\alpha\beta$	4.399	
$2BaO.3SiO_2$	Orthorhombic granular	1.620	1.625	1.645	53°30′	perfect $\beta\gamma$ poor $\alpha\beta$ and $\alpha\gamma$	3.93	Complete series of solid solutions.
$BaO.2SiO_2$	Orthorhombic tabular ‖ $\alpha\beta$	1.597	1.612	1.621	74°45′	perfect $\alpha\beta$ good $\beta\gamma$ and $\alpha\gamma$	3.73	
$BaO.2CaO.3SiO_2$	Hexagonal (?) fibrous	1.668 $=\varepsilon$		1.681 $=\omega$		prismatic	....	
$SrO.Al_2O_3.2SiO_2$	Triclinic (?)	0.574	1.582	1.586	large	?	3.043[b]	Solid solutions with anorthite.
$BaO.Al_2O_3.2SiO_2$	Monoclinic	1.587	1.593	1.600	large	perfect [010] good [001]	3.573[b]	Solid solutions with orthoclase.

[a] Sp. gr. determined by Brügelmann.
[b] Sp. gr. determined by Fouqúe and Michel-Levy.

minimum. The indices of refraction show a continuous though not linear variation with the composition.

The strontium and calcium metasilicates form a continuous series of solid solutions with a minimum in the melting curve. The indices of refraction and the densities of the mix crystals show continuous variation with the composition.

The barium metasilicate is not isomorphous with the calcium and strontium metasilicates, being optically biaxial, with low birefringence and probably of orthorhombic symmetry. It forms no solid solutions with α-$CaO.SiO_2$. Instead, there occurs a double compound, $2CaO.BaO.3SiO_2$ which melts incongruently, breaking up into α-$CaO.SiO$ and liquid. This compound is optically uniaxial and negative, unlike all the other metasilicates. In its refringence it is similar to $BaO.SiO_2$.

Neither strontium nor barium metasilicate forms, with magnesium metasilicate, a double compound analogous to diopside, $CaO.MgO.2SiO_2$. This is considered as a special case of the more common rule which seems to obtain generally in the compounds of the alkaline earth elements, namely, that calcium, in those compounds in which it can be replaced by magnesia and ferrous oxide, cannot be replaced by strontia or baryta, while the isomorphous series including strontium or barium compounds may have isomorphous and miscible analogs among sodium, potassium, or lead compounds.

Both strontium and barium form feldspars, analogous to anorthite. The strontium feldspar has indices of refraction exactly like those of anorthite, and the two seem to be completely miscible. The barium feldspar is monoclinic, like the natural celsian. It forms commonly Carlsbad twins of the contact type and the minute twin crystals therefore appear as if orthorhombic.

During this work I had pecuniary assistance, beside that from the Geophysical Laboratory, from two funds for the advancement of scientific research in my native country, Finland, namely, Alfred Kordelin's General Trust for the Advancement of Progress and Knowledge, and Herman Rosenberg's Traveling Bursaries Trust of the University of Helsingfors.

Geophysical Laboratory,
Carnegie Institution of Washington,
Washington, D. C.,
April, 1922.

Art. XXXII.—*Sedimentation in Lake Louise, Alberta, Canada;** by W. A. Johnston.

Introduction.

Lake Louise is a small but well-known lake along the line of the Canadian Pacific railway in the Canadian Rockies. The sediments being formed in the lake are glacial silts derived from Victoria glacier near the head of the lake. The character of the sediments and conditions of sedimentation are somewhat similar to those of the glacial lakes which existed in northeastern America and in other regions at the close of the Ice Age. A question of interest therefore arises as to whether seasonal banding occurs in the sediments and if so, whether it is similar to the supposed seasonal banding of the glacial lake deposits. Many geologists hold that the banding of the glacial lake clays is seasonal in character and estimates of post-glacial time have been made by counting the annual layers of the post-glacial clays. One of the most notable of these estimates is that of Baron Gerard de Geer who determined by this method that it is about 12,000 years since the ice-sheet disappeared from the vicinity of Stockholm, Sweden.[1] There has been, however, so far as known, no direct proof of the annual character of the layers or bands. In order, if possible, to determine this question core samples from the bottom of Lake Louise were obtained in June, 1921, by means of a bottom sampler and sounding machine, and an estimate was made of the average thickness of the annual layer of sediment being formed in the lake.

The character and origin of the lake basin was investigated and soundings of the lake were made by W. D. Wilcox[2] in 1899, and an excellent description of the characteristic features of Victoria glacier is given by William H. Sherzer in a paper published in the Smithsonian Contributions to Knowledge, vol. 24, 1907.

---

* Published by permission of the Director, Geological Survey, Canada.

[1] A geochronology of the last 12,000 years. Extrait du Compte Rendú du XI:e Congrès Géologique International, 1910.

[2] A Certain Type of Lake Formation in the Canadian Rocky Mountains; Jour. of Geology, vol. 7, pp. 247-260, 1899.

The writer is indebted to Mr. Basil Gartom and to other officials of the Canadian Pacific railway for information regarding Lake Louise and for assistance in the work.

Victoria glacier.

Victoria glacier originates at Abbots Pass upon the crest of the Great Continental divide and flows nearly north between Mounts Lefroy and Victoria to the main valley in which Lake Louise is situated, where it turns northeast and is joined by the tributary Lefroy glacier. The glacier is about 3 miles long measured along either branch. It terminates one mile from the lake and at its terminus is about 450 feet above the lake. The lower part of the glacier, or that part lying in the main valley, is covered by morainic material and by slide rock. Sherzer showed by observations on steel plates fixed in the glacier that the central part moved in 1904 at a rate amounting to 66 feet for the year and by observations at the end of the glacier that the forward movement is compensated for by melting.[3] The glacier is therefore active to some extent,—as is also shown by the silt laden waters discharged from the glacier,—but is not markedly so.

Lake Louise.

Lake Louise is 1¼ miles long and ¼ to ⅜ mile wide and has a surface area of nearly 1,000,000 sq. yards. It has an altitude of 5670 feet above the sea and is 600 feet above Bow River into which it discharges by a small stream 2½ miles long. The lake is held at its lower end by a drift dam, and is bordered on both sides, except near its lower end, by rock walls, which rise precipitously for considerable heights. The lake has a maximum depth of 230 feet; a considerable part of the bottom being nearly level. The lake freezes over in the latter part of October or early in November and remains frozen until some time in June, ice forming to a depth of about 40 inches.

It is stated by Mr. Gartom that water from the glacier flows into the lake even during the coldest part of the

---

[3] Glaciers of the Canadian Rockies and Selkirks, Smithsonian Contributions to Knowledge, vol. 24, p. 32, 1907.

winter, when the air temperature at times is as low as — 40 degrees F. It does not flow out at the surface but seeps through the drift dam at the lower end of the lake and issues as springs.

A delta and alluvial plain is being built at the upper end of the lake by the stream flowing from Victoria glacier. The delta extends into the lake about 400 feet and the alluvial plain extends upstream about 1/3 mile, thus indicating the amount of filling of the valley by sediment transported by the stream in post-glacial time.

The temperature of the water in the stream at the exit from the glacier is at or slightly above the freezing point. At the delta it was 36 to 38 degrees F. in June, 1921 and the temperature of the surface water at the lower end of the lake was 6 to 8 degrees higher. At a depth of 6 feet below the surface the temperature was 39 degrees. It is probable therefore the great mass of the water of the lake remains at the temperature of maximum density (39.2 degrees F.) through the year.

Rate of Sedimentation.

The stream flowing into the lake from the glacier carries in suspension the maximum amount of sediment at the time of the spring rains, when the snow at the lower levels is rapidly melting. It also transports considerable amounts during the summer but very little during the winter. Sherzer found that the stream at the exit from the glacier carried in suspension 506 and 230 parts per million of sediment at times of maximum and minimum flow in July, 1904.[4] Part of this material, however, is deposited on the flood plain of the stream and in the part of the delta that is submerged only during high water stages. Two samples of the water taken by the writer in June, 1921, from the stream at the point where it empties into the lake were found to contain an average of only 90 parts per million of sediment. The samples were taken at a time of approximately minimum flow of water for the summer months. As the water in the stream contains very little sediment during the winter months, the average amount of sediment carried into the

---

[4] Opus cit. p. 28.

lake by the stream throughout the year probably does not exceed 90 parts per million. Most of the sediment transported into the lake is deposited on the bed of the lake, for the outlet stream is nearly clear.

The inflow into the lake by the stream from Victoria glacier in June, 1921, during a period of moderate rainfall and melting of the ice, was estimated at 85 c. ft. per sec. Four determinations by Sherzer, in 1904, upon the inflow at the head of the lake gave an average of 80 c. f. s.; two at the outlet gave an average of 88 c. f. s., the small additional flow coming from Mirror Lake and Lake Agnes.[5] The inflow from these lakes is partly by underground passages and the water is clear. The greater part of the flow from the lake is carried by two pipes, one 33 and the other 20 inches in diameter. It is stated by Mr. Gartom that the flow during the summer months never falls below the capacity of these two pipes. During the winter months the inflow is greatly reduced as is obvious from the fact that, during the heat of a summer day, the flow from the glacier is much greater than at night. It is probable, therefore, that the average flow throughout the year does not exceed 50 c. f. s.

Taking the average flow from the glacier as 50 c. f. s., the average amount of material carried in suspension by the stream as 90 parts per million, the weight of the dry silt as 75 lbs. per c. ft. and the area of the lake as 1,000,000 sq. yds., the average thickness of the annual layer, if evenly distributed over the lake bottom, would be nearly 1/6 inch in thickness. This estimate is of course very approximate; it merely shows that the annual layer, if evenly distributed, probably would not exceed 1/6 inch in thickness. As the greater part of the sediment is deposited near the upper end of the lake, the annual layer is thickest near the upper end and thinnest at the lower end. The lake is being gradually filled by deposition of the glacial silt, but the process is so slow that at the present rate of sedimentation it will take over 1000 years to fill the basin; so that there is no danger of this "Gem of the Canadian Rockies," as it is popularly called, disappearing in the near future.

---

[5] Opus cit. p. 28.

Character and Significance of the Stratification of the Sediments.

Seasonal banding in the sediments being formed in the lake is to be expected because of the manner in which sedimentation takes place. Considerable quantities of silt are carried into the lake during the summer months and very little during the winter months. The coarse material quickly settles to the bottom, and the very fine material remains in suspension, so that by the end of the summer the water is slightly turbid and has the greenish shade characteristic of silt-laden glacial waters. During the winter this very fine material settles to the bottom and by spring the water is clear and has the blue color characteristic of pure water.[6] There is very little current through the lake, and, therefore, practically all the material deposited on the bed of the lake, except in the delta, is fine enough to be carried in suspension in nearly still water. A small amount of coarse material, which accumulates on the ice during the winter, and is derived from slides, wind-action or by streams flowing over the ice, falls to the bottom when the ice melts. It is to be expected, therefore, that the annual layers consist of two parts; that the material is mostly fine-grained and that there is a gradation in fineness from the coarser lower part of the layer to the upper finer-grained part. It is to be expected also, as pointed out above, that the thickness of the annual layers in the central part of the lake basin does not greatly exceed 1/6 inch. In the subaqueous part of the delta, at the upper end of the lake, conditions are different from those obtaining in the main body of the lake. The highly colored, turbid water of the creek flows out over the subaqueous part of the delta and extends into the lake for varying distances, depending upon varying conditions. The water flowing into the lake during the summer is nearly at the temperature of maximum density, but varies in temperature at different times, being colder in the morning than in the evening and varying at other times according to weather conditions. As the great mass of the water in the lake is at the temperature of maximum density and as the river water usually has nearly the same density—the silt

---

[6] William H. Sherzer, opus cit. p. 60.

carried in suspension only slightly increasing its density—the river water tends to diffuse through the lake water. At times it is lighter than the lake water and flows out on the surface over the subaqueous part of the delta, but only for a distance of 200 or 300 yards. At times also wind-induced currents carry the turbid river water out into the lake farther than usual or shift it from one side of the delta to the other. There is apparenly no tendency, so far as could be observed, for the river currents to follow the bottom of the lake and the diffusion through the lake of the silt in suspension and the steep underwater face of the delta seem to show that no appreciable currents follow the lake bottom.

The material forming the subaqueous part of the delta is silt and very fine sand. The very fine sand is probably moved along the bottom by current action and comes to rest along with the part of the silt which is too coarse to remain in suspension, when the current is checked. The underwater face of the delta is remarkably steep in its upper part, in spite of the fineness of the material. The soundings indicate that the slope is in places as much as 8 degrees. It is probable, therefore, that foreset bedding is well developed in the delta and that the material is marked by very fine laminations due to short, interrupted periods of sedimentation.

Figure 1 shows two core samples from the bottom of the lake, and, by way of comparison, one sample from the Champlain glacial clays of the Ottawa valley. The material from the bottom of the lake is mostly very fine-grained and of a uniform grayish white color. It is derived mostly from erosion of Cambrian quartzites and is therefore highly siliceous in character. Because of the unweathered character and uniform color of the samples the character of the stratification cannot be well shown by the photograph. The stratification is also somewhat distorted by the action of the bottom sampler and the samples are somewhat compressed but probably not much more than the lower compacted beds of the silt. These were found to be quite firm at a shallow depth. The bottom sampler, weighing 55 pounds, penetrated to a depth of only 3 feet or 4 feet when allowed to fall freely from the surface.

Fig. 1.

Bottom Sample No. 1
Lake Louise, Alta.
Depth 5 Fath.

Bottom Sample No. 2
Lake Louise, Alta.
Depth 35 Fath.

Section of
banded silt and clay
Ottawa, Ont.

Fig. 1.—Core samples (Nos. 1 and 2) of sediments being formed in Lake Louise, Alberta, Canada, and a section of banded silt and clay from Ottawa, Canada. The samples are mounted in plaster of paris and have been sectioned vertically to show the character of the stratification.

Sample No. 1 is from the subaqueous part of the delta at the upper end of the lake. In the upper and lower portions of the sample exceedingly fine lamination is faintly shown. In parts of the sample there is little or no trace of lamination. The very fine laminæ are apparently due to short interrupted periods of sedimentation—in part probably daily—which are the result of the conditions of sedimentation as outlined above. The samples from the delta show no definite evidence of seasonal banding, except possibly that the parts which are finely laminated are summer layers and parts which are not laminated are winter layers, but the lack of lamination may also be due to continuous sedimentation in certain parts of the delta during the summer.

Sample No. 2 is from nearly the deepest part of the lake at about mid-length. It shows a faint but definite banding. The material is all very fine except for a few coarse grains of sand which occur occasionally at the base of the individual bands. Each band consists of a coarser, lighter-colored, lower part which passes upward into a finer, darker-colored upper part, the two portions constituting a band. The bands vary in thickness and average between 5 and 6 to the inch. The thickness corresponds to the approximate estimate of the thickness of the annual layer and the character of the banding is that which is demanded by the conditions of sedimentation. The banding is, therefore, seasonal in character. It is remarkably thin but is probably considerably thicker than the seasonal layer formed in many of our rock bound lakes, whose waters are nearly clear throughout the year. It is also thinner than the average banding of many of the glacial lake clays of Pleistocene age, but closely resembles the banding of the glacial Lake Agassiz clays in the deep part of the basin at Winnipeg, Manitoba.

Sample No. 3 is from the base of the Pleistocene marine clays in the Ottawa valley and shows a definite banding, the darker layers being clay and light colored parts silt with some clay and sand. It differs from sample No. 2 in that the clayey layers are more sharply defined and the silt layers are much thicker. The material is also coarser. The banding is probably seasonal and the sharply defined character of the layers may be due to the deposition in brackish water. The Champlain (late Pleistocene) clays in the Ottawa basin are in places well banded. The banded clay rarely if ever contains marine fossils and was probably deposited in nearly fresh water. The clays containing marine fossils, and therefore deposited in salt water, are not definitely banded.

Seasonal banding in glacial clays.

De Geer holds that the banding of the late glacial clays is seasonal in character,—the coarser part of the band being the summer deposit and the finer part the winter deposit,—that the banding is due to the fact that glacifluvial rivers entering a lake or an only slightly brackish inland-sea have followed its bottom, being heavier than its water, and that this is clearly shown by the current-bedding and sand interbedded with the clay; whereas in the case of streams entering the sea, the river water flows out on the surface and can only transport the finest clay, the coarser sediment being dropped near the shore or ice-border, thus giving rise farther out to an almost unlaminated clay.[7]

In the case of Lake Louise, it does not appear, as already pointed out, that appreciable currents follow the bottom. It is well recognized that the great mass of the waters of the glacial lakes of Late Pleistocene time must have been at the temperature of maximum density through the year, and as silt and clay in suspension only slightly affect the density of the water,—unless the silt is large in amount and extremely finely divided—it seems improbable that appreciable river currents could have followed the bottoms of the lakes, except possibly under certain conditions. In places where the glacier terminated in a lake or inland sea and streams under hydrostatic pressure issued from the glacier, at some depth below the surface of the water, it is possible the river currents would continue for some distance along the bottom, if the density of the river water was slightly greater than the lake water. If the water body into which the stream flowed was brackish, the river water would be forced to rise to the surface because of its less density. The sand

---

[7] Opus cit. p. 250.

that occasionally forms part of the seasonal layers and the current marks may be accounted for in this way as suggested by de Geer. Part of the sand, however, may be derived from floating ice. Another factor which may be of some significance in explaining the current marks and minor irregularities in the seasonal bands is that, at certain times of the year when the whole water of the lake is at the temperature of maximum density, storms may disturb the waters down to the bottom and cause appreciable bottom currents.[8] Most of the material composing the banded clays is fine enough to remain in suspension for at least short periods in nearly still water and was evidently deposited in quiet water. The lack of lamination of the marine clays is probably mainly due, as was pointed out in the former paper,[9] to flocculation in salt water—an electrical phenomenon of surface tension—which causes the silt and clay in suspension in the river water to settle to the bottom together when the two waters are mixed.

The seasonal layers being formed in Lake Louise are much thinner than most of those of the glacial lake deposits which the writer has examined. Many of these are one-half to one inch or even more in thickness. The small thickness of the annual layers being formed in Lake Louise may be accounted for by the fact that Victoria glacier is only slightly active. The thickness of the annual layers would evidently vary according to the distances from the source of supply of the material and according to climatic conditions. The exact manner in which the annual layers were formed probably varied in different lake basins. There seems to be little doubt that the coarser lower part of the band is the summer deposit and the finer upper part the winter deposit, and that the difference is due to variations in transporting power of the streams in winter and in summer. It has long been known that streams issue from some glaciers in winter as well as in summer, because of friction raising the temperature of the ice above the melting point or because of the heat of the earth, but the amounts of material trans-

---

[8] Neeham and Lloyd: The life of inland waters, Ithaca, New York, 1916, p. 35.

[9] The character of the stratification of the sediments in the Recent delta of Fraser river, British Columbia, Jour. of Geol., vol. 30, p. 128, 1922.

ported by the streams is much greater in summer than in winter. Part of the very fine material which forms the upper part of the seasonal band may have been carried into the lake during the summer and deposited during the winter. In other cases, especially in brackish water bodies, the finer part was probably transported during the winter, for it could not long remain in suspension, if the water was even slightly brackish.

Seasonal deposition in aqueo-glacial sediments has been well discussed by R. W. Sayles,[10] who reviews in a well illustrated paper the literature on seasonal banding in glacial clays, describes the banded clays in the Connecticut valley and in Rhode Island and discusses the criteria for the study of aqueo-glacial sedimentation. He concludes that the seasonal hypothesis for the banded clays is in a very strong position and that there is little danger of its being abandoned. The present paper confirms this conclusion.

---

[10] Memoirs of the Museum of Comparative Zoology, vol. 47, No. 1, Cambridge, Mass., 1919.

Art. XXXIII.—*Imbricated Structure in River-gravels;*[1]
by W. A. Johnston.

Gravel deposits formed in river beds and bars frequently show a characteristic mode of arrangement of the coarse gravel and shingle. The stones, for the most part dip upstream and overlap or imbricate. This mode of arrangement of the stones was figured and referred to by James Geikie as imbricated structure.[2] It is only rarely described in text books on geology or physiography but has probably been noted by many geologists in the field. Because it is a criterion which can be used occasionally to distinguish marine from non-marine deposits and because of the fewness of such criteria, attention is here directed to it. Furthermore there seems to be a misconception on the part of some geologists as to the character of the structure.

Imbricated structure was described and its mode of formation explained by G. F. Becker in 1892, who stated[3]: "If a flattened pebble is dropped into a running stream, the water will exert a pressure upon the stone until its inertia is overcome, and during this time the pebble will tend to swing across the current so as to present its greatest area to the pressure. As soon as the resistance due to its inertia is overcome, the pebble will sink through the water as if the fluid were at rest until its edge touches the bottom, and it will then tip downstream until it meets support. . . . Many pebbles thus deposited will, with few exceptions, be inclined downstream and will rest against one another, like overlapping tiles." This view as to the attitude of the stones agrees with Geikie's description and with the present writer's observations. The important points are that the stones tend to dip upstream or, as the placer miners sometimes put it, the up-ends of the stones are the downstream ends or point downstream, and the upstream stones tend to overlap on the downstream stones. In a recent text-book, however, it is stated[4] that the pebbles in river beds may imbricate up-

---

[1] Published by permission of the Director, Geological Survey, Canada.

[2] James Geikie: Structural and Field Geology, 1905, p. 311.

[3] Finite Homogeneous Strain, Flow and Rupture of Rocks, Bull. Geol. Soc. Amer., vol. 4, pp. 53-54, 1893.

[4] Lahee, Frederick H., Field Geology, 1916, p. 88.

stream and dip downstream. This view is apparently incorrect. The stones finally assume a position in which they offer the least possible resistance to the current. If the stones dipped downstream they would present their edges to the current and therefore offer considerable resistance to the current. Moreover field observations show that the dip is upstream. It is well recognized that in hydraulic work it is necessary, in order to achieve maximum results, to direct the stream against the "stratification" of the stones, that is in a direction opposite to that of the current which deposited the stones. Imbricated structure is frequently used by placer miners as a criterion to determine the direction in which the streams in abandoned channels flowed and thus to attempt to trace the old channels. The inclined attitude of the stones is chiefly relied upon for this purpose and the further fact that the longer axes of the stones usually lie in the direction of the current. Imbricated structure

Fig. 1.

Fig. 1.—Vertical section of river gravels at Campbellford, Ontario, Canada, showing imbricated structure. The direction of the current was from right to left.

is, therefore, of economic importance and its character should be clearly understood.

Becker also pointed out that "On beaches pebbles are sometimes imbricated for a few feet in one or another direction and sometimes lie nearly flat. The constant reversal of the currents due to breaking and retreating waves prevents any extensive methodical arrangement, and this fact is of assistance in discriminating marine gravels from river deposits."[5] This criterion for distinguishing marine from non-marine deposits does not appear to have received much consideration by geologists, probably because of its limited application, but it may be occasionally used, as pointed out below, and is of importance because of the fewness of such criteria.

Fig. 2.

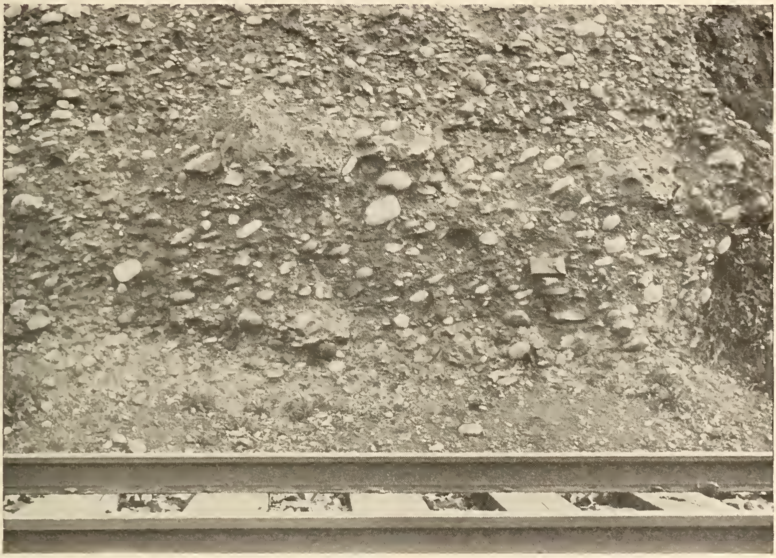


Fig. 2.—Vertical section of conglomerate, on Burrard inlet, near Vancouver, British Columbia, showing imbricated structure. The direction of the current was from left to right.

Imbricated structure is usually best shown in the very coarse gravel and shingle deposits of river beds, but is

---

[5] Opus cit. p. 54.

also shown, in places, in comparatively fine gravel as in fig. 1. This figure shows a section of river gravels in the bed of Trent river, at Campbellford, Ontario. The largest pebbles in the section are about 8 inches in diameter. The direction of the current was from right to left. Imbrication of the pebbles is not well shown because of the fineness of much of the material, but the pebbles have a fairly uniform dip in an upstream direction and lie with their longer axes in the direction of the current. The face of the section is vertical except in the lower part which is talus.

Fig. 2 shows a vertical section of Tertiary conglomerate exposed on the south side of Burrard inlet near Vancouver, British Columbia. Imbricated structure is fairly well shown in the conglomerate and shows that it was formed from river gravels. It is therefore non-marine. The section is an east-west one, and the stream which deposited the gravel flowed west, that is, from left to right in the section. The conglomerate beds have a general dip of 10 to 15 degrees towards the south. As the depositional dip must have been in the direction of the current, the dip towards the south is structural. Imbricated structure may be occasionally used, therefore, both to distinguish marine from non-marine deposits and for structural purposes.

Art. XXXIV.—*Zircon as Criterion of Igneous or Sedimentary Metamorphics;* by P. Armstrong.

The complete recrystallization of some igneous and sedimentary rocks with consequent total loss of their distinguishing characters has led petrographers to search for some definite criterion by which, in the absence of conclusive field evidence, the genetic origin of such recrystallized rocks can be accurately determined. Various means to this end have been proposed, amongst them the use of zircon.[1] This method rests on the assumption that zircon, like grains of sand, may undergo rounding during water transportation; those zircons contained in igneous rocks always show sharp crystal boundaries. A second postulate on which this method rests is that the extreme stability of zircon enables this mineral to resist physical and chemical changes even under the greatest of metamorphic forces.

Doubts as to the reliability of this method, which has been endorsed or employed by various geologists,[2] were expressed orally to Professor A. Knopf by several petrographers and led to its critical investigation by the writer. The conclusions arrived at are briefly set forth below.

The rocks to be investigated were pounded, not ground, in a mortar to pass an eighty-mesh sieve, panned down to the heaviest constituents, and dried. Under a binocular microscope, equipped with a 24mm. objective, a number of zircon grains, up to twenty in some trials, were isolated and carefully mounted on glass fibers. Each grain was then placed under a No. 4 objective of a petrographical microscope and by means of the glass fiber, resting on the stage, rotated so as to give a complete view of the grain from all sides. In the latter operation reflected light was used.

A preliminary study of four unmetamorphosed sandstones showed that the degree to which zircons are rounded diminishes with increasing coarseness of the

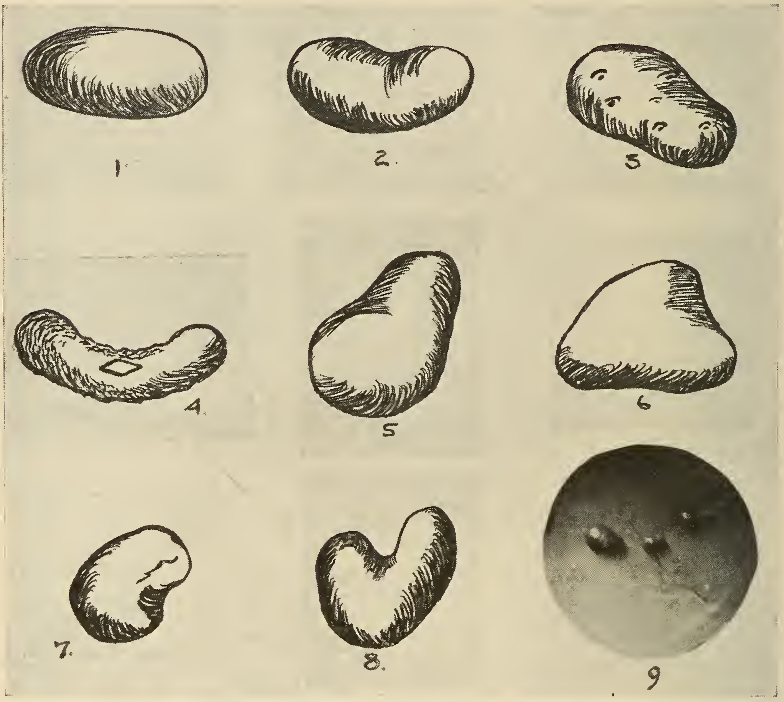
---

[1] J. D. Trueman: The value of certain criteria for the determination of the origin of foliated crystalline rocks, Journal of Geology, vol, 20, No. 3, 1912.

[2] A. N. Winchell: The Dillon quadrangle, Montana, U. S. G. S., Bull. 574, p. 129, 1914. Leith & Mead, Metamorphic Geology, 1915, p. 225 (H. Holt & Co.).

sand grains; some of the coarser sandstones yield zircons which under the high power show sharp-edged and lustrous faces. It is in highly zirconiferous sandstones, such as those described by Watson and Hess,[3] which are evidently the result of repeated re-concentration, that the rounding is most highly developed and gives rise to shapes characteristic of water-worn grains, such as flat-

Figs. 1 to 9.



Figs. 1, 2, 3.—Typical water-worn zircons from zirconiferous sands, Pablo Beach, Florida.

Fig. 4.—Deformed zircon, showing single secondary crystal face; from the Stony Creek gneiss (igneous), Connecticut.

Figs. 5-8.—Zircons from Stony Creek gneiss; all are covered with blistery growth and show small secondary faces.

Fig. 9.—Rounded zircons in a normal, undeformed granite; Norcross quarry, Stony Creek, Conn.

---

[3] T. L. Watson and F. L. Hess, Univ. of Virginia Phil. Soc., July, 1912.

tened spheres or lenses, kidney or bean shapes, (figs. 1-2), and another which by virtue of its general form and ''eye''-like depressions distributed over its surface may be likened to that of a potato (fig. 3). Associated with more or less rounded zircons are others in the same rock showing smooth, unbroken, and lustrous prism faces. Two explanations can be advanced for this fact: That the rounded grains had their source farther away from their point of sedimentation, or that the prismatic grains were transported, enveloped in a protective biotite flake. The latter explanation seems to be the correct one, as zircon grains attached to biotite have been observed in some of the sandstones, by the writer as well as by others.[4]

The study of undeformed granites led to the conclusion that zircon, the earliest mineral to crystallize out, may undergo during consolidation of the rock a certain amount of magmatic corrosion, as is evident from a more or less pronounced rounding and glassy smoothness, such as observed on the edges of a melting cake of ice, of its edges, principally those of its pyramidal terminations. Furthermore the zircons were found to show a peculiar pitting, not in isolated patches, such as might have been caused by the process of crushing, but all over the prism faces. It was found impossible to distinguish this kind of pitting from that seen on sedimentary grains and caused by the chipping of the grain during water transport. That magmatic corrosion of zircon is possible has been shown by C. Doelter,[5] who exposed this mineral to contact with molten basalt and produced a broad zone of corrosion around the zircon grain. The zircons in undeformed granites are generally prismatic, although some were found that show a distinctly ovoid form, due to a combination of magmatic corrosion and the development of numerous vicinal faces. The latter already have been described elsewhere.[6]

In examining igneous and sedimentary gneisses the fundamental assumption is often made that zircon has

---

[4] A. Gilligan: The petrography of the Millstone grit of Yorkshire, Quart Jour. Geol. Soc., London, vol. 75, No. 300, p. 266, 1920.

[5] C. Doelter, Handbuch der Mineralchemie, Vol. III, Part 1, p. 142.

[6] A. Gilligan, op. cit., p. 266.

been absolutely stable under the conditions of temperature and pressure to which it was subjected. However, the evidence collected during this investigation would speak against this assumption. The zircons of igneous as well as sedimentary gneisses were found to show a peculiar rough surface, blisterlike in appearance, the nature of which it was impossible to determine under the microscope. In the belief that this blisterlike appearance is due to a coating of silica, several grains were treated with warm hydrofluoric acid, but without result. The blisterlike covering has either destroyed, or, in any case, now completely obscures the original crystal faces; however, rotation of the grain under the microscope brings in view a great number of apparently irregularly placed, small, and more or less round faces of rather dull luster which appear to have developed on and within the blistered surface. Possibly the latter represents a decomposition product of zircon and may be one of the hydrous forms of this mineral, *e.g.* malaconite, described by Doelter.[7] A zircon, isolated from the igneous Maromas gneiss of Connecticut consisted of a splinterlike plate, extremely irregular in outline but having all its edges rounded by the blisterlike covering just mentioned. Similarly, parts of prisms were found in other igneous as well as sedimentary gneisses, one of their ends showing a pyramidal termination, the other a conchoidal fracture, the latter modified in exactly the manner as described under the Maromas gneiss. It should be of greatest interest to determine whether the composition of this blisterlike surface is either identical with or related to that of the zone of corrosion of Doelter's, previously mentioned. Our conception of the stability of zircon may then, perhaps, be greatly modified.

That zircons are deformed under metamorphic stress can be confidently asserted. From an igneous gneiss the writer separated a grain, having a curved sausage shape and showing on its concave side a single crystal face, embedded, so to speak, in the blistery growth which covered the rest of the grain (fig. 4). Others show pear or club shapes, and many are such perfect spheres that they would apparently fully justify the belief that they

---

[7] Op. cit., p. 136.

are of sedimentary origin. (See illustrations, figs. 5-8.) All these grains had the peculiar blisterlike covering, some, like the sausage-shaped grain, showing also small crystal faces, previously described. It is possible that the development of the latter is due to local solution and recrystallization under stress; in any case, the blisterlike covering seems to have been caused by conditions under which zircon was unstable.

Figure 9 shows three zircons imbedded in, what its thin section shows to be, a normal granite of undeformed hypidiomorphic granular texture, from the Norcross quarry, Stony Creek, Conn. The roundness of their outlines is striking, and a comparison of these grains with those shown by Trueman and Hess in their papers previously cited, it is believed, gives convincing proof that the origin of a gneiss cannot be determined from the study of its zircons in thin sections.

Since the ultimate source of both igneous and sedimentary zircons is the same, it was thought that the rounding due to abrasion superimposed on magmatically corroded zircons in sedimentary gneisses might lead to a means of distinguishing such gneisses from those of purely igneous origin. But no such distinction was found to be possible. Figs. 5-8 show zircons found in a distinctly igneous gneiss. It will be noticed that some of the grains are pearshaped and others are more or less curved.

From the foregoing the conclusion would appear justified that the rounding of zircons is no criterion of the sedimentary origin of the metamorphosed rocks in which they are enclosed, that the degree of rounding due to corrasion may not even be large enough, in some of the coarser sandstones, to serve as a distinguishing character, and that the diagnosis of a rock, so completely recrystallized as to obscure the petrological evidence of its origin, cannot be effected by the use of zircon as criterion.

Petrological Laboratory, Yale University,
New Haven, Conn.

Art. XXXV.—*The Minnesota Devonian and its Relationship to the General Devonian Problem of North America;* by Clinton R. Stauffer.

The Devonian of Minnesota has long been known and roughly mapped, but a detailed study of the rocks belonging to this system has been very much neglected. This is probably because the area in which it occurs is a drift-covered plain that has been only partially dissected by erosion and the outcrops that may be found are neither frequent nor very satisfactory. But the country has now been settled for a longer period than when the early surveys of Minnesota counties were made, hence more wells have been drilled and more quarries have been opened in the region so that the rocks of this system are now very much better known than they were thirty or forty years ago. Moreover certain parts of the Devonian have been found to be filled with fossils thereby making the age determination a certainty.

In all about 1,200 square miles of southern Minnesota are covered by Devonian rocks. This area lies in Fillmore, Mower and Free Born counties*(1). In the northern and western parts of this region, much of the surface is comparatively level and well covered by drift so that it is not always possible to trace the Devonian border in those directions. On the east side it approaches the driftless area and the mantle of glacial debris is reduced to a thin film, often insufficient to conceal the bed rock, and the possibilities for satisfactory stratigraphic work are much improved. Enough outcrops can be found to make it certain that the Devonian is slightly more extensive in this region than it is indicated to be on the present geological maps. Numerous masses and fragments of fossiliferous Devonian rock are known or have been picked up in the drift of central Minnesota, even as far north as Todd and St. Louis counties. Some of these masses are quite large (2). This has suggested that possibly there are other areas of Devonian, existing as outliers, which have not yet been recognized or which may be entirely drift covered. It is noticeable, however, that the larger frag-

---

* For references see the end of this article.

ments are all found in southern Minnesota and may indicate a somewhat greater extent of the present Devonian-covered area rather than the existence of other Devonian areas. Over the great ridge area of the buried Minnesota mountains the Devonian fragments in the drift are somewhat smaller and usually less abundant. Hence it seems probable that these scattered limestone bowlders and loose Devonian fossils have been brought down by the Pleistocene glaciers from the great outcrops of Devonian in the vicinity of Lake Winnipegosis and Lake Manitoba, and that the Minnesota Devonian deposits are confined to the southern part of the state.

The Devonian, as outcropping in the southern part of the state of Minnesota, consists chiefly of limestones of varying purity. Probably the great body of it runs as high as 17% to 18% $MgCO_3$ but occasionally layers are found with 97% to 98% $CaCO_3$ and only a fraction of a per cent of $MgCO_3$. The best outcrops are to be found in the central and southern parts of Fillmore county where the Devonian is usually exposed in every highway cut. Where both the top and the bottom show, the Devonian apparently rests disconformably on fossiliferous Maquoketa shale (Ordovician) and usually has no covering other than the drift. In the vicinity of Austin, however, the uneven upper surface of the Devonian limestone is covered by eight to ten feet or more of rather soft gray to red clay which has usually been classified as a Cretaceous(3) deposit, and which it probably is as clays and lignitic beds of that age have been reported in the deeper wells of Freeborn county to the west. However, some of the similar clays of central and southern Minnesota contain glacial pebbles and are undoubtedly of glacial origin. It has been suggested that a remnant of the higher Devonian shales may occur in western Mower county and perhaps in certain parts of Freeborn county, but up to the present this has not been certainly determined. The Western margin of the Devonian is lost under a covering of drift which in Freeborn county has been estimated to have a thickness of one hundred feet,(4) with perhaps even greater thicknesses in the adjacent county(5) to the west. There is thus little hope of continuing the Minnesota Devonian section, except by the drill, to the upper shales which are so well developed a short distance to the south of the state line. It seems entirely probable that these upper beds thin out in Iowa before the Minnesota line is reached. The limestones therefore carry the whole of the known Devonian record, as far as Minnesota is directly concerned. These rocks dip gently to the west and south thus bringing in higher beds along a line from northeast to southwest.

Much of the Devonian is a porous, weathered, impure, buff limestone but it changes rapidly in color and character as it is followed to the southwest. Where this former character is prevalent it is undoubtedly to be assigned, in large measure, to the leaching and weathering of a rock quite different from that which is now exposed. Following the direction of dip there are numerous shades and grades between a porous, abundantly fossiliferous buff rock, and a sparingly fossiliferous blue, or a non-fossiliferous compact gray to white rock. A number of sections were measured for detailed study and others might have been added. A few of them are given herewith to show the Devonian section of the state. They include some of the more important outcrops and give a good idea of the above mentioned variations as well as of the changing character of the fauna which seems to attend it.

Section along the South Bank of Bear Creek at Hamilton, Fillmore County, Minnesota.

Pleistocene and Recent. Thickness
7. Soil and drift .... 6′ 0″

Devonian (Cedar Valley limestone)
6. Limestone, gray to buff, containing the following fauna.
    Athyris fultonensis (Swallow) (c)
    Chonetes scitulus Hall (r)
    Productella subalata Hall (a)
    Schizophoria striatula? (Schlotheim) (r)
    Trochonema sp. (r) .... 15′ 4″

5. Limestone, gray to buff or brown, massive, abundantly fossiliferous.

Athyris fultonensis (Swallow) (r)
Atrypa histryx Hall (c)
Atrypa spinosa Hall (r)
Chonetes scitulus Hall (c)
Cyrtina hamiltonensis Hall (c)
Gypidula læviuscula Hall? (r)
Martinia sp. (c)
Productella subalata Hall (a)
Schizophoria striatula (Schlotheim) (c)
Spirifer bimesialis Hall (a)
Spirifer iowaensis Owen? (c)
Stropheodonta demissa (Conrad) (r)
Stropheodonta halli musculosa Cleland (?) (r)
Bellerophon perplexa Walcott (c)
Pleurotomaria sp. (r)
Trochonema sp. (c)
Coleolus sp. (r)
Proetus sp. (c)

.... 16′ 0″

4. Limestone, partly covered .... 10′ 8″
3. Covered interval .... 11′ 4″

Ordovician (Maquoketa shale)

2. Limestone, buff to brown, shaly, containing Strophomena fluctuosa Billings .... 10′ 0″
1. Shale, buff to brown, massive, extending to the level of Bear creek. It contains the following fauna

Dalmanella testudinaria (Dalman)
Lingula elderi Whitfield
Plectamonites sericeus (Sowerby)

.... 10′ 8″

These same Devonian beds outcrop abundantly around Spring Valley, Etna, and southward into Iowa. In Spring Valley the old city quarry, at the corner of Church Street and Broadway, exposes about eighteen feet of slightly higher limestone, but Larsen's quarry in the southwestern part of town is essentially the same horizon and affords better collecting.

Section of Larsen's Quarry in the Southwestern Part of Spring Valley.

Pleistocene and Recent. Thickness
4. Soil and drift .... 1′ 0″

Devonian (Cedar Valley limestone)
3. Limestone, gray to brown or buff, badly weathered, containing
    Atrypa reticularis (Linnaeus) (c)
    Productella subalata (Hall) (c)
    .... 5′ 0″
2. Limestone, buff, massive, with abundant fossils of which the following are the more important:
    Atrypa reticularis (Linnæus) (c)
    Cyrtina hamiltonensis Hall (c)
    Gypidula laeviuscula Hall, (r)
    Productella subalata Hall (aa)
    Nuculites sp. (r)
    Murchisonia cf. dowlingi Whiteaves (r)
    Trochonema sp. (r)
    Trochonema monroei Cleland? (r)
    Crinoid stems (c)
1. Limestone, brown to buff, with fossils common
    Chonetes scitulus Hall (c)
    Cranæna iowaensis (Calvin) (c)
    Cyrtina hamiltonensis Hall (t)
    Productella subalata Hall (a)
    Reticularia fimbriata (conrad) (r)
    Spirifer bimesialis Hall (r)
    Spirifer iowaensis Owen? (a)
    Spirifer sp. (r)
    Stropheodonta demissa (Conrad) (c)
    Paracyclas sp. (r)
    Bellerophon sp. (c)
    Trochonema sp. (r)
    Coleolus sp. (c)
    Proetus sp. (c)
    .... 3′ 4″

Somewhat higher beds occur along the state line highway. About five miles west of Granger the surface is strewn with fragments of the Devonian limestone and in some of the fields there are great heaps of rock that have been gathered from the surface in clearing the land for cultivation. At no place is this part of the Devonian well shown but there is a fair section shown on Mr. Grimm's farm where it sticks out along the road and in the field.

Section on Mr. Charles Grimm's Farm Five Miles West of Granger.

Recent.		Thickness
4.	Soil	0′ 6″
Devonian (Cedar Valley limestone)		
3.	Limestone, rough brecciated, brown in color	3′ 0″
2.	Limestone, fairly massive, rough, and gray to brown in color. It contains occasional masses of chert, and cavities filled with calcite crystals. Fossils are abundant. Cladopora magna Hall and Whitfield (r) Cladopora sp. (c) Favosites sp. (c) Zaphrentis solida Hall and Whitfield (a) Polypora sp. (c) Atrypa reticularis (Linnaeus) (c) Camarotœchia sp. (r) Cyrtina hamiltonensis Hall (c) Gypidula laeviuscula Hall? (c) Spirifer asper Hall (r) Stropheodonta demissa (Conrad) (r) Nucleospira sp. (r) Schuchertella chemungensis arctistriata (Hall) (c) Conocardium sp. (c) Leptodesma sp. (r) Palaeoneilo sp. (r) Bellerophon perplexa Walcott (a) Cyclonema sp. (r) Eunema sp. (c) Murchisonia dowlingi Whiteaves? (c) Pleurotomaria sp. (c) Raphistoma terrelli Cleland (r) Hyolithes alatus Whiteaves (r) Orthoceras sp. (r) Poterioceras 2 sp. (r) Phacops sp. (r) Proetus sp. (r)	10′ 0″

1. Limestone, gray to brown, rough, with numerous corals and stromatoporoids
   Acervularia davidsoni Edwards and Haime (c)
   Favosites sp. (c)
   Stromatoporella erratica (Hall) (c)
   .... 3′ 0″

Along the same highway, about two miles farther west, fourteen feet of brown to buff limestone outcrop in section 34, York Township, Fillmore County, and lie at a higher horizon than those beds given in the preceding section. Although these layers are not exceptionally fossiliferous, the fauna found here is rather large and consists of the following forms—

Idiostroma sp. (r)
Dictyonema 2 sp. (r)
Zaphrentis sp. (c)
Polypora 2 sp. (c)
Semicoscinium rhombicum Ulrich? (r)
Taeniopora Exigua Nicholson? (c)
Atrypa histryx Hall (c)
Atrypa reticularis (Linnaeus) (c)
Chonetes scitulus Hall (c)
Chonetes manitobensis Whiteaves (r)
Cyrtina hamiltonensis Hall (c)
Gypidula comis (Owen) (c)
Pentamerella multicostata Cleland? (r)
Productella sublata Hall (r)
Reticularia fimbriata (Conrad) (r)
Spirifer asper Hall (r)
Stropheodonta arcuata Hall (r)
Stropheodonta halli musculosa Cleland? (r)
Stropheodonta perplana (Conrad) (cc)
Stropheodonta variabilis Calvin? (r)
Stropheodonta sp. (r)
Phacops sp. (c)

The next beds above this are apparently those outcropping in the vicinity of LeRoy where the following section occurs—

Section of the Fowler and Pay Quarry One Mile East of LeRoy, Minnesota.

Pleistocene and Recent.	Thickness
11. Soil and drift	3′ 6″

Devonian (Cedar Valley limestone)

10.	Limestone, gray to brown, thin bedded, probably somewhat disturbed	4′	0″
9.	Limestone, gray to white, usually weathering to brown, fairly massive. It contains a few fossils among which are the following: Crinoid stems (r) Leptaena rhomboidalis (Wilckens)? (r) Stropheodonta demissa (Conrad) (r) Nucula sp. (r) Pleurotomaria sp. (r)	2′	0″
8.	Limestone, gray to brown, with occasional traces of fossils	1′	3″
7.	Limestone, gray, fairly fossiliferous Crinoid stems (c) Athyris fultonensis (Swallow) (c) Cyrtina hamiltonensis Hall (c) Spirifer orestes Hall and Whitfield (c)	0′	10″
6.	Limestone, gray to brown, containing indistinct masses resembling stromatoporoids	0′	8″
5.	Limestone, gray to white, compact and apparently containing no fossils	2′	5″
4.	Shale, green to gray, calcareous, irregular in thickness	0′	6″
3.	Limestone, gray to white, compact, rather massive. It contains a few fragmentary fossils.	2′	4″
2.	Covered interval	1′	0″
1.	Limestone, gray to brown, apparently lower than the beds given above	7′	0″

Recent drilling in this vicinity indicates that the total amount of the high-grade white limestone may exceed sixty feet. How much of the brown magnesian limestone may be interstratified with it is not definitely known but it is probable that there is as much in the deeper strata as there is mingled with the beds exposed at the surface. Certain layers of the limestone of this locality resemble the lithographic beds of Iowa and they may possibly represent the same horizon.

Higher beds occur in the vicinity of Austin. It is quite probable, however, that there is a covered interval of importance between this outcrop and the one just discussed. There is at least a marked change in sedimentation between the light gray to white limestone near LeRoy and the impure "cement beds" characteristic of the Austin region. The best outcrop in this latter region is along Rose Creek, about three miles south of Austin, where quarrying has been carried on for many years. Formerly this rock was used as a building stone but it weathered badly hence it has long been abandoned as a construction rock. It is now used only in the manufacture of a natural cement.

Section of the Fowler and Pay Cement Quarry along Rose Creek, Three Miles South of Austin.

Pleistocene and Recent.	Thickness
4. Soil and drift, the latter chiefly gravels	2′ 0″
Cretaceous?	
3. Clay, blue and red, in pockets over the uneven surface of the limestone	5′ 0″
Devonian (Cedar Valley limestone)	
2. Limestone, blue to gray, weathering to buff, and containing a few fossils— Athyris fultonensis (Swallow) (r) Spirifer iowaensis Owen? (r) Fish plates and scales (r)	10′ 0″
1. Limestone, gray to buff, rather massive, containing some chert and with pebble-like masses of limestone occurring in some of the lower layers. These beds extend to the level of Rose creek	15′ 0″

The beds which appear to be the highest of the Devonian limestone section in Minnesota, outcrop along Cedar River in the southwestern part of Mower County.

Section along Cedar River, Three Miles West of Lyle, Mower County.

Recent.	Thickness
4. Soil	5′ 0″

Devonian (Cedar Valley limestone)

3. Limestone, gray to buff, massive to thin bedded, it contains an abundance of a few fossil forms— Athyris fultonensis (Swallow) (aa) Atrypa reticularis (Linnaeus) (r) Murchisonia sp. (r)	4′ 0″
2. Limestone, gray to buff, or brown, rough, hard, and massive. Fossils very abundant in some layers but limited to one form Atrypa reticularis (Linnaeus) (aa)	10′ 6″
1. Limestone, gray to brown in color, partly covered, to the level of Cedar River	6′ 0″

It is quite impossible to present a complete section of the Minnesota Devonian at the present time. In fact it may never be possible to complete it satisfactorily unless at some future time the region should be drilled for water or other natural resources that may seem worth while. But it may be pieced together, from scattered outcrops and other information in somewhat the following manner.

General Section of the Minnesota Devonian.

Devonian (Cedar Valley limestone)	Thickness
9. Limestone, buff to brown, massive, coarse, fossiliferous. These are the beds exposed along the river just west of Lyle	20′ 6″
8. Limestone, blue to brown, argillaceous, forming the cement beds south of Austin	30′ 0″
7. Covered interval	10′±0″
6. Limestone, gray to white, compact, fine-grained, often alternating with coarser brown beds	22′ 0″
5. Covered interval	12′±0″
4. Limestone, brown, brecciated, with no fossils	6′ 0″
3. Limestone, gray to buff, massive, fossiliferous	10′ 0″
2. Limestone, gray to brown, massive, full of corals and stromatoporoids	3′ 0″
1. Limestone, buff, massive, abundantly fossiliferous	20′ 0″

It is noticeable that all portions of this section are not equally fossiliferous and that the fauna is not uniform for the whole formation. Thus the lowest beds are full of fossils and the species, the most abundant of which is *Productella subalata,* belong chiefly to the various genera of Brachiopoda. These beds are succeeded by others which are also quite fossiliferous but the number of species is small and they belong mostly to the Anthozoa. Then comes the most widely varied fauna of all in the beds which have been made the third division of the general section. Although the Brachiopoda are still abundant the conspicuous forms are Gastropoda and the whole fauna differs decidedly from that of both the basal beds and those higher in the section.

The brecciated beds appear to contain few if any fossils. The fine-grained compact limestone and the associated brown beds are sparingly fossiliferous. The argillaceous limestone beds of the cement quarry near Austin contain fish remains and an occasional *Spirifer,* while the uppermost portion of the section is again fairly fossiliferous but the number of species is small. These latter are chiefly *Athyris fultonensis* and *Atrypa reticularis.* The brecciated beds, or the unknown deposits which doubtless occur between the outcrops from which the section herewith was made, may represent important breaks in sedimentation during which marked faunal changes occurred, but the evidence so far obtained is not sufficient to determine that point. It is perhaps significant that similar faunal changes have been observed in the equivalent beds of Iowa (6).

The following is a list of the genera and species that have been collected from the Devonian outcrops of Minnesota.

Fauna of the Minnesota Devonian.

Dictyonema 2 sp.
Idiostroma sp.
Stromatoporella erratica (Hall and Whitfield).
Acervularia davidsoni Edwards and Haime.
Cladopora magna Hall and Whitfield.
Cladopora sp.
Favosites sp.
Hederella filiformis (Billings).
Zaphrentis sp.
Crinoid stem.

Polypora sp.
Semicoscinium rhombicum Ulrich ?
Taeniopora sp.
Athyris coloradoensis Girty.
Athyris fultonensis (Swallow).
Atrypa histryx Hall.
Atrypa reticularis (Linnaeus).
Atrypa spinosa Hall.
Camarotœchia sp.
Chonetes manitobensis Whiteaves.
Chonetes scitulus Hall.
Cranæna iowaensis (Calvin).
Cyrtina hamiltonensis Hall.
Gypidula comis (Owen).
Gypidula læviuscula Hall ?.
Leptaena rhomboidalis (Wilckens) ?.
Martinia sp.
Nucleospira sp.
Pentamerella multicosta Cleland ?.
Productella subalata Hall.
Reticularia fimbriata (Conrad).
Schizophoria striatula (Schlotheim).
Schuchertella chemungensis arctistriata (Hall).
Spirifer asper Hall.
Spirifer bimesialis Hall.
Spirifer euryteines Owen.
Spirifer iowaensis Owen ?.
Spirifer orestes Hall and Whitfield.
Spirifer pinonensis Meek ?.
Spirifer sp.
Stropheodonta arcuata Hall.
Stropheodonta demissa (Conrad).
Stropheodonta halli musculosa Cleland ?.
Stropheodonta perplana (Conrad).
Stropheodonta variabilis Calvin ?.
Stropheodonta sp.
Tropidoleptus occidens Hall.
Conocardium sp.
Nuculites sp.
Nyassa parva Walcott.
Palaeoneilo sp.
Paracyclas sp.
Bellerophon perplexa Walcott.
Bellerophon sp.
Coleolus sp.
Cyclonema sp.
Eunemia sp.

Loxonema sp.
Murchisonia dowlingi Whiteaves?.
Murchisonia sp.
Pleurotomaria cf. koltubanica Tschernyschew.
Pleurotomaria sp.
Raphistoma disciformis Tschernyschew?.
Raphistoma terrelli Cleland.
Straparollus clymenoides? Hall.
Trochonema monroei Cleland?.
Trochonema sp.
Hyolithes alatus Whiteaves?.
Tentaculites sp.
Orthoceras sp.
Poterioceras 2 sp.
Phacops sp.
Proetus sp.
Fish scales.

In all the Minnesota Devonian is known to contain seventy-seven species and some of them are probably new. The formation continues southward into Iowa where it is said to have a much larger fauna. It is apparently the equivalent of the Cedar Valley limestone of Iowa and this is a satisfactory formational name in Minnesota because much of it is found outcropping in the valley of Cedar River and its tributaries. It is possible, however, that the limits of the Cedar Valley limestone of Minnesota do not correspond exactly to those of the same formation in Iowa if the entire Minnesota Devonian is included in that formation.

The Devonian of Manitoba and the Mackenzie valley carry a few of the same fossil forms that are common in the Cedar Valley limestone of Minnesota. Unfortunately the fauna of that northern region is not as well known as might be desired. Whiteaves studies (7) have given a very good idea of several divisions especially that of the *Stringocephalus* zone in Manitoba and a fair knowledge of the same zone at the "*Ramparts*" on the Mackenzie River (8). Although the finding of two drift specimens of *Stringocephalus burtini* has been reported in Minnesota (9) the species is not known in the Devonian limestones of this state. In fact the Cedar Valley limestone fauna of Minnesota has nothing in common with the *Stringochalus* zone except certain long range species that are likely to be found in the Middle Devonian of most any part of North America. A comparison of the Minnesota fauna with that of other northwestern Canadian localities, as mentioned by Whiteaves (10), gives no more encouraging results. Whiteaves himself says, of his whole list from the Mackenzie valley, ten species are common to the Iowa (11) Devonian while twenty-two species are found in the Hamilton of Ontario and New York. This is a very significant suggestion as to the relationships of the north-

Paleogeographic Map of the North American region during late Middle Devonian.

western Devonian faunas but there are still others equally suggestive. Of those common to the Iowa Devonian half are general Hamilton forms while most of the others belong in the fauna of the Lime Creek shales and are hardly to be considered the most characteristic Iowa Devonian fossils. And at any rate the Lime Creek fauna is quite different from the Cedar Valley fauna and decidedly a later development as far as North America is concerned. The *Stringocephalus* zone of Manitoba carries about 20% Onondaga forms but less than 5% Cedar Valley species. The later Devonian faunas of the northwest are also decidedly different from that of the Cedar Valley and appear to have even less in common with it. In short, so remote is the relationship between the fauna of the Minnesota Devonian and that known from Manitoba and the Mackenzie valley that the idea of a direct sea connection between these two regions, during the deposition of the Cedar Valley limestone, should be abandoned. Unless the studies at present being pursued in Canada by Dr. Kindle, in Iowa by Professor Thomas, and in Missouri by Dr. Branson, should show a closer relationship for the upper beds than is indicated by our present knowledge it is probable that the supposed sea connection across Minnesota during Upper Devonian should also be abandoned.

The buried granite ridge, which crosses central Kansas (12) in a north-northeast direction, was land during Devonian time and probably an extension of the land area of the Lake Superior region. In fact the pre-Cambrian of this latter region crosses Minnesota as a buried ridge and disappears, under the Sioux quartzite, near the southwestern corner of the state. While the sea evidently crossed part of this old mountain range during certain periods such as the Upper Cambrian and the late Cretaceous, there are no definite indications that any part of it was submerged during the Devonian and the lack of the expected relationship between the Devonian faunas on either side of the ridge seems to indicate that there was a land barrier in that region during the life of these faunas.

The Devonian is represented by 8000 feet of limestone and shale in the Great Basin. Its fauna is only partially known but Walcott (13) found it to be a large and varied one with many similarities to that found typically in the Onondaga of New York and Ohio, but Hamilton and Chemung species are apparently not lacking in it. This relationship cannot be wholly accidental. But perhaps the most significant fact about this Devonian deposit is that it carries such a large percentage of species not known as a part of the eastern fauna. Many of these occur in the Iowa Devonian fauna especially in the upper beds. But there is still a considerable residue of forms most of which have not been specifically identified. It is in this latter that hope lies in an attempt to trace the Cedar Valley fauna, which probably has its ultimate origin in the Devonian of Russia and western Europe, or some region which supplied emigrant to all three of these areas. About 20% of the Minnesota Devonian species occurs in the fauna of the Great Basin Devonian and 30% more of it may be the same as those listed by Walcott (14). In the 6000 feet of limestone, which make up the lower division of the Devonian of the Great Basin, nearly the whole of Walcott's collection came from the lower 500 feet, thus leaving more than 5000 feet of massive limestone almost unexplored and a fruitful field for future research. The relationship that exists between the fauna of the Cedar Valley limestone of Minnesota and that of the Devonian limestone of the Great Basin, and somewhat more remotely of the middle Devonian of some of the Alaskan islands, has suggested the Paleogeographic map which accompanies this paper. It is in part a modification of one of Professor Schuchert's Devonian maps but it contains much for which he bears no responsibility. A map of this sort can only be suggestive of the conditions as they probably existed during any period or epoch. This follows from the fact that there has been so much erosion during subsequent time and this has probably removed all traces of the older deposits over wide areas, while land barriers that once existed have been likewise obliterated. Such maps are therefore subject to constant revision as new facts are discovered and new relationships become evident. The most striking fact that comes out during this study is the remoteness of the relationship between the fauna of the Cedar Valley limestone of Minnesota and that of the Devonian of Manitoba.

REFERENCES.

(1) Geological Survey of Minnesota, vol. I, 1884, pp. 303-307; 357-361.
(2) Idem, vol. I, 1884, p. 384; vol. II, 1888, p. 184.
(3) Idem, vol. I, pp. 353-356.
(4) Idem, vol. I, p. 385.
(5) Idem, vol. I, p. 460.
(6) Iowa Geological Survey, vol. XIII, 1903, pp. 268-279.
(7) Contributions to Canadian Paleontology, vol. I, pt. 4, 1892, pp. 255-359, pls. 23-47.
(8) Idem, pt. 3, 1891, p. 249.
(9) Referred to by Schuchert in U. S. G. S., Bull. 87, p. 417.
(10) Op. cit. pp. 247-250.
(11) Idem, p. 251.
(12) Bull. Am. Assoc. Petroleum Geologists, vol. 4, No. 3, 1920, pp. 255-261.
(13) U. S. G. S., Monograph VIII, pp. 4-8, 1884.
(14) Idem, pp. 99-211; 274-278; 284-285; and pls. II-VII; XIII-XVII.

University of Minnesota, Minneapolis.

SCIENTIFIC INTELLIGENCE.

I Chemistry and Physics.

1. *A New Method of Separating Arsenic from All Other Metals.*—L. Moser and J. Ehrlich have been led by theoretical considerations to a modification of the well-known method of separating arsenic from other metals by the distillation of arsenic trichloride. Instead of carrying out this operation in a stream of gaseous hydrochloric acid, or also with the vapor of methyl alcohol, they employ a stream of air with successive additions of strong hydrochloric acid solution.

The apparatus and the method of operation are very simple. A flask of 300 cc. capacity is used as the retort, and this is heated by placing it in boiling water up to the neck. A rubber stopper with three holes closes the flask, with a glass tube through which air is led to the bottom of the flask, with a glass dropping funnel supplied with a stop-cock for the introduction of hydrochloric acid solution, and with a bulbed outlet tube which leads to the receiver. The latter is a 400 cc. beaker containing 250 cc. of water.

Starting with the substance, with the addition if necessary of a reducing agent, such as ferrous sulphate or potassium bromide (which has been recommended by Gooch and Phelps for this reduction), 50 cc. of hydrochlorine acid (sp. gr. 1.19) are added, the apparatus is placed in the hot water, a rapid stream of air is passed through, and, after periods of ten minutes each, 20 cc. of the hydrochloric acid are added. With 0.15 to 0.25 g. of As_2O_3 the whole of it passes over in about 40 minutes. Very good results were obtained by test-analyses where the arsenic was determined volumetrically in the distillate, and it was found that no antimony passes over under these conditions.—*Berichte* **55**, 437. H. L. W.

2. *A New Volumetric Method as Applied to Certain Problems in Inorganic Chemistry.*—Paul Dutoit and Ed. Grofet have devised a method which is unique in furnishing evidence of the existence of certain compounds. From a burette which is thermally isolated a solution is delivered into a Dewar flask containing another solution where a reaction takes place between the two dissolved substances. A thermometer graduated to 0.01° is read during the titration, and the burette reading is plotted against the changes in temperature. Straight-line curves are found, with sharp breaks at the ends of reactions. Such diagrams show breaks when H_2SO_4 is half neutralized by sodium hydroxide, and also when the normal sulphate is formed. The several stages of neutralization of H_3PO_4 by NaOH are clearly indicated. Addition of HNO_3 to Na_3PO_4 give curves

with breaks at each step of the reaction with the trivalent salt. The addition of NaOH to $Zn(NO_3)_2$ gives breaks corresponding to the formation of $ZnNO_3OH$, of $Zn(OH)_2$ and of $Zn(ONa)_2$ and similar results are obtained with NaOH and lead, magnesium and copper salts. The salts of Cu, Co and Ni give evidence of the formation of successions of complexes as NH_3 is added. It is to be expected that this method of investigation will be of great value in furnishing a very simple method for the investigation of many chemical reactions.—*J. chim. pharm.*, **19**, 321 (1922). H. L. W.

3. *Theories of Organic Chemistry;* by FERDINAND HENRICH. Translated and Enlarged by TREAT B. JOHNSON and DOROTHY A. HAHN. 8vo, pp. 603. New York, 1922 (John Wiley & Sons, Inc.).

The wonderful achievements in connection with the theories applied to the carbon compounds are extremely well presented in this book, and it furnishes a most excellent source of information for advanced students and teachers of chemistry. The translators deserve much praise for making this important German work available for the use of English-reading chemists, as well as for the introduction of several new chapters and other additions which deal particularly with the work of American investigators, especially with that of the late J. U. Nef and of Arthur Michael. The German author has furnished a preface to the American Edition in which he approves of these additions and modifications.

The subject is presented historically, with naturally less attention to the older, superseded views than to those now prevailing or under active consideration. The discussions of the modern theories are very full and clear, the translation of the German text into English appears to be most excellent, and the difficult typography involving many, frequently complex, structural formulas has been very well done. H. L. W.

4. *The Chemistry of Combustion;* by J. NEWTON FRIEND. 12mo, pp. 110. New York, 1922 (D. Van Nostrand Company. Price $1.25 net).—This monograph is the outcome of a series of lectures recently delivered by the author in the Birmingham Municipal Technical School. It gives a clear and satisfactory presentation of the subject in its modern aspects, and since it appears that there has been no small text-book of this kind to which students may be referred, it may be regarded as filling an obvious gap in our literature.

The first chapter is devoted to definitions, then the phlogiston theory is briefly discussed, while the other sections are devoted to the combustion of solid carbon, flame, the combustion of gaseous hydrocarbons and other gases, ignition temperatures, the inflammation of gaseous mixtures and the propagation of flame in them, and surface combustion. The references to the literature are numerous and satisfactory. H. L. W.

5. *Petroleum, Where and How to Find It;* by ANTHONY BLUM. 12mo, pp. 367. Chicago, 1922 (The Modern Mining Books Publishing Company).—This book has been prepared by an operator in the "oil business," who has evidently had much experience in it, for the benefit of those who are or may become interested in this great industry. It is a popular, rather than a scientific, book. It presents many interesting facts and statistics, and gives much practical information and advice in regard to the production of petroleum. H. L. W.

6. *The Heavier Constituents of the Atmosphere.*—Sir J. J. THOMSON has recently applied his method of positive ray analysis to several problems involving possibly unknown constituents of certain gases. For the first case he had been supplied by Professor Dewar with a considerable amount of the residues obtained by evaporating many thousand tons of liquid air. These residues had been absorbed by charcoal and the subsequent evaporation of the gases from the charcoal apparently effected a fractionation so that only components heavier than krypton were retained by the charcoal.

The positive ray photographs showed the line of xenon very prominently and also lines of at least two heavier constituents corresponding to atomic weights of approximately 163 and 260.

The author is of the opinion that these lines are due to molecules of krypton and xenon, as these numbers are about twice the atomic weights of the respective gases. Experiments were further made to see if these constituents showed any properties analogous to the emanation of radio active substances, but evidence of ionization resulting from such presumed emanation could not be detected.

Another application by Professor Thomson of his method was to the analysis of the gases obtained from a tube in which 70 mgm. of radium chloride had been sealed, after exhaustion of the air, for a period of thirteen years. The positive ray line for helium was very strong and a faint line corresponding to $m/e = 5$ was also found. This latter he ascribes to a compound of helium and hydrogen. Neon was not detected.

A third problem was the testing of gases which had stood over radium and also gas lit by deflagrating wires. In these cases quadruply charged atoms of nitrogen were detected and triply charged atoms of oxygen, nitrogen, and carbon. The compound OH_4 invariably carried a double charge.—*Proc. Roy. Soc.* **101,** 290, 1922. F. E. B.

7. *The Corrosion of Iron and Steel.*—Careful estimates of the amount of steel and iron structures or materials which are annually rendered unserviceable by rusting place it as high as

40 million tons. Whether these figures are exaggerated or not the wastage by corrosion is so great that the concerted efforts of engineers to produce some form of steel alloy with a capacity for resisting corrosion seems imperatively demanded. Apart from the known valuable properties of chromium steel which is too expensive for use on any considerable scale the most promising suggestion has been the introduction of a small percentage of copper into a mild steel, which has been thought by several investigators to give it a superior resisting power. The report of a new series of corrosion tests by Sir Robert Hatfield upon some American steels containing from .02 to .27 per cent. of copper has just been published. The results of the author's observations may be stated as follows: (a) Under atmospheric corrosion copper steel was rather less affected than ordinary steel especially in the more corrosive condition of an industrial atmosphere. The superiority was of the order of 10 per cent. in pure air and 25 per cent. under the industrial contamination. As is generally the case, material with the rolling scale removed was more resistant than with the scale on. (b) In sea water ordinary steel corrodes more rapidly at first but the rate of corrosion for both materials slows up showing a certain degree of self-protective action which was a little greater for ordinary steel. The total corrosion of the copper steel however was slightly less at the end of 16 weeks than that of ordinary steel. (c) In tap water (Sheffield, England) there was little to choose between the two materials. Though initially not so corrosive as sea water, over a long period it was more corrosive due to the absence of any self-protective action in the presence of tap water. (d) In a 50 per cent. sulphuric acid bath both materials were rapidly attacked at first but whereas the solution of ordinary steel continued at a steady rate, that of the copper steel showed a very much reduced rate after the scale had been removed. The steel containing copper was apparently very resistant to a 50 per cent. sulphuric acid solution. (e) A 20 per cent. sulphuric acid solution showed a more vigorous action than the 50 per cent. solution but the superior resistance of the steel containing copper was again confirmed.

The deductions to be drawn from these experiments are (1) that the superiority of copper steel under atmospheric corrosion is due to and dependent on the amount of sulphurous impurity carried by the air; (2) that no advantage will be gained by the use of copper steel in ordinary fresh water; and (3) that for long immersion in sea water this alloy is probably inferior.

The author is further of the opinion that as in the majority of service conditions iron or steel is subjected to total or partial immersion in natural waters it is by no means certain that a copper content as a commercial constituent of mild steel might not be deleterious.—*Proc. Roy. Soc.* **101**, 472, 1822. F. E. B.

8. *The Mathematical Theory of Probabilities;* by ARNE FISHER. Vol. I, pp. XXIV, 289. New York, 1922 (The Macmillan Company).—The author who is an actuary by profession has written this treatise chiefly for students of statistics, but the reader will have to be an expert mathematician to follow the analytical development of the theorems. In this second edition twelve chapters are devoted to the theory of probabilities of homograde statistics, by which is to be understood such series of events as appear in games of chance. Two chapters are given to the fitting of various analytical formulas and series to statistical data or frequency distributions. The remaining four chapters explain and illustrate in detail the method of computing the parameters in numerical series. It is difficult to believe that any set of data could justify the expenditure of so much labor in analyzing the curve into what is after all but an arbitrary set of functions. The author's work is characterized by his devotion to the methods of Laplace in the development of the theory, and the use of the semi-invariants of Thiele, in preference to Pearson's method of moments, in the calculation of the parameters of the frequency function. F. E. B.

II. GEOLOGY.

1. *The Paleontology of the Zorritos Formation of the North Peruvian Oil Field;* by EDMUND M. SPIEKER. Johns Hopkins University Studies in Geology, No. **3**, 196 pp., 10 pls., 1922.—In 1867, Mr. E. P. Larkin and Professor F. H. Bradley made collections of Miocene fossils in the area of Zorritos, Peru, and these were described three years later by Edward T. Nelson. Recently far more material was collected in this region by Professor Singewald, and all of the known collections are here reported on in detail. The Zorritos formation now is known to have 44 species of gastropods and 57 of pelecypods. Of these, 64 are new. The time appears to be in the main Burdigalian, though the higher beds may be of Helvetian age. The fauna is a shallow-water one, of warm waters, and correlates best with similar faunas of Panama and the Antillean areas. C. S.

2. *The Recession of the last Ice Sheet in New England;* by ERNST ANTEVS. Amer. Geog. Soc., Research Ser., No. **11**, 120 pp., 6 pls., 19 text figs., 1922.—In this well printed and edited book, the author describes the De Geer method of determining the rate of annual deposition of "varved" glacial clays and also the rate of recession of the ice lobes in the lake-filled river valleys. This method is, in addition, the only known one for measuring earth chronology in actual years. Antevs' work relates in the main to the Connecticut valley from Hartford,

Connecticut, north almost to the Canadian border. It took the ice something like 4100 years to melt back this distance. How long ago the American continental ice sheet began its melting away is not yet known. The average recession of the ice appears to have been about one mile in 22 years, though locally the rate varies from 83 to as much as 1100 feet per year. At times there was even a slight re-advance of the ice sheet.

It took about 5000 years for the ice to melt back from southernmost Sweden north for 480 miles. Since the ice melted away, another 8500 years has elapsed, so that it is about 13,500 years since the continental ice sheet began its recession in southernmost Sweden.

The term "varve" is a Swedish word, and in geology signifies the annual cycles of sedimentation of glacial clays, beginning in the coarser, lighter colored material of summer deposition and ending in the darker winter deposit of the finest blue muds, having a greasy feel. Varved clays are all laid down in fresh-water lakes in front of ice lobes, and when glacially derived muds are laid down in the sea, it is said that they are not varved but are homogeneous, in that the coarser material is mixed with the finest of muds. In fjords, however, such muds may also be faintly varved.

The measuring of the varves and the making of the local graphs to show the varying rate of annual deposition is not a difficult matter, but requires patience, since the work is both laborious and time-consuming. The greatest difficulty of the method lies in finding a succession of closely adjacent clay (not sand) exposures and in correlating these by means of the graphs from place to place. The method tends somewhat to underestimate the total time and never to overestimate it. Commonly, there are two easily distinguishable layers to a varve, but often the lighter colored summer portion will be much thicker and more or less banded, while the darker greasy winter layer is usually not banded. The normal varve, or the cyclic material for one year, is usually much less than one inch in thickness, but in the vicinity of drainage the summer deposition, when of sand, may rise to as much as 12 feet.

The De Geer method of evaluating varves also reveals the climatic periodicity of the time of deposition, not only as to the short cycles, but the long ones as well. When fossil leaves are abundant, one can also discern in years the rate of floral adaptation and migration.

The memoir is concluded with a most interesting map by Professor Goldthwait, which plots for the area of New York, Pennsylvania, New Jersey, and the New England States the direction of ice flow, boulder trains, terminal and recessional moraines, and the position of the ice-edge for every 100 years, as determined by Antevs between Hartford, Connecticut, and the Canadian boundary.

A ready means is now at hand for a definite chronology of post-glacial time, and our thanks and congratulations are due to Doctor Antevs for his successful results. C. S.

3. *A Section of the Paleozoic Formations of the Grand Canyon at the Bass Trail;* by L. F. Noble. U. S. Geol. Survey, Prof. Paper **131-B**, pp. 23-73, pls. 19-25, 4 text figs., 1922.—In this memoir the author brings together in great detail all that he has learned about the Paleozoic sequence—Cambrian, Devonian, Mississippian, Pennsylvanian, and Permian—of the marine and continental strata in the Grand Canyon of the Colorado River, during the years 1914, 1916 and 1920. Various sections are described from Bass Trail eastward for 35 miles, and all of the zones and sections correlated into a generalized sequence having a thickness of 4014 feet, besides 506 feet of Triassic formations. The Grand Canyon should be the Mecca for all stratigraphers, and the worshippers at this grandest of Nature's shrines will find guidance and inspiration in Doctor Noble's careful study of the sediments deposited here by an epeiric sea, from shore to deeper water. C. S.

4. *Essentials for the Microscopical Determination of Rock-Forming Minerals and Rocks in Thin Sections;* by Albert Johannsen. Pp. 53, with 24 text figures. Chicago, Ill., 1922. (The University of Chicago Press, $2.00.)—This work is a revision of the author's well-known laboratory manual, "A Key for the Determination of Rock-forming Minerals in Thin Sections," which was published in 1908. The new edition appears in a markedly different format, being now in quarto instead of octavo, and by rearrangement of the determinative tables it has been very notably reduced in bulk—from 542 pages to 53. The descriptions of the individual minerals have been slightly condensed. Brief notes on the modes of geologic occurrence have been added, and the diagnostic differences between minerals of somewhat similar optical properties are more adequately emphasized. A summary exposition of the author's quantitative mineralogical classification of igneous rocks has also been added.

Adolph Knopf.

5. *The Rocks of Mount Everest.*—The efforts of the members of the Mt. Everest expedition of 1922 to reach the Summit of the mountain have already been fully given in the public press. That it was found possible to reach an altitude of 27,300 feet, with the aid of oxygen, is sufficiently noteworthy. It is still more interesting that a third expedition is already being tentatively considered and a greater degree of optimism is felt by the climbers as to ultimate success than after the effort

of 1921; this is based practically on the fact that the physiological effects at altitudes of 26,000 and above were found to be less serious than anticipated.

Dr. A. M. Herron has given the results of the examination of rock specimens collected at heights from 23,000 to 27,000 feet. The conclusion is reached that "Mount Everest is a pile of altered sedimentary rocks—shales and limestones—converted into banded hornfels, finely foliated calc-silicate schists, and crystalline limestones. The hornfels and fine schists are in the field blackish or dark green rocks, conspicuously slabby and with a general low dip to the north, which, I believe, adversedly and even dangerously affected climbing. The crystalline limestones are fine-grained pure white rocks. The specimens from 23,000 and 25,000 feet show in microscope sections a very fine-grained aggregate of quartz and a greenish mica, with irregular lenticles and veins of chlorite and epidote, and in addition sometimes calcite pyrites and sphene.

"The mountain, from 21,000 to 27,000 feet, is made up of these black and dark green rocks, with occasional beds of white limestone, and veins of quartz and muscovite granite. From 27,000 to 27,500 feet extends an almost horizontal belt, a sill in fact, of schorl muscovite granite, along the whole length of the mountain, which rock presumably, by its superior hardness, gives rise to the prominent shoulder of the mountain north-east of the main peak (shown as 27,390 on Major Wheeler's photographic survey map). Above this again are black schists. Captain Finch informs me that he saw ammonites at a height of about 26,500 feet, but was unable to collect them.

"As to the age of the rocks forming Mount Everest, they may perhaps be assumed, for the present, to be Jurassic or Trias." *London Geological Journal*, September, 1922, pp. 219, 220; see also July, pp. 67-71, August, pp. 141-144 and October, pp. 288-291, with fifteen beautiful reproductions from photographs.

6. *A newly Found Tennessee Meteoric Iron;* by G. P. Merrill (communicated).—State Geologist William A. Nelson has forwarded to the U. S. National Museum a mass of meteoric iron recently found by Messrs. C. D. McKnight and M. W. Spencer while working on the roadway leading from Savannah to Cerro Gordo, some four miles northeast of the first named town in Hardin county, Tennessee. The mass is 18 inches in length, roughly dumb-bell shaped and weighs 132 lbs. It is an octahedrite in crystallization and much weathered, undoubtedly representing an old fall. A cast will be made of it, after which it will be cut and analyzed a portion being retained at the National Museum and a portion returned for the State collection at Nashville.

7. *Minor Faulting in the Cayuga Lake Region;* by E. T. Long.—The following corrections should be made in the above article in the number for April (pp. 229-248).

The first line on p. 232 should read: *The Watkins Glen-Catatonk folio deals with,* etc.

Page 233, line 26 from top, *Enclinal* should read *Encrinal.*
Page 236, line 4 from top, *north* should read *south.*
Page 247, line 18 from top, *Cayuga* should read *Cayuta.*
Page 247, line 23 from top, *Cayuta* should read *Cayuga.*

III. MISCELLANEOUS SCIENTIFIC INTELLIGENCE.

1. *Foundations of Biology;* by LORANDE LOSS WOODRUFF. Pp. xviii, 476, with 211 illustrations. New York, 1922 (The Macmillan Company).—This text book, designed particularly to supplement the laboratory work of college students in the elementary course in biology, has been prepared with more than usual care both as to scope and proportion. In it the reader will find a logical and comprehensive account of the underlying principles of the organic world, leading from a simple discussion of the physical basis of life through the organization, metabolism, reproduction, differentiation, heredity, and adaptation of organisms, to the evidences of organic evolution. The nineteen chapters embracing this part of the work are so skilfully correlated as to make a continuous and harmonious account of the vital phenomena in both plants and animals. In the final chapter is told the story of the historical development of biological science from the earliest times to the present, with a brief account of the work of those who have made the most important contributions to the subject. A synoptic classification of organisms and a concise glossary of technical terms are appended. Many well-drawn original diagrams are found among the numerous illustrations.

The book has so many points of excellence that it is not too much to say that its careful reading will give to those who pursue the subject no further a clear, broad, comprehensive and well-balanced conception of life and its evolution, while to those who contemplate further work in biology it will furnish an ideal foundation for their more advanced studies. W. R. C.

2. *The Study of Living Things: A Course in Biology for Secondary Schools;* by W. H. D. MEIER. Boston, New York, etc. (Ginn and Company).—This laboratory guide is issued in the form of a pad of sheets of generous size to be filled out by the pupil with answers or drawings according to the special instructions on each sheet. Ninety-six exercises, covering the entire field of elementary biology, are included, each requiring a practical investigation on the part of the pupil and compelling him to do some independent thinking. No better plan has been devised for bringing the pupil into direct contact with the most important aspects of the subject. W. R. C.

3. *Field Museum of Natural History. Annual Report of the Director,* D. C. Davies, *to the Board of Trustees, for the year 1921.* Pp. 75, with 16 plates. Chicago, 1922.—This report is made of especial interest since it opens with a notice and portrait of Dr. Frederick J. V. Skiff, who served as director from December 16, 1893, until his sudden death on February 21, 1921. What Dr. Skiff did towards the development of the museum during a period of service extending over nearly thirty years is best appreciated by those who were closely associated with him. The museum has also suffered by the loss of Dr. Frank W. Gunsaulus, one of the original trustees, and of Charles B. Cory, curator of Zoology. The Museum was reopened in its new building on May 2, 1921, at that time everything was in readiness of the renewal of its work. The entire deficit in the building fund has been assumed by President Stanley Field, who had earlier contributed the sum of $150,000. Capt. Marshall Field has agreed to contribute $50,000 annually for five years to pay for expeditions in the field, for new exhibition cases and for the publication of papers by members of the staff; he had already contributed $65,000 toward the deficit in the building fund.

4. *Publications of the British Museum of Natural History.*—Recent publications are the following:

Catalogue of the Fossil Bryozoa (Polyzoa) in the department of Geology: The Cretaceous Bryozoa, volume IV. This volume (pp. 1-404, with 8 plates) by W. D. Lang is part II of the catalogue of the Cribrimorphs, completing the Cretaceous Cribrimorph Cheilostomata. See introduction to volume III.

Catalogue of Books, Manuscripts, Maps and Drawings. Vol. VI, Supplement, A to I. Pp. 551, 4to. With Addenda and Corrigenda to vols. I and II, A to Hooker. Pp. 48. The first volume of this Catalogue was published in 1903; volumes II-V followed in 1904-1915. These were prepared by B. B. Woodward, who, with some clerical aid has compiled the present Supplement.

5. *National Academy of Sciences.*—The autumn meeting of the National Academy will be held in New York City, November 14 to 16. The opening session will be on Tuesday morning in Schermerhorn Hall, Columbia University, at 10 o'clock. The session for the presentation of papers will immediately follow the business session. This will be opened by a brief address of welcome from President Butler. So far as possible, papers from the Sections of astronomy, chemistry, geology and paleontology will be assigned to this day. On Tuesday evening President and Mrs. Butler will receive the visiting members and their friends at the President's house, 60 Morningside Drive, beginning 8.30. A subscription dinner will be held on Wednesday evening, at a place to be announced later.

On Wednesday, November 15, the meeting will be held at the Rockefeller Institute, Avenue A and 66th Street. So far as possible, papers from the Sections of botany, zoology and animal morphology, physiology and pathology, anthropology and physiology, will be given on this day. The meeting of Thursday will be held in the auditorium of the United Engineering Societies Building, 29 West 39th Street. Papers from the Sections of mathematics, physics, and engineering will be given on this day. Thursday evening has been left open for informal gatherings of members. The headquarters of the Academy are at the Hotel Astor, 44th St. and Broadway.

OBITUARY.

DR. ALEXANDER SMITH, professor of chemistry and head of the chemical department in Columbia University from 1911 to 1921, died in Edinburgh, his birthplace, on September 8 at the age of fifty-seven years. Professor Smith held many University positions, contributed important researches on the forms of sulphur, and (with A. W. C. Menzies) on vapor pressures, wrote numerous useful textbooks and in brief was a man of great energy and wide influence.

DR. F. T. TROUTON, emeritus professor of physics in the University of London, died on September 21 at the age of fifty-eight years. Born in Dublin in 1863, he was graduated from Trinity College where he early showed his rare keenness of mind. He was made at once assistant to the professor of physics, and in 1902 became Quain professor in University College, London. He will be remembered for many important researches, those leading to the establishment of Trouton's Law, on Hertzian waves, on the viscosity of solids and others of no less importance.

DR. DAVID SHARP, the veteran English entomologist, died on August 27 at his home in Brockenhurst, at the age of eighty-two years.

DR. WILLIAM KELLNER, the eminent chemist, died on September 12, in his eighty-third year. He was born and received his education in Germany, but came to England in 1862 as assistant to Sir Henry Roscoe at Manchester. He was made chemist to the British War Department in 1902.

DR. ARTHUR LALANNE KIMBALL, for thirty-one years professor of physics at Amherst College, died on October 22 at the age of sixty-six years.

DR. ALBERT AVERN STURLEY, instructor in physics in Yale University, died on October 22 at the age of thirty-five years.

CONTENTS.

SCIENTIFIC INTELLIGENCE.

VOL. IV DECEMBER, 1922

Established by BENJAMIN SILLIMAN in 1818.

THE
AMERICAN
JOURNAL OF SCIENCE.

EDITOR: EDWARD S. DANA.

FIFTH SERIES
VOL. IV—[WHOLE NUMBER CCIV].

No. 24—DECEMBER, 1922.

NEW HAVEN, CONNECTICUT.

1922.

THE TUTTLE, MOREHOUSE & TAYLOR CO., PRINTERS, 123 TEMPLE STREET.

Published monthly. Six dollars per year, in advance. $6.40 to countries in the Postal Union; $6.25 to Canada. Single numbers 50 cents; No. 271, one dollar.

Entered as second-class matter at the Post Office at New Haven, Conn., under the Act of March 3, 1879.

Wiley Books

for Mineralogists and Geologists

Published During 1922

October

Elements of Optical Mineralogy—Part I, Principles and Methods.

Second Edition, Entirely Rewritten and Much Enlarged.

By **ALEXANDER N. WINCHELL**, Doct. Univ. Paris.

An introduction to microscopic petrography, adapted to the study of minerals, both in thin sections and in powdered form immersed in liquids.

216 pages. 6 by 9. 215 figures. Cloth, $2.50.

March

Coal: Its Properties, Analysis, Classification, Geology, Extraction, Uses and Distribution.

By **ELWOOD S. MOORE.**

Anyone desiring to obtain a general knowledge of the subject of Coal can do so with the aid of this book.

462 pages. 6 by 9. 142 figures. Cloth, $5.00.

January

A Text-book of Mineralogy, By **EDWARD S. DANA.**

Third Edition, Revised and Enlarged, By **WILLIAM E. FORD.**

The changes made consist chiefly of additions bringing the work right up to date.

720 pages. 6 by 9. 1050 figures. Cloth, $5.00.

Mineral Land Surveying. Third Edition.

By **JAMES UNDERHILL, PH.D.**

This new edition has been revised to represent present-day practice in the western portion of the United States.

237 pages. 4½ by 7. 43 figures. Flexible, $3.50.

Send for any Wiley book on *Free Examination* terms.

JOHN WILEY & SONS, Inc.

432 Fourth Avenue
New York

London
CHAPMAN & HALL, Ltd.

Montreal, Quebec
Renouf Publishing Company

AJS 12.22

THE

AMERICAN JOURNAL OF SCIENCE

[FIFTH SERIES.]

◆

Art. XXXVI.—*John Day Felidæ in the Marsh Collection*; by George F. Eaton.

[Contributions from the Othniel Charles Marsh Publication Fund, Peabody Museum, Yale University, New Haven, Conn.]

To the surviving personal friends of O. C. Marsh, and also to the younger generation of vertebrate paleontologists, Marsh's eagerness to secure fossils from newly reported localities in the western United States, and the success of the collectors he employed, no longer present any novelty. It need therefore occasion no surprise that the Marsh Collection of Vertebrate Fossils in the Peabody Museum of Yale University should contain a considerable amount of material, from the John Day Valley of Oregon, that was collected principally between the years 1870 and 1877. The present short article is based on that portion of this material from the John Day Valley which includes the Felidæ.

While it would be ungracious to criticise the methods of collecting in vogue in the seventies of the last century, it appears that the superior value of a good skull over the other skeletal parts, which were then somewhat disparagingly termed "joints," was a little over-emphasized in Marsh's instructions to his collectors. A result of this is possibly to be seen in the predominance of cranial material, unaccompanied by other skeletal parts that might otherwise have been saved, and that would now greatly enhance the value of the collection. Then, too, the stratigraphy of the region was neither so well understood nor regarded as of the same importance in connection with the search for fossils as it has been of recent years, and accordingly it would be unwise to accept as authoritative, in some instances, the recorded statements of the collectors regarding the horizons from which specimens were obtained. For this reason the present article must be limited, in the main, to a discussion of the osteology and affinities of the material examined, and less attention can be paid to stratigraphic considerations than would otherwise be desirable. Yet notwithstanding real or suspected shortcomings in field work during pioneer days, the fact remains that this material, collected half a century ago, is worthy of careful study, and contains forms specifically distinct from those previously described. It is a pleasant duty therefore to express the admiration that is felt for the generous enthusiasm that led Professor Marsh to be one of the first paleontologists to visit the John Day Valley and to encourage the search for fossils in that region.

Tables.—For convenience in comparing the new species, here described, with the earlier types, cranial measurements have been arranged in parallel columns in Table A (page 442). While most of the measurements, selected for this purpose, conform with those used by previous authors, three new measurements have been introduced, and an external palatal length has been substituted for the old mid-line measurement. This table as originally constituted included practically all the measurements of cranium and mandible used by Merriam and by Thorpe; but while extremely useful in the study of material in the laboratory, it was thought too large for convenience of publication at the present time. The table has therefore been cut down to about one third of its original size by the omission of all mandibular and nearly all dental measurements, as well as of several cranial measurements that, on trial, did not yield satisfactory differential indices. Although the number of measurements and indices has been reduced, it has seemed desirable that the series of specific types, and other crania, tabulated under the several genera, should be as complete as possible, in order that the range of the indices characterizing these genera might be reliably determined. For this purpose four of the best preserved crania of the genus *Nimravus* in the Marsh Collection have been measured and the resulting indices recorded. Examination of several of Cope's types, now in the American Museum of Natural History in New York, has been possible through the courtesy of Dr. W. D. Matthew of that institution; and Professor John C.

Merriam, lately of the University of California, has very kindly supplied certain measurements of his types of *Pogonodon davisi* and *Nimravus* (*Archælurus*) *debilis major* in addition to those given in his original description of these two types. The illustrations accompanying this article are by Mr. R. Weber, and have a value of their own quite apart from the text.

Where the number of species to be compared is large, interpretation of the absolute measurements is facilitated by a further table expressing *relative* cranial proportions. The system of indices, so extensively used by anthropologists, eliminates the factor of mere size and is admirably adapted to this requirement. Accordingly the basal length, measured from basion to prosthion, which is probably the most rational single element of size, has been chosen as a convenient basis for the comparison of the major cranial proportions. From several of the cranial measurements in Table A, indices have been derived by the simple process of dividing these measurements, as taken on each skull, by the basal length of that skull, and multiplying the quotient by 100. In the case of minor cranial proportions and dental proportions, other dimensions than the basal length are more suitable as the bases of comparison; but as in every case the definitions of the indices, arranged in Table B, refer to the serial numbers of the absolute measurements, recorded in Table A, no confusion regarding the identity of the indices in Table B need arise.

The measurements recorded in Table A call for little explanation. The axial length from the prosthion to the posterior surfaces of the occipital condyles has been retained principally because of its long use by previous authors as a convenient over-all dimension; but the basal length from basion to prosthion, which can be readily taken in some skulls where Cope's axial length is impracticable, has been preferred as a basis for the comparison of size and proportion. There has been little uniformity in the past regarding the measurement of palatal length. The margin of the palatine bones bounding the posterior nares is seldom perfectly preserved, and even when complete it seems to be subject to some individual variation of form due to the development of a posteriorly directed mid-line process homologous with the posterior nasal spine of the human skull. It has seemed desirable therefore to discard the mid-line palatine length, and to substitute for it a palatal length measured from the prosthion to a line tangent to the posterior surfaces of the maxillary parapets. This is precisely the same as the external palatal length of human craniometry. Since the index of palatal length, computed from this dimension and the basal length, is remarkably constant in all the species of *Nimravus, Dinictis,* and *Pogonodon* examined during the preparation of these tables, the palatal length furnishes an excellent basis for computing indices of palatal breadth.

Pogonodon Cope.

This genus was founded by Cope[1] on the characters of a skull that he had originally described as *Hoplophoneus platycopis.*[2] In a later article[3] he stated that "This genus [*Pogonodon*] represents a station on the line connecting *Dinictis* with the higher sabre-tooths, being intermediate between the former genus and *Hoplophoneus,*" and provisionally referred to the same genus incomplete material which he had made the type (partim) of *Machærodus brachyops.*[4] *Pogonodon platycopis* and *P. brachyops* were transferred by Adams[5] to *Dinictis,* the reason for this change being that "The genus *Pogonodon* as proposed by Cope does not differ from *Dinictis* as regards tooth structure, and the absence of the second inferior molar, which in *Dinictis* is much reduced, is not sufficient grounds for retaining it as a distinct genus, since in several specimens of *Dinictis* it is variable in size and in one is absent from one side." Matthew[6] referred *Pogonodon platycopis* to Cope's genus *Nimravus,* regarding *Pogonodon* as a distinct sub-genus; and to the same genus he referred *P. brachyops* also, stating his opinion that the latter species was "like *N*[*imravus*] *gomphodus* and doubtfully separable from it except by absence of the infracarnassial exostosis." In the same

---

[1] E. D. Cope, Am. Nat., 14, 143, 1880.
[2] E. D. Cope, Am. Nat., 13, 798a, 1879.
[3] E. D. Cope, Am. Nat., 14, 847, 1880.
[4] E. D. Cope, Proc. Am. Phil. Soc., 18, 72, 1878.
[5] G. I. Adams, This Journal (4), 1, 433, 1896.
[6] W. D. Matthew, Bull. Am. Mus. Nat. Hist., vol. 28, 310, 1910.

article, in his discussion of *Hoplophoneus,* Matthew notes that Merriam's *Pogonodon davisi,* which Matthew had not then had an opportunity to examine, ''appears from Merriam's figures to be referable to this genus [*Hoplophoneus*] and distinct from any of the *Dinictis* phylum.'' On the other hand, Merriam[7] in his announcement of *Pogonodon davisi* has stated at considerable length the reasons for which it seemed to him ''advisable to use the arrangement proposed by Cope, and to separate *platycopis, brachyops,* and *davisi* [from the deinictid group in the John Day beds] as the *Pogonodon* group, of at least subgeneric rank.'' In this status *Pogonodon* has rested for several years. My colleague M. R. Thorpe[8] has recently found it expedient to recognize the validity of Cope's *Pogonodon* in order satisfactorily to record the affinity of a feline mandible from the White River beds of South Dakota. Similarly in the case of the skull about to be described, the practical convenience of retaining *Pogonodon* as a distinct genus, or subgenus, is not to be denied.

Pogonodon serrulidens, sp. nov.

(Figs. 1-3.)

Holotype, Cat. No. 10520, Y. P. M. Upper Oligocene (John Day), Turtle Cove, John Day Valley, Oregon. Collected by L. S. Davis in 1875.

The type material consists of a cranium, not particularly well preserved, together with two fragments of the right mandibular ramus, the proximal portion of the right ulna, and the proximal portion of the left metatarsal III. From the indications of age afforded by the sutures alone, this skull would appear to be that of an animal nearly or quite adult, but the dentition proves that the animal was immature. The permanent premolar and molar series is, or was, complete, while the deciduous canine of the left side is still present, being but partly overlapped, on its inner side, by its permanent successor. On the right the deciduous canine has been lost with part of the maxilla, so exposing considerably more of the permanent canine than the portion that had actually protruded beyond the parapet. The premaxillary alveolar border has been damaged, and none of the

---

[7] J. C. Merriam, Univ. of Calif., Bull. Dept. Geol., vol. 5, 57, 1906.

[8] M. R. Thorpe, This Journal (4), 50, 223, 1920.

incisors are preserved. While the immature development of the skull admittedly detracts somewhat from its value as a specific type, this deficiency is nearly compensated by the fact that the teeth of the permanent set exhibit practically no signs of wear, and therefore present, so much the more clearly, their characteristic form.

The material is provisionally attributed to the upper John Day because of the gray color of the ashy matrix, which, although slightly tinged with green, can not be described as bluish-green; but as this stratigraphic reference is unsupported by field records or other data, it should not be regarded as established beyond question.

FIG. 1.

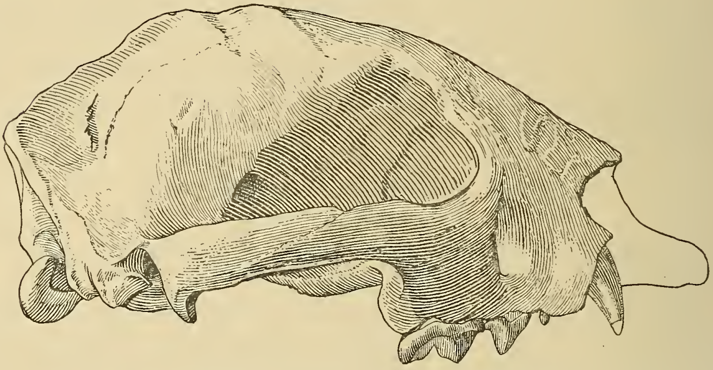


FIG. 1.—*Pogonodon serrulidens,* sp. nov. Holotype. × ½.

Dentition.—I^3, C^1, P^3, M^1. The upper canines are compressed. The anterior margin of the right upper canine, which is exposed to view for nearly half its length, is sharper than in *Nimravus,* the serrated anterior ridge following the actual anterior margin of the tooth for a greater distance from the point than is the case in *Nimravus.* P^2 is very small, practically vestigial, and single-rooted. P^3 is much smaller in proportion to P^4 than in *Dinictis* and *Nimravus,* in this respect nearly resembling *Pogonodon davisi.* P^4 is without a positive inner cusp (protocone), the inner root being small and closely adpressed to the anterior root. It has a small but definite anterior accessory cusp (parastyle) distinctly separated from the sharp anterior margin of the paracone by a narrow oblique cleft. This is a character which the present species shares with *Pogonodon davisi,* but not with *P. platycopis,* for according to Cope[9] the upper sectorial of the latter species has no parastyle. The paracone and metacone of P^4 are separated by a deep notch much as in *Dinictis* and *Nimravus,* and judging from the illustrations of *Pogonodon davisi,* as in that species also. M^1 is small with much reduced inner lobe. P_4 which is fortunately preserved in one of the mandibular fragments, has a relatively greater transverse breadth than I have observed in specimens of *Nimravus.* In this greater breadth and in the extent and form of the notch separating the posterior basal tubercle from the principal cusp, this tooth closely resembles the P_4 of Thorpe's *Pogonodon cismontanus,* Cat. No. 10053, Y. P. M.

The cutting edges of all the teeth, including even the vestigial P^2, are finely serrated. This condition would facilitate the sectorial action of the teeth of a young and comparatively weak animal. It would be of progressively less advantage as the jaws and their muscles acquired greater strength. By the time the animal was fully adult, the serrations would probably be nearly or quite worn away from all the cheek-teeth, while on the canines, which because of their special function are less subject to detrition, the serrations might be expected to persist much longer. Sand and gritty substances taken into the mouth with food are a constant cause of dental detrition among the Carnivora, not excepting even the cleanly *Procyon lotor,* and in view of the habit of some recent large felines of crunching bones,[10] it is probable that similar habits, acquired as the large extinct felines approached maturity, would hasten the destruction of the serrated sectorial edges. The resemblance of these serrated teeth to small saws has suggested the specific name, but it is not assumed that the cheek-teeth were serrated only in this species, or indeed in this genus alone.

One of the mandibular fragments supports a lower permanent canine lacking the upper half of the crown.

---

[9] E. D. Cope, Report of the U. S. Geol. Survey of the Territories, vol. 3, 981, 1884.

[10] Dr. W. Reid Blair, D. V. S., of the New York Zoological Park, informs me that the lion, tiger, leopard and puma all use the large cheek-teeth for this purpose.

The tooth is not quite fully protruded. The order of dental replacement, exhibited in this skull, should be noted. Disregarding the incisors, none of which have been preserved, there are actually in place and functional, in the lower jaw, a permanent canine and a permanent P_4, and in the upper jaw, on one side, all the permanent premolars and molars. On the left side the alveolar margin where P^2 should be has been destroyed. From the foregoing it appears that the deciduous upper canines remained in place until all the permanent upper cheek teeth were fully erupted. The presence of P_4 in the mandible renders it probable that the replacement of the lower cheek-teeth also was nearly if not quite completed, for in recent carnivores the lower carnassial is the first permanent cheek-tooth to appear. The best example at hand of a recent wild feline, showing the dental replacement, is a skull of the bay lynx (*Lynx rufus*), No. 0926, Y. P. M. Comparison of this lynx skull with that of *Pogonodon serrulidens* shows that, the replacement of the canines being at approximately the same stage in the two skulls, the replacement of the cheek-

Fig. 2.

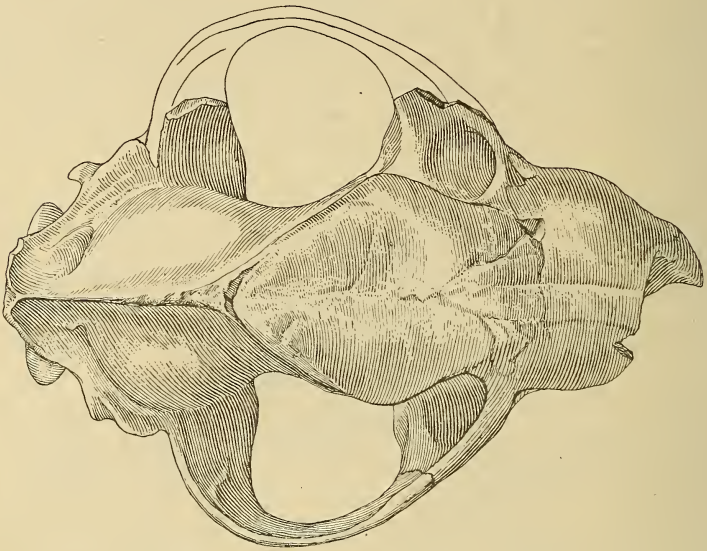


Fig. 2.—*Pogonodon serrulidens,* sp. nov. Holotype. × ½.

teeth has been relatively earlier in the fossil skull, for here the permanent cheek dentition is nearly or quite complete, while in the recent skull the upper deciduous carnassials and all the lower deciduous cheek-teeth are still in place and functional, although, on each side, the principal cusp of P^3 has just appeared, and the crowns of P^4 and M^1 have protruded to about half their height. If preferred, the cheek-teeth may be taken as the basis of comparison, in which case it would appear that the replacement of the canines was relatively tardier in the fossil skull than in the recent lynx.

Cranium.—The basal length of the skull, measured between the basion and the probable position of the prosthion, is 167 mm. This shows the skull to be considerably shorter than that of *Pogonodon davisi* where the similar measurement is about 198 mm. Viewed from the side, the general proportions of the skull of *P. serrulidens* resemble those of *P. davisi* more closely than they do those of *Nimravus.* This is especially noticeable in the low and straight nasal region, and in the frontal profile which rises higher from the base-line in the neighborhood of the bregma than in the region between the postorbital processes. The sagittal crest does not however, rise as high posteriorly in the present species as in *P. davisi.*

The maxilla and the jugal, on each side of the skull, contribute to the formation of what may conveniently be termed the anterior zygomatic pedicle. It is believed that the widely varying proportions of this part of the skull will be found of considerable taxonomic value in the extinct Felidæ. In certain genera the anterior zygomatic pedicle affords two excellent measurements, namely, a *height,* taken as the minimum distance between the inferior margin of the orbit and the alveolar margin of the maxilla, and a *length,* taken as the minimum distance between the external margin of the infra-orbital foramen and the posterior margin of the zygomatic process of the maxilla. By dividing the measured height by the length, and multiplying the quotient by 100, an index is obtained, admirably suited to the comparison of cranial form, since it is entirely independent of actual size. The anterior zygomatic pedicle of *Pogonodon serrulidens* is considerably higher than long, as it is in

P. davisi and *P. platycopis,* the indices of this part of the skull, in these three species, being 120, 148, and 162 respectively, and so differing greatly from *Nimravus* where the length of the pedicle is equal to, or slightly greater than, the height, the corresponding index of *N. gomphodus* being 100, of *N. debilis* 88, and of *N. debilis major* 92, while in *Dinictis cyclops* it is 106, and in *D. squalidens* (No. 8777, A. M. N. H.) it is 107.

Fig. 3.

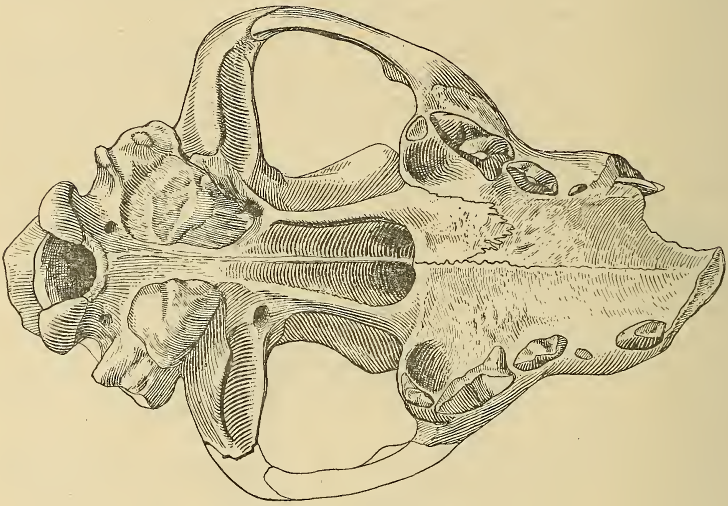


Fig. 3.—*Pogonodon serrulidens,* sp. nov. Holotype. × ½.

Another remarkable characteristic of *Pogonodon serrulidens* is the large size of the infra-orbital foramen. The vertical and transverse diameters, taken within the foramen, not at its outlet, are respectively 13 mm. and 10 mm. This is a variant toward the typical *Hoplophonic* form that at once distinguishes the present species from *Nimravus.* The true significance of very large infra-orbital foramina in certain groups of extinct Felidæ is not clear. As the foramina are traversed by important branches of the external carotid artery and trigeminal nerve supplying the lower eyelid, side of the muzzle, and the upper lip, it may ultimately appear that the size of these foramina was directly correlated with the size and mobility of the upper lip in those extinct species that had long upper canines. It is not known to what extent the long knife-like upper canines of the true saber-tooth cats were curtained by pendulous upper lips when the mouth was closed in a state of rest; yet obviously such lips would have to be raised to avoid injuring them in the act of biting. Whatever the explanation, the fact remains that in the typical saber-tooth *Smilodon* the infra-orbital foramina are very large and in the false saber-tooth *Nimravus* comparatively small.

The fragment carrying P_4 shows that the mandible at this section is much shallower and broader than the mandible of *Nimravus.* The vertical and transverse measurements of the mandible of *Pogonodon serrulidens,* taken immediately behind P_4, are 23 mm. and 14 mm. respectively, and in *P. cismontanus* 32 mm. and 14.5 mm. respectively. I can not quote exact corresponding measurements in the types of the several species of *Nimravus,* but in other material, referred to that genus, the height is uniformly about three times as great as the transverse diameter. Cope evidently thought this character to be of taxonomic value, for he stated of *Nimravus gomphodus*[11]: "The ramus of the mandible is longer, deeper, and more compressed than in the recent species of *Uncia* and the *Pogonodon platycopis*"; and of *Pogonodon platcopis*[12] he wrote "The mandibular rami are robust, and not so high and compressed as in *Nimravus* and its allies." Regarding the form of the anterior portion of the mandible in *Pogonodon serrulidens,* little can be ascertained from the fragment carrying the lower canine; but the broad and flat anterior surface and the thickness of the bone external to the root of the canine are distinctly favorable to the supposition that there was a flange for the protection of the upper canine.

The foramina of the basicranial region, so far as it has been possible to locate them, occur as in *Dinictis* and *Nimravus.* The mastoid process, in point of size, resembles *Nimravus* rather than *Dinictis*, but it is directed a little more forward than in *Nimravus,* in this respect being more like *Dinictis.* The glenoid surfaces

---

[11] E. D. Cope, Report of the U. S. Geol. Survey of the Territories, vol. 3, 965, 1884.

[12] E. D. Cope, Report of the U. S. Geol. Survey of the Territories, vol. 3, 984, 1884.

are not projected downward as in *Hoplophoneus,* but, on the contrary, they rise considerably above the level of a line adjoining the basion and prosthion.

The two fragments of limb-bones, already mentioned, have been compared with the corresponding parts of a puma, *Felis concolor,* No. 015, Y. P. M., whose skull is of almost exactly the same basal length as that of *Pogonodon serrulidens.* The lengths of the ulnæ of the two animals can not be accurately compared, owing to the imperfection of the fossil bone, but a well-marked difference is presented in certain other proportions. While the shaft of the ulna of the fossil species is the more slender of the two, the diameter of its greater sigmoid cavity, measured in the axial direction of the limb, is considerably greater than in the recent species. This indicates also a greater diameter of the trochlea of the humerus. An analogous condition is presented by the fragmentary metatarsal III, the proximal articular surface of the bone being of almost exactly the same extent as in the example of *Felis concolor,* while the shaft of the fossil bone is slenderer.

The present species is differentiated from *Nimravus* and *Hoplophoneus* by the aggregate of the cranial and dental characters, mentioned above, although, as might be expected, not by each of these characters severally. From *Dinictis* its differentiation is not so clearly denoted; yet in consideration of the low nasal region and the relatively high parietal region, the reduction in size of upper premolars 2 and 3, the reduction of the inner root of P^4 with loss of protocone and addition of a well-marked parastyle, I cannot consistently assign to it a place with *Dinictis felina, D. cyclops, D. squalidens,* and *D. paucidens. Pogonodon* alone of known genera seems open to its reception, and the species to which, on the whole, it shows the closest affinity is Merriam's *Pogonodon davisi.* From this it is specifically distinguished by its smaller size, relatively lower sagittal crest, more compressed form of superior canines,[13] relatively greater diameter of the postorbital constriction, relatively lower and longer anterior zygomatic pedicle, and judging from Merriam's illustration of the teeth, by the lesser prom-

---

[13] The canine alveoli of *P. davisi,* although they do not furnish an exact basis for comparison, indicate a considerably greater transverse diameter.

inence of the inner root of the P^4. Yet so close to *Pogonodon davisi* is the present species, that the two must share the same fate, should *Pogonodon* in the final analysis fail of recognition as a distinct genus or sub-genus.

Dinælurus crassus, gen. et sp. nov.

(FIGS. 4-6.)

Holotype, Cat. No. 10518, Y. P. M. Upper Oligocene (upper John Day), Turtle Cove, John Day Valley, Oregon. Collected by Wm. Davis in 1875.

The type is a cranium without the mandible. It is well preserved, except that the posterior part of the sagittal crest and the contiguous parts of the lambdoid ridges have been destroyed and the postorbital process of the right frontal has suffered some abrasion.

FIG. 4.

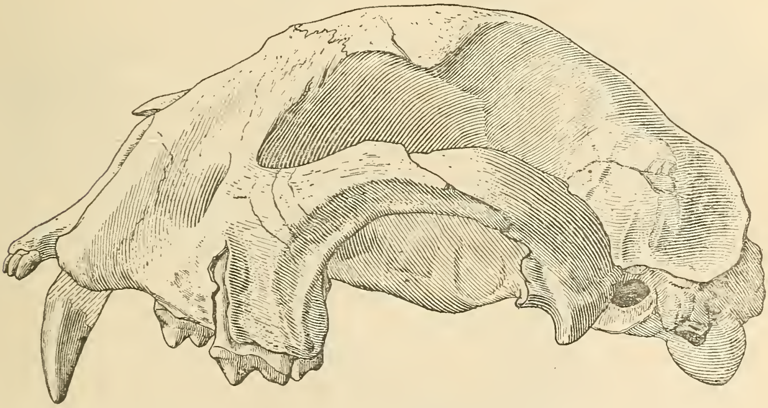


FIG. 4.—*Dinælurus crassus,* gen. et sp. nov. Holotype. × ½.

Dentition.—I^3, C^1, P^2, M^1. The teeth are worn to a degree that indicates middle age, but not to such extent as to involve any modification of the alveolar parapet. The incisors, in their present condition, closely resemble those of *Nimravus.* Of the right canine only the base of the crown remains protruding from the alveolus. The left canine too has been broken, and a little of the base of the crown is lacking, but its characteristic form is shown sufficiently well to differentiate it from *Nimravus, Dinictis, Pogonodon,* and *Hoplophoneus.* Briefly characterized, it is more truly feline than the canines of these genera, being more nearly elliptical in section throughout its length and less flattened on the inner surface. The maximum (antero-posterior) diameter of the canine at the alveolar margin is 15.5 mm. and the transverse diameter 11 mm. Dividing the transverse diameter by the maximum diameter, and multiplying the quotient by 100, an index of 71 is obtained. The corresponding indices of the superior canines of several well-known species of extinct Felidæ are as follows: *Nimravus gomphodus* 47, derived from Cope's measurements; *N. debilis* 57; *N. debilis major* 56; *Pogonodon platycopis* 54; *P. davisi* 52, derived from alveolar diameters; *Dinictis cyclops* 64; *D. felina* 47. The diameters of the superior canine of *Pseudælurus quadridentatus,* at the level of the neck, given by Filhol,[14] transverse 8 mm. and antero-posterior 12.7 mm., yield an index of 71. In examples of three recent feline species I find the corresponding indices to be: *Felis tigris* 73; *Felis concolor* 81; *Cynælurus jubatus* 79. The vertical length of the canine in the present species cannot be exactly determined because of its imperfection. Its length, however, appears to have been about the same, relative to the length of the skull, as in *Nimravus debilis;* and relatively less than in *N. gomphodus.* Except in young adult animals the length of the canines is of course an unsatisfactory quantity. The anterior ridge of the tooth lies further back from the actual anterior margin than in *Nimravus,* and in this respect also the present species is further advanced and more cat-like. The posterior ridge is not continued along the neck of the tooth to the alveolar margin. This has much to do with the broad, elliptical section of the neck of the tooth. There is no trace, on either side, of P^2 or its alveolus. For this reason two premolars only are postulated in the dental formula stated above. If in early adult life there was a P^2, it can hardly have been other than exceedingly small and vestigial, as the shortness of the postcanine diastema, 9.5 mm. on one side and 10 mm. on the other, renders the presence of a P^2 of any considerable size highly improbable. The shortening of the postcanine diastema with reduction of P^2 to vestigial size would have practically the same significance as the shortening of the diastema

---

[14] H. Filhol, Annales des Sciences Géologiques, 21, 76, 1891.

with total loss of P²; either condition would denote a variation from the more complete dentition of *Nimravus.*

P³ is a large tooth, its principal cusp being sub-equal in size to the paracone of P⁴, as in *Nimravus debilis.* From the last named species it differs in having a slightly greater transverse diameter of the crown relative to the antero-posterior diameter, and the inner division of the posterior root is much stouter, a condition that suggests further advance toward *Pseudælurus* and *Felis.* P⁴ exhibits less development of the inner root than I have observed in any specimens of *Nimravus,* and the inner root does not support a positive protocone. There is less trace of a parastyle than in *Nimravus,* and the external outline of the crown is slightly convex instead of being slightly concave as is usually the case in *Nimravus.* This convexity of crown gives the tooth an appearance of greater breadth, if the buttress formed

Fig. 5.

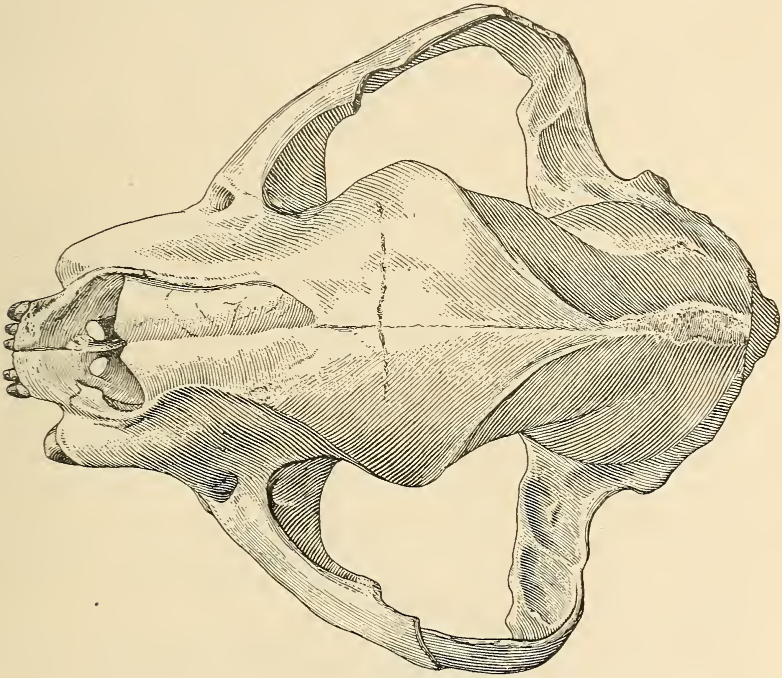


Fig. 5.—*Dinælurus crassus,* gen. et sp. nov. Holotype. × ½.

by the inner root be disregarded, than in *Nimravus.* M^1 is a very small tooth, and the reduction of its inner lobe has proceeded so far that the transverse diameter of the tooth-crown is not greater than the antero-posterior diameter. Since the external margins of the premaxillæ, between the canines and the lateral incisors, are widely and deeply concave, when viewed from above or below, it may be inferred that the lower canines, which were given clearance by these concave diastemata when the jaws are closed, were also of larger transverse diameter than those of *Nimravus;* and this inference is supported by fragments of a lower canine that were found embedded in the matrix. So deeply concave are these precanine diastemata that they extend further to the rear than the anterior margins of the maxillary parapets enclosing the canine alveoli.

Cranium.—The skull in its general proportions shows a greater resemblance to *Nimravus* and *Dinictis* than to *Hoplophoneus.* From *Pogonodon,* which is in some respects intermediate between *Dinictis* and *Hoplophoneus,* it is not so distinctly separated by cranial proportions as by dentition. The foramina of the basi-cranial region, the height of the glenoid articulations relative to the base-line of the skull, and the form and position of the mastoid processes are essentially the same in the present species as in *Nimravus;* but in the wide spread of its zygomatic arches and in the breadth and massiveness of the entire fore part of the skull—characters that have suggested the specific name—the present species departs widely from the proportions of the species of *Nimravus* and *Dinictis.*

With a basal length of 174 mm., measured from basion to prosthion, the bizygomatic diameter is 164 mm. The relation of these measurements is expressed by the bizygomatic index of 94, which is well outside the range of the corresponding indices of *Nimravus, Dinictis,* and *Pogonodon.* The bizygomatic indices of the best known species of the three above-named genera are as follows: *Nimravus gomphodus* 72; *N. debilis* 76; *N. debilis major* 71; *Pogonodon davisi* 74 (approx.); *P. platycopis* 78 (approx.); *P. serrulidens* 77 (approx.); *Dinictis cyclops* 85; *D. squalidens,* No. 8777, A. M. N. H., 82; *D. felina* 76; *D. paucidens* 79; *D. fortis* 82 (from illustration).

Similarly the interorbital breadth of the present species exceeds the corresponding measurements in *Nimravus, Dinictis,* and *Pogonodon,* as may be seen from the comparison of the interorbital indices, computed from the interorbital diameter and the basal length. The interorbital breadth index of *Dinœlurus crassus* is 35 while that of the other well-known speices is as follows: *Nimravus gomphodus* 25 (approx.); *N. debilis* 26; *N. debilis major* 24; *Pogonodon davisi* 28 (approx.); *P. platycopis* 27 (approx.); *P. serrulidens* 28 (approx.); *Dinictis cyclops* 33; *D. squalidens*, No. 8777, A. M. N. H., 28; *D. fortis* 33 (from illustration).

FIG. 6.

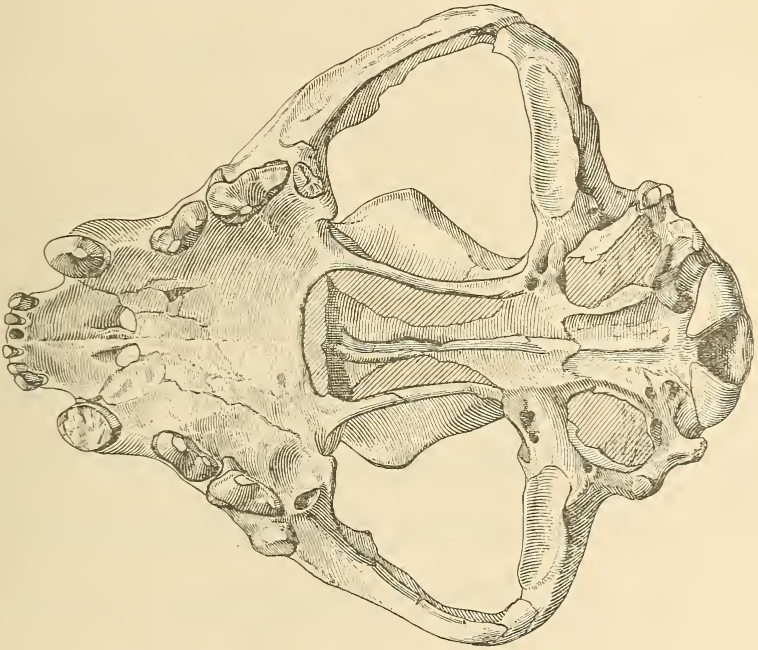


FIG. 6.—*Dinœlurus crassus,* gen. et sp. nov. Holotype. × ½.

The diameter of the postorbital processes of the frontal, which here gives an index of 46 when contrasted with the basal length, is relatively much greater than in *Nimravus* where the range is from 34 to 36. In *Pogonodon* this index has a wider range, as the following values show:

TABLE A.

Measurements of Crania in mm.

Serial nos. of measurements.		*Nimravus gomphodus* Cope. Holotype, No. 6933, A. M. N. H.	*Nimravus debilis* (Cope). Holotype, No. 6930, A. M. N. H.	*Nimravus debilis major* (Merr.). Holotype, No. 1681, Univ. Calif.	*Nimravus debilis* (Cope). No. 10044, Y. P. M.	*Nimravus debilis* (Cope). No. 10045, Y. P. M.	*Nimravus debilis* (Cope). No. 10517, Y. P. M.	*Nimravus* sp. No. 10046, Y. P. M.	*Dinictis cyclops* Cope. Holotype, No. 6937, A. M. N. H.	*Dinictis squalidens* (Cope). No. 8777, A. M. N. H.	*Dinictis felina* Leidy. Leidy's 2d type.*	*Pogonodon platycopis* (Cope). Holotype, No. 6938, A. M. N. H.	*Pogonodon davisi* Merr. Holotype, No. 789, Univ. Calif.	*Pogonodon serrulidens*, sp. nov. Holotype, No. 10520, Y. P. M.	*Dinælurus crassus*, gen. et sp. nov. Holotype, No. 10518, Y. P. M.
1	Basal length	198a	176	211.4	199	200a	198	167a	132	142a	149a	226a	198a	167a	174
2	Axial length	206	180	225	207	208a	208	175a	142	152	159	240a	208a	178a	185
3	Bizygomatic diameter	142a	133	150	150a	144a	142	128	112	117	113a	176a	157	128a	164
4	Breadth of ant. nares	30a	29		36	34	34	29	22			42			36
5	Interorbital breadth	50a	46	50.7	51	53	54	47	44	38		60a	55.5	46	61
6	Diam. of postorbital processes	70a	63.5	71.3	73	75	77	64	67	50a	51	69a	84.5	60	81
7	Postorbital constriction	38	37	40.5a	41	39	41	39	36	32	33	39	41	42	44
8	Palatal length		84	95.5	93	91	93	81	65			108a	97a	87a	81
9	Ant. palatal breadth		30		27.5	34	29	28	23.5			38	30		31
10	Post. palatal breadth		48.5	56	52	52	51	48a	35			55	50	43.5	58
11	Height of ant. zyg. pedicle	37	29	36	34	33	34	29	25	32a	15.5a	42	39.5	30	46
12	Length of ant. zyg. pedicle	37	33	39	36.5	39	38	36	23.5	30a	26a	26	26.6	25	30.5
13	Sup. canine, max. diam.	17	14	16.5	17	17	18.5	14	12.5		15	26	21.5a		15.5
14	Sup. canine, trans. diam.	8a	8a	9.2	10	9	10	8	8		7	14	11a		11

a = approximate.

* Measurements 2, 3, 13, 14 are fide Riggs; 6 fide Leidy; 7 fide Adams; while 1, 11, 12 are taken from Leidy's figure of the skull.

TABLE B.

Indices of Crania.

(Heavy-face numerals refer to serial numbers in Table A.)	*Nimravus gomphodus* Cope. Holotype, No. 6933, A. M. N. H.	*Nimravus debilis* (Cope). Holotype, No. 6930, A. M. N. H.	*Nimravus debilis major* (Merr.) Holotype, No. 1681, Univ. Calif.	*Nimravus debilis* (Cope). No. 10044, Y. P. M.	*Nimravus debilis* (Cope). No. 10045, Y. P. M.	*Nimravus debilis* (Cope). No. 10517, Y. P. M.	*Nimravus* sp. No. 10046, Y. P. M.	*Dinictis cyclops* Cope. Holotype, No. 6937, A. M. N. H.	*Dinictis squalidens* (Cope). No. 8777, A. M. N. H.	*Dinictis felina* Leidy. Leidy's 2d type.	*Pogonodon platycopis* (Cope). Holotype, No. 6938, A. M. N. H.	*Pogonodon davisi* Merr. Holotype, No. 789, Univ. Calif.	*Pogonodon serrulidens*, sp. nov. Holotype, No. 10520, Y. P. M.	*Dinælurus crassus*, gen. et sp. nov. Holotype, No. 10518, Y. P. M.
Bizygomatic index $\left(\frac{\mathbf{3}\times 100}{\mathbf{1}}\right)$	72	76	71	75	72	72	77	85	82	76	78	74	77	94
Index of interorbital breadth $\left(\frac{\mathbf{5}\times 100}{\mathbf{1}}\right)$	25	26	24	26	27	27	28	33	28		27	28	28	35
Height index of ant. zyg. pedicle $\left(\frac{\mathbf{11}\times 100}{\mathbf{12}}\right)$	100	88	92	93	85	89	81	106	107	59	162	148	120	151
Index of postorbital constriction $\left(\frac{\mathbf{7}\times 100}{\mathbf{1}}\right)$	19	21	19	21	20	21	23	27	23		17	21	25	25
Breadth index of postorbital processes $\left(\frac{\mathbf{6}\times 100}{\mathbf{1}}\right)$	35	36	34	37	38	39	38	51	35	34	31	43	36	46
Ant. narial index $\left(\frac{\mathbf{4}\times 100}{\mathbf{1}}\right)$	15	16		18	17	17	17	17			19			21
Index of palatal length $\left(\frac{\mathbf{8}\times 100}{\mathbf{1}}\right)$		48	45	47	46	47	49	49					52	47
Index of ant. palatal breadth $\left(\frac{\mathbf{9}\times 100}{\mathbf{8}}\right)$		36		30	37	31	35	36						38
Index of post. palatal breadth $\left(\frac{\mathbf{10}\times 100}{\mathbf{8}}\right)$		58	59	56	57	55	59	54			51	52	50	72
Diametral index of sup. canine $\left(\frac{\mathbf{14}\times 100}{\mathbf{13}}\right)$	47	57	56	59	53	54	57	64		47	54	52		71

Pogonodon davisi 43 (approx.); *P. platycopis* 31 (approx.); *P. serrulidens* 36 (approx.). From the following values of this index for *Dinictis,* it will be seen that only one species of this genus is known to have a relatively greater postorbital breadth than *Dinælurus crassus: Dinictis cyclops* 51; *D. squalidens,* No. 8777, A. M. N. H., 35; *D. felina* 34; *D. fortis* 37 (from illustration).

The breadth of the anterior nares, relative to the basal length, when reduced to an index of 21, is also greater than in the other species with which it has been compared in Table B. *Pogonodon platycopis* with an anterior narial index of 19 approaches the present species most closely in this character, but this index has been computed for only a few type skulls. The breadth of the postorbital constriction, which may in like manner be expressed by the index 25, separates the present species from *Nimravus,* but not from all the species of *Dinictis* and *Pogonodon, Dinictis cyclops* having a corresponding index of 27 and *Pogonodon serrulidens* of 25 (approx.), while the highest value in *Nimravus* is an index of 21 for *N. debilis.* The bimastoid diameter is relatively greater than in *Nimravus gomphodus, N. debilis, Pogonodon platycopis, P. serrulidens,* and *Dinictis squalidens* (No. 8777, A. M. N. H.), but slightly less than in *Dinictis cyclops* and *D. felina.* With regard to the bicondylar diameter, the series of type skulls, on which this measurement has been taken, is too limited to admit of any definite statement about the generic value of the bicondylar index.

In conformity with the remarkable breadth of the fore part of the skull, the palate also is broader than in the allied genera with which comparison has been made. This is especially noticeable in the posterior palatal breadth as expressed by the transverse measurement between the inner roots of the upper carnassials. In the present species the index derived from this measurement and the palatal length is 72, which greatly exceeds the corresponding indices computed for *Nimravus debilis, N. debilis major, Pogonodon davisi, P. platycopis, P. serrulidens,* and *Dinictis cyclops.* The species that approaches nearest in this respect is *Nimravus debilis major* with an index of 59. The three species of *Pogonodon* and *Dinictis cyclops* fall short of this last value.

For the other species of *Dinictis* this index has not been computed, but, judging from published illustrations none of them appear materially to exceed *D. cyclops* in the relative posterior palatal breadth. The entire posterior portions of the maxillæ, including the zygomatic processes, are exceedingly massive, and the palatine processes of the maxillæ, instead of forming thin, sharp-edged orbital floors, as in the examples of *Nimravus, Pogonodon,* and *Dinictis* that I have examined, are thick and rounded posteriorly. The palatal vault is much deeper than in *Nimravus.* This is caused, not by a more pronounced arching of the palatines and the palatine processes of the maxillæ, but entirely by the greater vertical depth of the alveolar processes which form the sides of the vault. A direct result of this modification is seen in the almost complete elimination of the circular pits, in the palatine processes of the maxillæ, that in *Dinictis, Nimravus, Pogonodon, Pseudælurus,* and *Hoplophoneus* receive the principal cusps (protoconids) of the lower carnassials when the jaws are closed. Slight irregularities in the contours of the maxillæ, at the lowest points of origin of the masseter muscles, are by no means uncommon in the Felidæ, recent and extinct, and osteological peculiarities of this description would probably be most noticeable in middle-aged individuals of large size and robust form. Accordingly caution must be exercised lest too much importance be given to differences that may be due solely or largely to individual variation. It would, however, be a serious omission to fail to note the form of the maxillæ immediately external to the superior molars in the present species. On each side of the skull, the powerful development of the masseter muscles has apparently caused changes in the maxillary contours amounting almost to the production of bony masseteric processes. The lack of symmetry, displayed on the two sides, must of course be attributed to individual variation, yet so pronounced is the smaller outgrowth on the left side, that, in view of the unusually massive character of the entire fore part of the skull, it may properly be regarded as of at least specific value. In this connection, the following quotation from Wortman's[15] description of *Dromocyon vorax* is of interest: "On the under surface

---

[15] J. L. Wortman, This Journal (4), **12**, 293, 1901.

of the arch, at the point of junction of the molar with the maxillary, there is a prominent process for the tendinous origin of the most anterior fibres of the masseter. This process is apparently wanting in the carnassident skull, but is large and prominent in that of the Opossum, Dasyure, and to a less extent in *Sarcophilus.*"

One of the most distinctive characters of this skull is the form of the portion of the maxilla that, for want of a better name, I have termed the anterior zygomatic pedicle. The minimum height from the alveolar margin to the inferior margin of the orbit is 46 mm. and the minimum length, measured on the outer face of the maxilla, from the infra-orbital foramen to the posterior margin of the zygomatic process, is 30.5 mm. Dividing the first of these measurements by the second, and multiplying the quotient by 100, an index of 151 is obtained. Inspection of Table B for allied genera and species will show that by the proportions of this part of the skull, the present species is easily distinguished from *Nimravus* and from *Dinictis cyclops, D. squalidens,* and *D. felina.* Judging from Riggs' figure of the skull of *Dinictis paucidens*[16] and Adams' figure of *D. fortis,*[17] the anterior zygomatic pedicle in these species also is low and long, as in *D. felina.*

The glenoid fossæ are projected no further below the basicranial plane than in *Nimravus.* The mastoid and paroccipital processes are similar in size and direction to those of *Nimravus.* The basicranial foramina occur as in *Dinictis* and *Nimravus,* with this important exception that in *Dinælurus crassus* the posterior opening of the carotid canal is a veritable foramen, completely enclosed by the thin lateral expansion of the basi-occipital, and not merely an open notch in this lateral expansion, as is the case in various examples of *Nimravus,* and as represented in Cope's figure of the type of *Nimravus debilis.*[18] Scott's illustration of the skull of *Dinictis felina*[19] might be supposed to indicate that the carotid

---

[16] Elmer S. Riggs, Kan. Univ. Quar., 4, No. 4, 239, 1896.

[17] Geo. I. Adams, Am. Nat., 29, pl. XXVI, 1895.

[18] E. D. Cope, Report of the U. S. Geol. Survey of the Territories, vol. 3, 952, 1884.

[19] W. B. Scott, Proc. Acad. Nat. Sci., Philadelphia, 41, 213, 1889.

canal passes through the basioccipital, but I am inclined to believe that such is not the regular occurrence in *Dinictis,* for in Matthew's detailed figure of the basicranial region of *Dinictis,*[20] presumably drawn from the excellent specimen of *Dinictis squalidens,* No. 8777, A. M. N. H., the entrance to the carotid canal is apparently through an open notch in the lateral expansion of the basioccipital, and precisely the same condition has been observed in a skull in the Marsh Collection, Yale University, Cat. No. 10048, identified as *Dinictis squalidens.* The otic bullæ, although incomplete, are much more fully developed than in *Nimravus,* a considerable portion of the thin wall of the bulla, on each side, being preserved in extension of the thickened tympanic ring, and traces of the median walls of the bullæ being visible, closely pressed against the lateral expansions of the basi-occipital. In this respect the present species shows a decided advance beyond the stage reached by *Nimravus;* and a like further development toward the recent Felidæ may be observed in the shortened length of the alisphenoid canal and in the slenderer proportions of the bridge of the alisphenoid bone, protecting the external carotid artery at this point. The brain-chamber appears to have been a little larger, in proportion to the basal length of the skull, than in *Nimravus,* but this superiority may be more apparent than real, since external measurements only are available, and it is possible that the cranial walls of the present species, in keeping with the robust development of the skull generally, may be slightly thicker than in the species with which comparison has been made.

The fossil skull and the hard ashy matrix are very light gray in color, and so appear to satisfy the requirements of the upper John Day beds, as they occur in the Cove on the John Day River, where the record states the specimen to have been found. This reference of the type to the upper John Day is further supported by the advance, shown in certain cranial and dental characters, beyond the stage of evolution denoted by *Nimravus debilis* and *Nimravus debilis major,* both of which species are understood to be from the middle John Day.

---

[20] W. D. Matthew, Bull. Am. Mus. Nat. Hist., vol. 28, 299, 1910.

Genus *Nimravus.*

Four of the crania in the Marsh Collection, whose measurements and indices have been included in the tables, require but brief mention. Those listed under the numbers 10044, 10045, and 10517 have been referred to *Nimravus debilis* because on the whole, although they differ mutually in minor characters, they resemble *N. debilis* and *N. debilis major* rather than *N. gomphodus.* It is true that these three crania have almost exactly the same basal length as the type of the latter species, viz., 198 mm.; but the argument, founded on size alone, fails, since within the species *N. debilis,* the basal length has a range variation from 176 mm. to 211.4 mm., as shown in Table A.

Fig. 7.

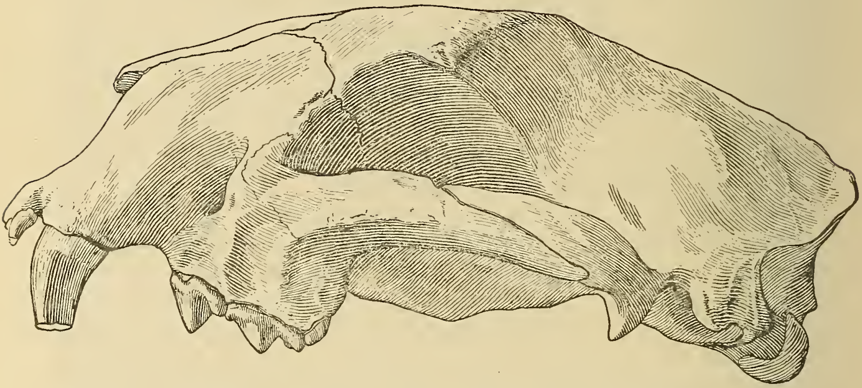


Fig. 7.—*Nimravus debilis* (Cope). Cat. No. 10517, Y. P. M. × ½.

Three views of the cranium designated as No. 10517 are given in figures 7, 8, and 9, and two views of the cranium No. 10045 appear in figures 10 and 11. The mandible of the latter is the better preserved of the two, and is believed to show the form of masseteric fossa regarded by Merriam as characteristic of *N. debilis* and *N. debilis major.* The following is quoted from Merriam's painstaking discussion of Cope's *Nimravus gomphodus* and *N.* (*Archælurus*) *debilis* : "Practically the only character which seems distinctive is found in the form and size of the masseteric fossa. In *N. gomphodus* its inferior margin is separated from the lower border of the horizontal ramus by a wide bar. In *A. debilis* the fossa extends farther forward and reaches down to the inferior margin of the jaw, which it may follow for some distance.''[21] Cranium No. 10045 is in many respects better preserved than No. 10517, although the condyles have been lost, and it shows admirably the positions of the basicranial and palatal foramina, and also the delicate tympanic ring of the right side.

FIG. 8.

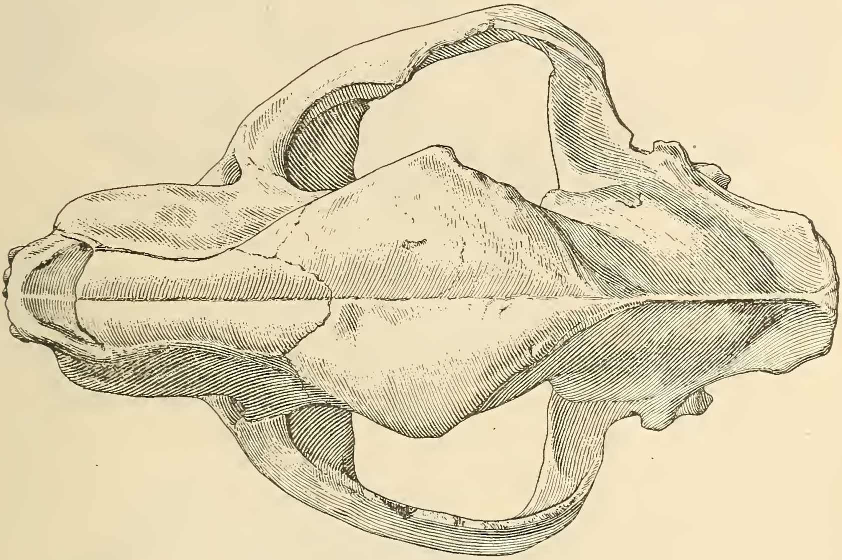


FIG. 8.—*Nimravus debilis* (Cope). Cat. No. 10517, Y. P. M. × ½.

As regards the size of the infracarnassial exostoses, it may be said that in the mandibles of the three individuals, Nos. 10044, 10045, and 10517, these outgrowths are strongly developed. No. 10045 originally possessed four superior premolars on each side, P^1 on the right side being double-rooted. In the mandible of this specimen the first and second premolars have been lost, the only

---

[21] J. C. Merriam, op. cit., p. 43.

FIG. 9.

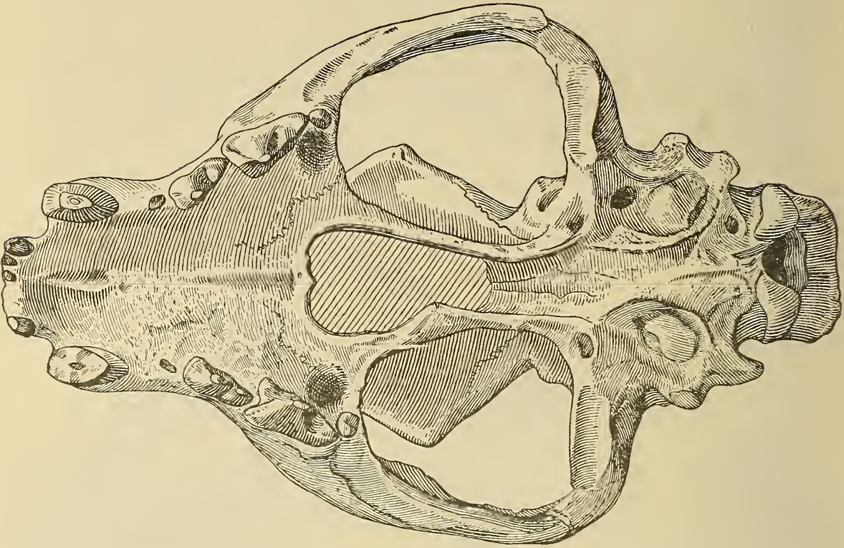


FIG. 9.—*Nimravus debilis* (Cope). Cat. No. 10517, Y. P. M. × ½.

FIG. 10.

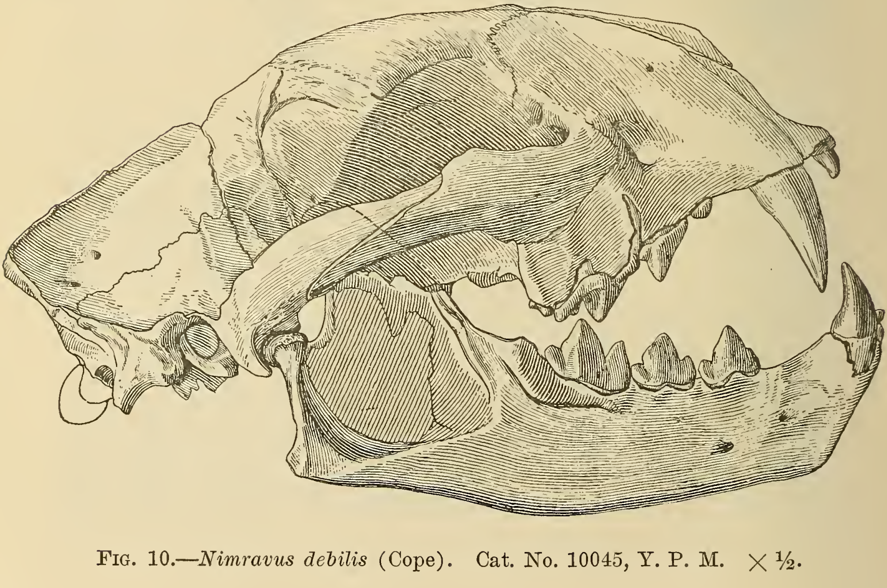


FIG. 10.—*Nimravus debilis* (Cope). Cat. No. 10045, Y. P. M. × ½.

trace of any of these teeth being the nearly closed alveolus of P_2 on the right side. Just how much reliance can be placed on the diameters of the superior canines, as specific characters, is uncertain; still, attention should be called here to the fact that, in the diametral indices of the superior canines, the three specimens, Nos. 10044, 10045, and 10517, agree much more closely with the types of *N. debilis* and *N. debilis major* than with *N. gomphodus;* and the same may be said with reference to the height index of the anterior zygomatic pedicle.

Fig. 11.

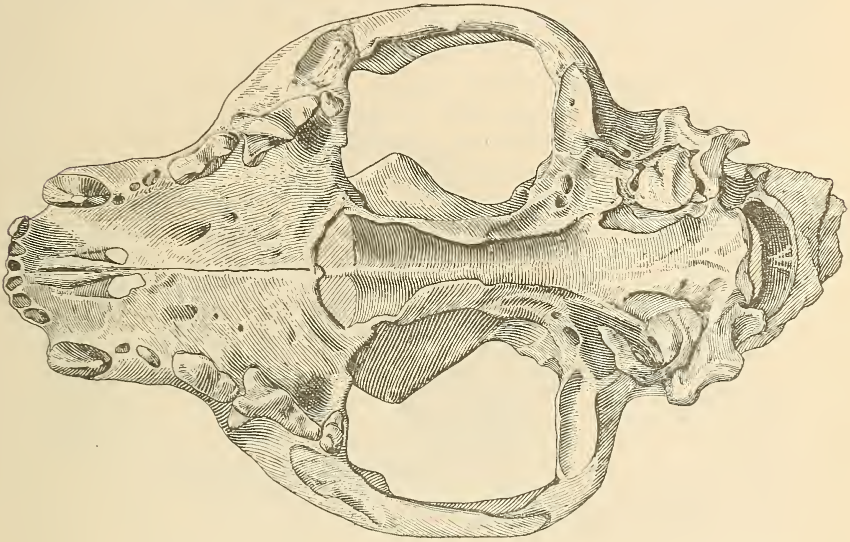


Fig. 11.—*Nimravus debilis* (Cope). Cat. No. 10045, Y. P. M. × ½.

The fourth skull, No. 10046, Y. P. M. (fig. 12), whose measurements and indices are given under the genus *Nimravus,* is much smaller than the three last enumerated, being in fact even smaller than the type of *N. debilis.* The superior canines are relatively longer than in that type, yet their measured diameters are almost exactly equal to those of *N. debilis.* The postcanine diastemata are short; and in the reduction of the premolar teeth, as well as in the slight development of the infracarnassial exostoses, this specimen differs from the type of

N. debilis. Viewed in profile, the anterior surface of the mandible appears to rise more nearly at a right angle with the horizontal ramus than in the types of *N. debilis* and *N. gomphodus;* and this squarely truncated appearance of the mandible is increased by the development of a prominent mental rugosity. Labels accompanying this skull show that, at one time, it was provisionally identified as *N. gomphodus,* at another time as *N. debilis.* On the whole its indices point to a closer affinity with *N. debilis* than with *N. gomphodus.* The skull of Cope's *N. confertus* is but little smaller than No. 10046; but as *N. confertus* is represented only by a very imperfect mandible, a satisfactory comparison of the specimens is impossible. There is, however, a remarkable similarity in the form of their mandibular symphyses. In each the symphysis is very short horizontally and extends but little to the rear of the posterior margins of the lower canine teeth. No. 10046 is supposed to have been found in the middle John Day.

Fig. 12.

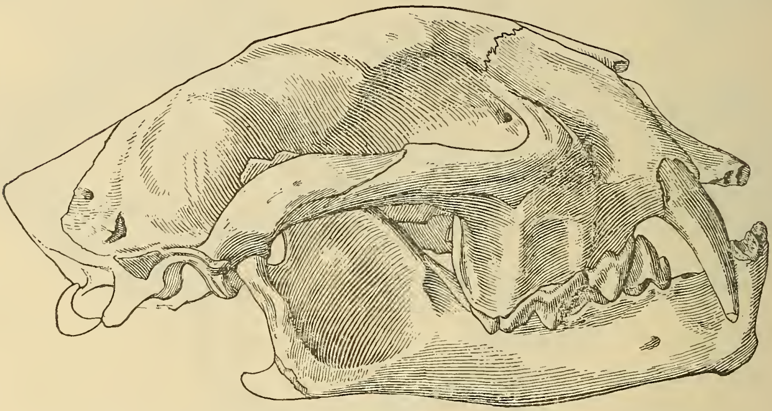


Fig. 12.—*Nimravus* sp. Cat. No. 10046, Y. P. M. × ½.

Art. XXXVII.—*The Antimony Mines of Shiu Chow, China*; by George D. Hubbard.

Introduction.—Shiu Chow is a walled city in the northern lobe of Kwangtung province, where the boundary between the two provinces of Hunan and Kiangsi comes south to their more famous neighbor, Kwangtung. It is about 30 miles from the Kwangtung border both west, northwest, and north, where the latter curves around in the midst of rather mature but little used mountains. It stands at a fork in the Pei Kiang, or North River, which has opened up a valley leading south to Canton and Hongkong. A railroad has also been constructed from Canton northward as far as Shiu Chow in its reach to connect with Changsha and Hankow.

Topography.—Shiu Chow has grown up in topography a little more mature than that along the provincial border west and north, but not nearly so old as that which has been partly submerged to make the great fingered and island-spattered Canton bay, into which both Pei Kiang and Si Kiang or West River flow.

Stratigraphy.—The rocks of the region are very deeply weathered Paleozoic limestones, sandstones, and shales, probably ranging in age from Ordovician to Carboniferous inclusive. The strata have been elevated in rather closely pressed folds whose trend is practically north and south, or perhaps north-northeast and south-southwest. While in many places within a few miles east and south the rocks dip more gently, all about the mines they dip very steeply, usually over 80°. Strikes observed at several points range from N 10° E to N 20° E. One can get strikes of very diverse angles in this region, but those departing far from the above are local. The trend of the big limestone ridges very nearly north and south is quite systematic.

Beginning some 5 or 6 miles north of Shiu Chow and just west of the mines (fig. 1), the rocks crossed in a section eastward for a mile or more do not seem to repeat at all.

Provisionally, the massive, dark blue, calcite-veined limestone, west of or above the mines, has been called the Ordovician. The evidence is both in its position with reference to the succeeding beds to the east, including the coal, and in its fossil content. A few fossils of gastropods and brachiopods have a distinctly Ordovician facies, though no species are identified. I saw none of the big cephalopods so commonly found in the Ordovician in other parts of China, but learn from Chinese observers

Fig. 1.

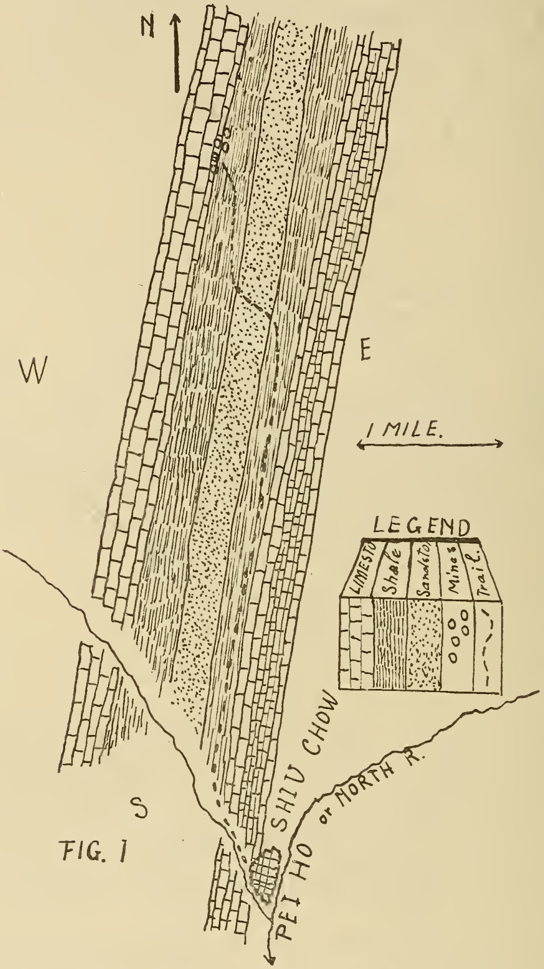


Fig. 1.—Geologic map, Shiu Chow to antimony mines.

that they occur near here. (Exact location and horizons unknown.) This big limestone makes a rather rugged ridge of very uneven height, yet continuous southward to the west branch of the river and several miles beyond.

A shale bed, probably as thick as the limestone, follows the latter and, is succeeded by a quartzitic limestone. The shales give low, open country, but the quartzite makes a small ridge. Next comes a thick series of shales of many colors,—blues, greens, reds, and browns. Some beds of this series are a little more resistant than others, but none of them are strong enough to hold up ridges.

Farther east than the shales and about a mile from the blue limestone is another ridge-maker, parallel with the first. Its beds are thinner and mostly gray, not blue, and not as dark as the former, but violently contorted and plicated. It has a few veins of calcite, but no such development as the other limestone has. No fossils were seen in any of these series except in the western limestone, but no search could be made because of lack of time.

Structure.—Coal is reported a short distance east of this second limestone and is mined 6 or 7 miles downstream, which would probably be not more than 5000 feet east, stratigraphically, of the contorted limestone. In the vicinity of the coal, the dips in shales and sandstones are S. E. by E. and not strong, while in the limestones and quartzites above Shiu Chow, nearly everything is about on end. Time did not permit scouting to the west to ascertain certainly, but the structure has the appearance of a great anticline, the east half of which is two miles or more across. The rocks in the west part of the sections would then be the oldest seen, and the coal and associated rocks the youngest. The most probable interpretation for the ages of the rocks, then, is that the western or dark blue is, as suggested, Ordovician; the lower shales may be Silurian; the quartzites and upper shales then would follow as Devonian; and the contorted limestone may be Mississippian, with Coal Measures above or on eastward.

Ores.—For several years, in the stream beds leading down eastward from the older limestones, the peasants have been picking up pieces of stibnite and more or less oxidized masses of antimony ore. In the summer of 1920, Mr. S. P. Chen became interested in this locality and began digging to find the ore in place. Several prospect pits and a shaft 25 feet deep were made. Ore was found in most of them in float, and still more was found in the stream beds, especially after rainy seasons. Finally, when prospecting had shown the more favorable course to pursue, a horizontal tunnel was directed straight into the hill from a point well up, but believed to be safely below the source of the ores. Before this tunnel was extended 100 feet, it struck the stibnite body in the limestone. The ore body is at least 3 or 4 feet thick, seems to be nearly perpendicular, though it probably dips with the rocks, hence 80° to 85° eastward.

The distribution of the float ore indicates that the vein of ore runs more or less continuously along the top of the limestone beds and below the shales. This contact seems especially favorable for ore deposition. The author suggests that the deposits may have been put in place as a vein before the folding occurred, or in part a replacement accumulation in the limestone, and that the less pervious beds of the shales above may have prevented the waters from rising higher and thus localized the deposition of the ore. No igneous rock could be found in the vicinity, and inquiry of the operator and others brought the universal testimony, "No granite; all limestone, shale and sandstone." In the impregnated limestone occur occasional little clusters of tiny pyrite crystals.

Toward the top, the vein is weathered, and the weathered products of stibnite occur. The only primary ore is this sulphide of antimony; the weathered ores are rarely stained more than a tint, confirming the belief in the absence of pyrite.

Some 12 to 13 miles south to southwest of these works, the float ore has also been found and followed up by the same exploiter, but so far, no primary deposits have been found. These finds are along the same limestone beds, but 7 or 8 miles south of Shiu Chow.

In its intimate associations, the ore varies from almost pure stibnite to stibnite and calcite gangue with only small per cents of the sulphide. The mixed ore is very pretty, for the calcite is coarse-grained, crystalline, and nearly clear, and is thrust through in every direction by the prismatic crystals of shiny metallic stibnite. The best stibnite ore runs about 65% antimony. Pure stibnite, Sb_2S_3, carries 71.4% of metal. The black, less crystalline ore runs about 50%, but those rich in the gangue calcite can be worked down to 30% antimony. The oxide ores, mostly stibiconite, produce 50 to 55% antimony, not a very pure ore.

About 33 miles north by northwest from Shiu Chow are small native workings for antimony ore in float and in stream beds. Some of this is practically pure stibnite. It is brought to Shiu Chow to be smelted.

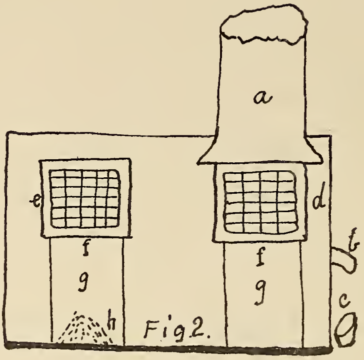
Mining and Transportation.—All the work in this whole region is carried on by the simple, laborious, native methods. Ore and dirt are moved in baskets on carrying poles or carried in the hands. Hoisting is done with a hand windlass. Tools, too, are quite crude and inefficient.

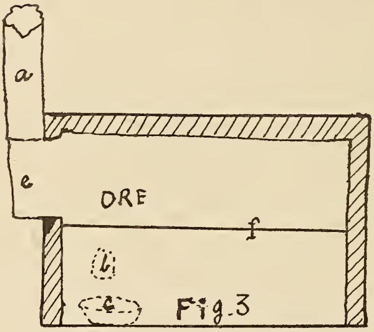
The ore is carried over a tortuous path, usually paved with limestone slabs or with irregular quartzite blocks, five miles, from the mines to the smelter at Shiu Chow. About 100 men were digging and picking at the time of my visit, and nearly 200 carriers were tramping along the road. Probably 2/3 of the porters were women. Strong men carry a picul or 100 catties (about 130 pounds). Most of the carriers are content with 60 or 80 catties and make three trips a day. They get the munificent sum of 25 cents a picul. Thus these hard workers obtain from 45 to 75 Chinese cents a day, and walk 20 to 30 miles, loaded one way.

The operator, Mr. Chen, leases these lands at a fixed sum per year, with no royalty. Then he hires all the help he can use, and mines as much ore as possible.

The Smelter.—The same man owns and runs the simple smelter in Shiu Chow. It contains two brick reverberatory furnaces, fed by hand and fired with wood, because "wood seems just as good and is cheaper than coal or charcoal." The metal is drawn out at the side from the floor of the furnace, and the sulphur goes up the stack with the smoke. The plan of the furnaces is shown in the accompanying drawings. (Figs. 2, 3, 4.) When drawing time comes, the antimony is run into molds of two kinds. One is small and oblong and holds only 25-30 pounds, and the other is about 8 or 10 times as large. These mouldings or ingots of antimony are sold both in America and in England. The smaller ones are considered essentially

FIGS. 2-4.





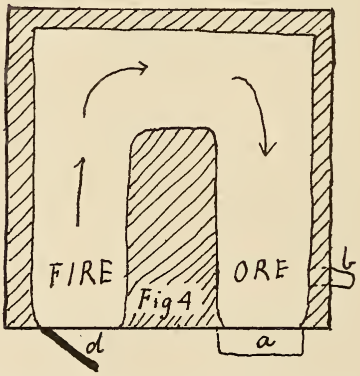


FIG. 2.—Front elevation of antimony furnace used at Shiu Chow to reduce stibnite ores.

FIG. 3.—Section, front-back, through ore side of furnace.

FIG. 4.—Horizontal section through furnace about two inches above grates. Oblique hatched part is made of bricks and mortar; cross hatched = doors. Scale, 1″ = about 4′.

a—stack; *b*—chute to draw off metallic antimony; *c*—mold for ingots of antimony; *d*—fire door; *e*—ore door; *f*—grates; *g*—air draft; *h*—ashes.

pure antimony; the larger ones are called "crude antimony."

Antimony in Other Parts.—China seems wonderfully well supplied with antimony. Her mines near Changsha have been known for years. Here two great bodies of ore are worked. One is 150 miles west and the other about 80 miles northwest. They may have been on the same strike, but this connection seems not to be substantiated. The ore is in limestone and is extensively worked. The deposits to the northwest are a real vein 5 inches to 2 feet thick, having definite contacts with the limestone. Work has been in progress here 20 years, and the shafts are now 200 to 300 feet deep. The body is a nearly perpendicular sheet, and the stibnite is of very good quality. It has a weathered zone of antimony oxides, as has the Shiu Chow vein. The other deposit west of Changsha is not a vein proper. Much float is collected, and the mines are in a limestone more or less impregnated with stibnite. No igneous rock is known near either deposit.

FIG. 5.

FIG. 5.—Masses of ore. On right, one piece of solid stibnite; large piece next to it = antimony oxide, stibiconite; large piece on left, dark blue limestone with calcite veins and 5% of stibnite; the four remaining pieces are from a vein of ore and consist of white calcite penetrated with long crystals of brilliant stibnite.

Antimony production is reported from several other provinces. Arranged in order of output, they stand as follows:—Hunan, Anhwei, Hupeh, Kwangsi, Kwangtung, Szechuan, and Yunnan. Of these seven provinces, Hunan is far in the lead, and the Tze Kiang or Su Ho valley is the richest area known on earth. The deposits extend from Yi Yang in the north close to the south side of Tung Ting Lake to Paoking, 150 miles upstream or southwest. Hunan, Anhwei, and Hupeh constitute an antimony petrographic province with less characteristic extensions south into Kwangtung and southwest into Kwangsi. Smelters are reported from Chihtsun in Yunnan and Samshui in Kwangtung, besides at Changsha and Shiu Chow as noted above.

Oberlin College,
Oberlin, Ohio.

Art. XXXVIII.—*A Trilobite retaining Color-Markings;* by Percy E. Raymond.

It has often been questioned, whether trilobites shared the brilliant coloring of some of the modern Crustacea, or whether they in life exhibited the rather dull and drab appearance which characterizes most of their fossil remains.

This problem still remains unsolved, but a small pygidium which I collected from the Cambrian of Cherokee County, Alabama, in 1921, shows a distinct banding, indicating that in some cases, at least, the body was not of a uniform color.

The pygidium mentioned is 9.5 mm. long and 16 mm. broad, and lies upon the surface of one of the siliceous fragments into which the shales of that locality weather. The banding is not very conspicuous, in fact, the specimen was examined several times before I became assured that it was not of accidental origin. The surface is covered by transverse stripes of light and dark gray, the latter almost black. At the anterior margin is a narrow light band, followed by the broadest one of all, quite dark in tone. The two remaining pairs of dark bands are much narrower, the last almost in line with a continuation of the dorsal furrows. The first two pairs cross the axial lobe, but as all turn backward they have a somewhat radial effect. In addition to the bands, there are many small, irregularly placed spots of a yellowish hue.

These markings probably do not retain the original colors, which may well have been brilliant. It is interesting to note that the pattern is such that the animal would not easily have been detected if viewed from above were the surface of the water gently agitated, and also suggests patches or shadows of sea weeds. This trilobite seems in fact to have been protectively colored, although it lived at a time before the advent of jaw-bearing fishes or cephalopods and could have had few if any active enemies. The specimen is unique, not only as the only trilobite yet found showing a color pattern, but also as being the most ancient fossil so marked, the next oldest being a little gastropod, *Holopea harpa* (Hudson), described by the writer from the Chazy.[1]

I am not sufficiently familiar with the colors of recent crustaceans to make any extensive comparisons, but it appears that those of the deep sea are often brightly colored, but without markings, those inhabiting caverns and other dark places are very pale to dead white, whereas those in the shallow photic waters are of many colors, and often mottled, banded, striped and shaded.

FIG. 1.

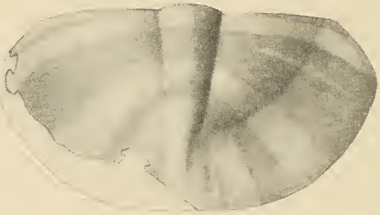


FIG. 1.—A pygidium of *Anomocare vittata,* retaining color-markings. × 3.

Pelagic crustacea usually have pigmentless tests, and owe their brilliant colorations to chromatophores, circulating fluids, or the structure of their shell. The present specimen, as was to be expected, falls in with the group in the shallow waters.

The shells of the branchiopods and copepods do not commonly contain pigments but among the amphipods and isopods are to be seen some patterns which are similar to the one on this trilobite. Della Valle in particular has published colored figures of Amphipods[2] showing strongly contrasted transverse bands of pink, alternating with yellow, white, or green.

According to Newbigin,[3] red lipochromes are the dominant pigments in the Crustacea. Where the shell is thin, red and pink prevail, as in the deep sea crustaceans. When much lime is present in the shell an orange tint is often produced. This being the case, and

---

[1] The Nautilus, 19, p. 101, 1906.

[2] Gammarini del Golfo di Napoli, 1893, pls. 3-6.

[3] Colour in Nature, London, 1898, p. 128.

the tests of many trilobites being rather thick and calcareous, it may be possible to predict various shades of orange in their coloration. With an appropriate organic base the red lipocrome apparently produces a blue compound, which with the yellow and red produces green and brown. With the aid of these general principles and applying previously gained knowledge of the probable habits of any particular form, it may be possible to approximate somewhat reasonably to the actual appearance of one of these animals in nature.

Trilobites usually possess colors which are obviously considerably influenced by the nature of the sediment in which they are imbedded, and since carbon and its compounds or oxides of iron are the most common coloring agents in the rocks, the specimens are usually from rusty brown through dark gray to black. A light-colored limestone would seem to be the most favorable matrix for the preservation of original colors, for in this case there would probably be only loss of pigment, without much chance of substitution except where recrystallization has taken place. A number of light-colored limestones yield fossils, and I have always felt that there must be some significance in the fact that the trilobites of the Maquoketa of Iowa, the Upper Ordovician of southern Ohio and Indiana, and the Lower Ordovician of the Ladoga region east of Petrograd were all of about the same color. On the best preserved specimens from which the matrix has been chiseled away the color is a rich chocolate-brown, whereas the ones which have weathered out naturally are usually much lighter, ranging toward yellow or cream-colored. It seems entirely possible that both red and yellow pigments may have entered into the composition of the original coloring matter of these specimens. The fact that all the trilobites of these localities, whatever the family, show the same chromatic characteristics may indicate one of three things; that the color is really in some way due to the composition of the matrix; or, that only the basic colors have left traces; or, that the Ordovician trilobites were rather uniformly colored and exhibited only shades of the primitive red which is dominant among crustaceans at the present time. Trilobites from the light-colored limestone of the Silurian of Indiana, England, and Bohemia, and other examples which could be cited from Ordovician and Devonian, also show the chocolate tints, so that it seems hardly possible that the constitution of the matrix has anything to do with it.

There is practically no literature on this question of coloration in the trilobites, but henceforth specimens will probably be scrutinized more closely, and it is hoped more evidence will be produced. Banding of the clean cut sort exhibited by this individual seems not to be especially common among modern Crustacea and one would expect that shadings of one color, mottling, and splashes would be more common among the trilobites.

The identification of this individual with any described species has not been possible, and it may therefore bear the name of *Anomocare vittata* sp. nov.

Walcott[4] has described *Anomocare convexa* as a common fossil from the Conasauga formation in northeastern Alabama. This pygidium can not be referred to that species because it has a narrower axial lobe which extends as a very low ridge almost to the posterior border. The axial lobe shows very faintly a pair of rings, and the pleural lobes a pair of ribs which are so inconspicuous that they are not put on the figure.

The specimen was collected by the writer from the Conasauga shale near Moshat's Cross-roads, 3 miles southeast of Center, Cherokee Co., Ala., during the Shaler Memorial Expedition of 1921.

Museum of Comparative Zoology,
Cambridge, Mass.

---

[4] Smithson. Miscl. Colls. vol. 57, p. 87, 1911.

Art. XXXIX.—*On the Occurrence of Richthofenia in Japan;* by Ichirô Hayasaka.

The eastern, or Pacific half of the northernmost part of the main Island of Japan, the area between the strait of Tsugaru and the Bay of Sendai, is called Kitakami mountainland. The southern part of this plateau-like land has for a very long time been known to yield many interesting and important fossils of Paleozoic as well as of Mesozoic ages. The famous locality of Triassic ammonites, described first by Mojsisovics and later by Diener, called Inai, is situated in the southernmost part of the mountainland; *Pseudomonotis* occurs at several localities a little north of Inai. Many other animal fossils, as well as land-plants, are found a little further north.

These Mesozoic formations rest unconformably upon the abraded surface of a complex of black clay slate, with sandy clay slate and limestone, that together compose the younger Paleozoic system of the region under consideration. The Paleozoic rocks also are at certain places very rich in fossils, and several of the latter have been described by Yabe and by myself.

The Paleozoic of southern Kitakami yields, besides a few species of *Fusulina,* several forms of brachiopods and corals. Of the former, *Lyttonia* was described by Yabe[1] in 1900, and more recently by myself[2] in 1917. In addition, I have described several other species of brachiopods, and the paper is now ready for publication. Yabe and myself[3] have described several species of corals, and a part of this has been published in a preliminary form. Another species worthy of notice is *Amblysiphonella*[4], which was formally recorded as *Steinmannia* by Yabe.[5]

In general, brachiopods are associated with *Fusulina,* but corals do not occur with either of them as a rule,

---

[1] Yabe: The Brachiopod *Lyttonia,* etc., Jour. Geol. Soc. Tokyo, No. 79.

[2] Hayasaka: On the Brachiopod Genus *Lyttonia,* etc., Ibid., No. 288.

[3] Palaeozoic Corals from Japan, etc., Ibid., vol. 22.

[4] Hayasaka: *Amblysiphonella* from Japan and China, Sci. Rep. Tohoku Imp. Univ., vol. 5, No. 1, 1918.

[5] Yabe: Materials for a Knowledge of the Anthrac. Fauna of Japan, Jour. Geol. Soc. Tokyo, No. 104, 1902.

though there are a few corals in the *Fusulina* limestone. The geological and stratigraphical relations between the latter and the coral limestone are now being studied.

The above summarizes our knowledge of the paleontology of Kitakami mountainland. In this paper I intend to report the occurrence of *Richthofenia*, an associate of *Lyttonia* and *Amblysiphonella* at several localities in other countries. My material of *Richthofenia* consists of only one piece of black limestone in which a fragment of the fossil is buried. This was presented to me by Uyemura of the Imperial Geological Survey, in the summer of 1915. By cutting this piece of limestone I got an oblique section of *Richthofenia,* which is shown by fig. 1. Its specific determination is not possible owing to the fragmentary condition of the specimen.

Fig. 1.

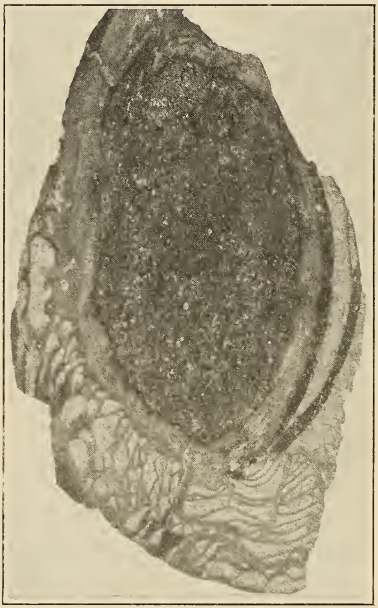


Fig. 1.—An oblique section of a *Richthofenia* from Japan; 3 times nat. size.

Figure 1 shows a thin section cut obliquely through the body chamber (cavitá ventrale of Di-Stefano)[6] of a conically elongated ventral valve. The dark substance occupying the median elliptical area is the matrix filling the chamber. The wall directly surrounding it is the innermost layer of the shell, and is composed of a fine lamellar tissue with silky lustre. This inner shell layer is remarkably well represented in the illustrations of Waagen[7] and Di-Stefano. The median shell layer is composed of small vesicular dissepiments arranged vertically. Waagen calls this layer "the median cystose shell layer," while Di-Stefano names it "struttra cellulosa dello strato media." Böse[8] describes it as follows: "It is formed by a network of cells which are constituted in the lower part of the apex region by nearly hemispherical cysts, while on the side of the animal chamber these cells are more irregular, their bottoms being directed obliquely towards above and towards the outside." In the present specimen, this median layer is only partly exhibited. The outermost shell layer is almost entirely broken away, although there remains a very small fragment, showing its former existence.

The shell is penetrated by numerous canals which are said to pass into hollow spines projecting upon the exterior surface of the shell. Inside the visceral chamber these canals open into circular pits, each of which is lying on a wart. Such warts give rise to longitudinal ridges that gradually become indistinct, or fade away downwards. Such a feature is very well shown by Waagen in one of his plates (fig. 7, pl. 83), while it is indicated in the present thin section by the cut edges of warts and ridges.

Just below the lower portion of the cut edge of the body chamber, something like an axial region of a tetracoral is exhibited. It is a section of a part of the so-called "cavitá miofora" of Di-Stefano, but is not, as it first appears to be, that of the lower, tabulated portion of the visceral cavity, since further below the median cystose layer is once more shown, this time in a nearly transverse section. Vertical septa are also very indistinctly seen.

---

[6] Di-Stefano: Le *Richthofenia* dei Calcari, etc. Palaeontogr. Italia, vol. 20, 1914.

[7] Waagen: *Productus*-limestone Fossils, Brachiopoda. 1885.

[8] Böse: Contributions to the Knowledge of *Richthofenia,* etc. Bull. Univ. Texas, No. 55, 1916.

On the whole, the section cuts through a *Richthofenia* obliquely from the upper part of the opposite side of the hinge line to a little below the hinge line. It was only by chance that I was able to prepare such a thin section from the limestone piece.

Distribution of the Genus.—Richthofenia attracts attention not only because of its peculiar form and shell structure, but also because of its wide geographic distribution as contrasted with its limited time range. So far as I know, the genus has been discovered in the following places:

1. Palermo, Sicily[9]	Palaeo-dyas.
2. Carnic Alps.[10]	
3. Armenia[11]	Permian.
4. Salt Range, India[12]	Permian.
5. Lo-ping, prov. Kiang-hsi, China[13]	Upper Permian.
6. Semenow Mountains, Nan-shan[14]	Permian.
7. Sutschan, near Wladiwostok[15]	Schwagerina stage.
8. Kobama, prov. Rikuzen (Kitakami mountainland)	Lower Permian.
9. Texas (Gaudalupe Mountains, etc.)[16]	Permian.

Geological Age.—As to the geological age of the genus, we must conclude, from what has been given in the above list, that it is an important index fossil of the Permian, although the detailed range in the Permian is as yet to be determined. Detailed examination of all the species described may throw some light upon the specific differences and stratigraphical positions.

Institute of Geology and Paleontology,
Tohoku Imperial University, Sendai, Japan.

---

[9] Gemmellaro: La fauna dei calcari con *Fusulina* della valle del fiumo Sosio (after Frech, Lethaea palaeozoica).

[10] Schellwien: Die Fauna des karn. Fusulinenkalks, I. Palaeontogr., 39, 1892.

[11] Stoyanow: On Some Permian Brachiopods of Armenia, Mém. Com. Géol., Nouv. ser., **111**, 1915.

[12] Waagen: op. cit.

[13] Kayser: Obercarb. Fauna von Loping, Richthofen's China, vol. IV, 1883.

[14] Schellwien: Palaeozoische u. Triadische Fossilien aus Ost-Asien, Futterer's Durch Asien, III.

[15] Tschernyschew: Die obercarb. Brachiopoden des Ural u. des Timan, p. 731.

[16] Girty: The Guadalupian Fauna, 1908.
Böse: op. cit.

Art. XL.—*On the Crystal Structure of Ammonium Chloride;* by Ralph W. G. Wyckoff.

Introduction.—Crystals of ammonium chloride are of interest because their symmetry as previously determined by the conventional methods of face development and etch figure formation are completely at variance with the symmetry of the arrangement of their atoms as found from studies of crystal structure using X-rays.

Studies of face development and of etch figures that seem fairly definite both agree in assigning crystals of ammonium chloride to the enantiomorphic hemihedral (plagihedral) class of cubic symmetry.[1] X-ray powder measurements[2] (and a single spectrometric observation),[3] on the other hand, have been interpreted as yielding a structure which is possessed of hemimorphic hemihedral (tetrahedral) cubic symmetry. On the basis of space-group reasoning it has also been shown that the powder data are such as to seem to preclude the possibility of any atomic arrangement possessing enantiomorphic symmetry being in agreement with them.[4] In view of the importance of the conclusion which must be drawn from these conflicting observations, both for crystal structure study and for crystallography itself, it has been considered desirable to study Laue photographs of ammonium chloride to see if the greater number of data which they can furnish will be in agreement with the powder measurements.

Laue Photographic Data for Ammonium Chloride.[5]—Clear optically isotropic crystals in the form of rectangular prisms several millimeters on one side and usually from one to two millimeters thick were obtained by desiccating a solution of ammonium chloride containing urea.

A measurement of the refractive index of one of these crystals for the purpose of insuring their purity was

---

[1] See P. Groth, Chemische Krystallographie, Vol. I, p. 182 (1906) for references.

[2] G. Bartlett and I. Langmuir, J. Am. Chem. Soc. 43, 84, 1921.

[3] W. H. and W. L. Bragg, X-rays and Crystal Structure, p. 110 (London, 1918).

[4] Ralph W. G. Wyckoff, this Journal, 3, 177, 1922.

[5] Some of these experimental data were collected in the Gates Chemical Laboratory of the California Institute of Technology.

made by H. E. Merwin, to whom the writer wishes to express his sincere gratitude not only for this determination but also for discussions of the crystallographic aspects of this problem. He says: "The refractive index of ammonium chloride crystals grown from solution with urea was the same as that of the pure salt used for the solution, 1.639±0.001. This is lower than Grailich's rough value usually quoted. Contamination

Fig. 1.

Figure 1. A Laue photograph of ammonium chloride produced by passing the X-rays in a direction roughly normal to a cube face.

by urea would presumably lower the index about 0.001 for each per cent.''

Passage of a beam of X-rays in a direction roughly normal to a cube (100) face of several of these crystals yielded a series of very beautiful Laue photographs. A reproduction of one of these is given in figure 1; the gnomonic projection of a photograph having an orientation very close to that of figure 1 is shown in figure 2. With the aid of these two figures and the plate distances of typical spots which have been recorded in Table I, it is possible to reproduce approximately the original data found upon this second photograph.

Fig. 2.

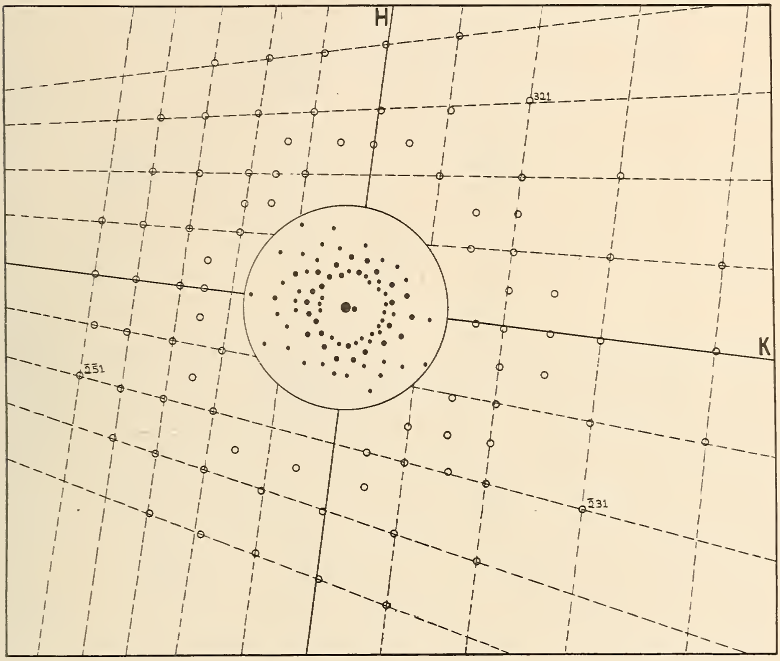


Figure 2. A gnomonic projection of a Laue photograph of ammonium chloride which had very nearly the orientation of the photograph of Figure 1. With the aid of Table I (which refers to the photograph of Figure 2) and an enlargement of this projection it is possible to reconstruct the original data.

From the powder photographic data[6] the length of

---

[6] G. Bartlett and I. Langmuir, op. cit.

the side of the unit cube which would contain a single chemical molecule of NH_4Cl was found to be 3.859A.U. This information is of course all that is required to calculate the value of $n\lambda$, where n is the order of the reflection and λ is the wave length of the reflected X-rays, for each spot upon the Laue photographs. If this is done and if the true unit cube were a larger one containing not one but eight chemical molecules within it, then some reflections should be found with a value of $n\lambda$ less than 0.24, which is the smallest wave length in the X-ray beam employed in these experiments. On none of the photographs, one of which was given an exposure from four to five times as long as usual in order to bring out faint reflections, were any spots found having such a low value of $n\lambda$; the Laue photographic data are thus in agreement with the powder data in assigning one chemical molecule to the correct unit cell for this form of ammonium chloride crystals. The approximate intensity calculations, carried out in the usual manner,[7] are readily shown to be in accord with the only structure containing one molecule within the unit which the theory of space-groups indicates as possible. There can consequently be no legitimate doubt of the correctness of the usual structure assigned to ammonium chloride. In this structure the atoms have the following positions:

Table I. Typical Laue Photographic Data
(for application to Figure 2).

Indices	Distance from Central Spot	Estimated Intensity	Wave Length ($n\lambda$)
231	2.35 cm	7	0.450A.U.
$\bar{2}31$	2.32	7	.445
$\bar{2}\bar{5}1$	2.65	0.5	.340
$4\bar{3}1$	2.62	1	.363
$\bar{1}31$	2.72	4	.573
031	2.87	10	.630
$\bar{2}\bar{3}1$	3.75	6	.650

Nitrogen atoms: $\frac{1}{2}\frac{1}{2}\frac{1}{2}$.
Chlorine atoms: 000.

Hydrogen atoms: uuu; $\bar{u}\bar{u}u$; $\bar{u}u\bar{u}$; $u\bar{u}\bar{u}$, where the value of u is not determinable. The arrangement is shown in Figure 3.

---

[7] Ralph W. G. Wyckoff, this Journal, 50, 317, 1920.

Conclusions.—The conclusions which were given previously can now be stated in even more definite terms.[8] If the hydrogen atoms of ammonium chloride have an arrangement which conforms to the symmetry of the crystal as a whole, then this symmetry must be hemimorphic hemihedral (tetrahedral); if, as is perhaps conceivable, the hydrogen atoms have a more or less haphazard distribution about the nitrogen atoms, its symmetry will be holohedral. In no case, however, can the symmetry of the arrangement of the atoms of this crystal agree with the enantiomorphic hemihedry which studies of both face development and etch figures assign to it. If these crystallographic data are correct, it will therefore be necessary to conclude that such studies even when carried out under ideal conditions to yield the maximum amount of data conceivable can not always indicate the symmetry of the arrangement of the atoms within a crystal.

Fig. 3.

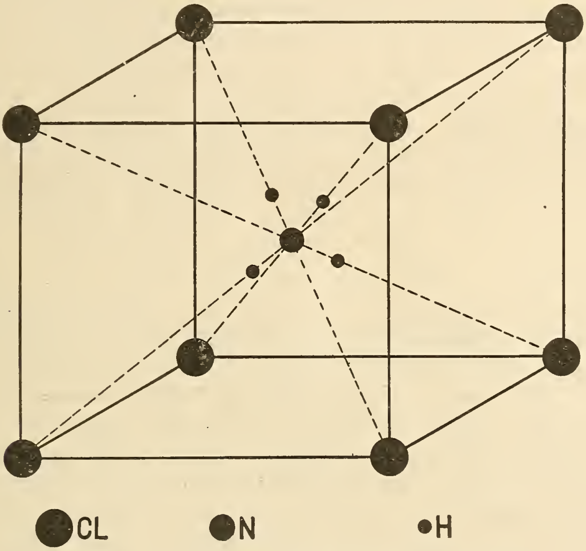


Figure 3. The unit cube of ammonium chloride.

This conclusion is not only of significance to crystallog-

---

[8] Ralph W. G. Wyckoff, this Journal, 3, 177, 1922.

raphy itself but it is of the greatest import to students of crystal structure. By making uncertain a choice of the appropriate class of symmetry in advance of X-ray studies, it considerably lengthens the problem of crystal structure determination.

The difficulties of crystallographic description in the case of crystals to which different symmetry characteristics are assigned by different methods of study have recently been emphasized.[9] It has been suggested that such crystals should be especially segregated into a group by themselves and that a complete description of their symmetry will include both a statement of the symmetry of the crystal as obtained by such "physical" methods as a study of the electrical or optical properties or the X-ray diffraction effects and a statement of the "latent" symmetry which is supposed to be made evident by the "chemical" means of etch figures and growth forms. The creation of this additional classification is not satisfactory if only for the reason that the concept of "latent" symmetry is not precise. The symmetry of a crystal as deduced by the various "chemical" means is different in many instances not only for these various methods but it may even be different for the same method carried out under changed external conditions. Thus the symmetry deduced from the face development upon scheelite (for face development must be reckoned among the "chemical" means of symmetry determination) is hemihedral though the etch figures that have been obtained are strictly holohedral[10]; or in the case of dolomite etch figures have been produced which show sometimes holohedral[11] and sometimes hemihedral[12] characters. From the point of view of those students of crystal structure who have felt the force of the difficulties into which such cases as this one of ammonium chloride have led them, the symmetry characteristics which have here been called "latent" are probably determined not by the symmetry of the crystal itself but rather by certain properties inherent in the constituent atoms. Etch figures, face development and the like are therefore to be considered as essentially surface phenomena, and

---

[9] E. T. Wherry, this Journal, 4, 237, 1922.
[10] H. Traube, Zeitsch, f. Kryst. 30, 398, 1899.
[11] P. Gaubert, Bull. Soc. franc. de Min., 24, 326, 1901.
[12] P. Koller, Neues Jahrb. Min. Beil. Bel., 42, 488, 1919.

the internal symmetry of the crystal itself is only one of a number of important factors which bear upon the nature of these surface phenomena.[13]

For the crystal analyst, at least, the formal part of these difficulties must, however, be met by a greater precision in the definition of what is meant by the symmetry of a crystal. Symmetry, from this point of view, can only mean that of the arrangement of the constituent parts (the atoms) of which a crystal is composed.

This case of ammonium chloride seems to require that both the crystal analyst and the crystallographer must make a considerable revision in their estimate of the value of the usual crystallographic information relating to the symmetry of a crystal, and it is therefore worth while to reemphasize the desirability of a repetition of the purely crystallographic study of ammonium chloride.

SUMMARY.

It is shown that the Laue photographic data obtained from crystals of the low temperature form of ammonium chloride are in agreement with the powder data in assigning to it a structure containing one chemical molecule within the unit cube. The consequences introduced by the disagreement between the symmetry of this uniquely determined structure and the symmetry as obtained by ordinary crystallographic means are discussed. It is pointed out that it is not permissible to accept etch figure data and face development as definite indications of the symmetry of the arrangement of the atoms within a crystal.

Geophysical Laboratory,
Carnegie Institution of Washington,
Washington, D. C.
October, 1922.

---

[13] It would seem that Wherry's views (*op. cit.*) are in accord with these, but it is not at all clear from his discussion that such is the case.

Art. XLI.—*The Alleged Variable Composition of Triple Chlorides Containing Silver and Gold;* by Horace L. Wells.

[Contribution from the Sheffield Chemical Laboratory of Yale University.]

A few months ago I made[1] a re-investigation of Pollard's ammonium-silver-auric chloride[2] and showed that this salt has the formula $(NH_4)_6Ag_2Au_3Cl_{17}$ instead of the slightly differing one, $(NH_4)_8Ag_3Au_4Cl_{23}$, ascribed to it by Pollard. There was no indication, however, from the results of either of us, that this compound has a variable composition. Soon afterwards I described[3] the salt $Cs_2AgAuCl_6$ as one of five analogous triple chlorides, the others of which contained zinc, mercury, copper, and aurous gold in place of the silver of the first one ($Cs_4ZnAu_2Cl_{12}$ etc.), these compounds, also, were undoubtedly of constant composition when free from isomorphous and other impurities.

It is much to be regretted that when these salts were described I was unaware that Professor Emich and his associates, of Graz, Austria, had previously published results of investigations upon triple halides containing silver and gold. Emich published[4] a preliminary communication upon a new microchemical reaction for gold, silver and rubidium (and cesium), based upon the formation of magnificent blood-red crystals when solutions of the three chlorides (in the case of rubidium) are evaporated upon the microscopic object-glass. These tests are evidently very excellent and useful ones.

My thanks are due to Professor Emich for a very courteous letter, together with reprints of the articles published by himself and his associates, calling my attention to their priority in work with triple halides containing silver and gold. This priority is, of course, acknowledged, but it may be observed that only one salt, the one to which I have ascribed the formula $Cs_2AgAuCl_6$, has been analyzed both by me and by them, and that they

---

[1] This Journal, 3, 257, 1922.
[2] Jour. Chem. Soc., 117, 99, 1920.
[3] This Journal, 3, 315, 1922.
[4] Monatsh. f. Chem., 39, 775, 1918.

arrived at a variable composition for it, very far from the correct one.

E. Bayer[5] made a further and very satisfactory study of Emich's microchemical tests, including the application of cesium chloride for the purpose, and he attempted to determine the composition of the two products containing rubidium and cesium. After making six analyses of the rubidium salt he came to the conclusion that it had the formula $Rb_6Ag_2Au_3Cl_{17}$. This result is very interesting, as this formula corresponds exactly to mine for Pollard's ammonium compound, and, since the two things appear to correspond closely in the color and form of their crystals, it seems very probable that this formula is the correct one. However, after obtaining astonishingly variable results with the cesium salt, Bayer made two more analyses of the rubidium compound, using products only slightly freed from the liquid by suction on the filter paper, and consequently contaminated to a greater extent than usual with the mother-liquors which were rich in rubidium chloride. He says that this was done because it was only the proportion of silver to gold that he wished to find. He thus obtained slightly varying results and concluded that the rubidium salt also was a variable compound. The following table gives his results, where the last two analyses represent the more impure products:

	Calculated for $Rb_6Ag_2Au_3Cl_{17}$	Bayer's Analyses							
Rb,	26.66	27.3,	27.5,	26.6,	26.8,	26.9,	26.4,	28.8,	28.2
Ag,	11.22	12.2,	12.0,	11.0,	11.2,	11.1,	11.2,	9.76,	10.8
Au,	30.77	30.1,	30.4,	30.7,	30.5,	30.7,	30.9,	31.1,	30.7
Cl,	31.35	31.6,	31.7,	31.2,	31.3,	31.5,	31.3,	31.9,	31.8

From these results, considering the difficulty of purifying such small crystals, and the nature of the last two products, there can be no doubt that the compound has a constant composition and that this is probably represented by the given formula. Moreover, the formula $Rb_3(Ag_6 \text{ or } Au_2)Cl_9$, which Bayer gives to the salt to make it analogous to his results with the cesium compound, agrees very poorly with the analyses, as can be

---

[5] Monatsh. f. Chem., 41, 230, 1920.

seen by referring to Bayer's article, where the atomic ratios are given.

Bayer gives no less than 14 analyses of the cesium salt, the results of which vary widely, particularly in the percentages of silver and gold, and in no instance do they correspond to my formula for the compound. The variations may be shown as follows:

	Calulated for $Cs_2AgAuCl_6$	Bayer's extreme results
Cs,	33.90	34.1—35.7
Ag,	13.77	3.9—10.9
Au,	25.17	27.6—32.2
Cl,	27.16	27.4—28.2

The most reasonable explanation of Bayer's results is that he analyzed mixtures, and it appears to be absolutely certain that his products were such from his statement[6] that the crystals of the cesium compound showed different colors, varying from black, through violet, to dark brown, since the salt, as prepared and analyzed by me, was entirely and absolutely black, even in the finest state of division.

From the wide variations in the percentages of silver it appears that Bayer's mixtures contained a constituent that was free from that metal, and the double salt $Cs_5Au_3Cl_{14}$, recently described[7] by me, is the probable impurity, as it is very slightly soluble in strong hydrochloric acid containing a rather large amount of cesium chloride, so that it would be expected to be deposited with the black triple salt under the conditions employed by Bayer, where gold and cesium were in excess over the silver required for the formation of the black compound, and where strong hydrochloric acid was employed as the solvent.

The following calculations have been made to find how well Bayer's results agree with the mixture that has been mentioned, the proportions of the two salts being based upon the percentage of silver:

---

[6] *Loc. cit.*, p. 241.

[7] This Journal, 3, 414, 1922.

	Calculated for black triple salt, A $Cs_2AgAuCl_6$	Calculated for dark red double salt, B $Cs_5Au_3Cl_{14}$	Bayer's analysis with highest silver	Calculated for 0.8A + 0.2B
Cs,	33.90	37.90	34.1	34.7
Ag,	13.77	....	10.9	11.0
Au,	25.17	33.77	27.6	26.9
Cl,	27.16	28.33	27.6	27.4

	Another analysis by Bayer	Calculated for 0.73A +0.27B	Another analysis by Bayer	Calculated for 0.6A +0.4B	Another analysis by Bayer	Calculated for 0.54A +0.46B
Cs,	34.9	35.0	34.6	35.50	35.0	35.74
Ag,	9.92	10.0	8.27	8.26	7.47	7.44
Au,	28.0	27.5	29.3	28.61	29.6	29.13
Cl,	27.72	27.5	27.74	27.63	27.85	27.70

	Another analysis by Bayer	Calculated for 0.5A +0.5B	Another analysis by Bayer	Calculated for 0.4A +0.6B	Analysis by Bayer with least silver	Calulated for 0.28A +0.72B
Cs,	35.3	35.9	35.4	36.30	35.7	36.78
Ag,	6.99	6.9	5.55	5.51	3.90	3.86
Au,	29.9	29.5	31.1	30.33	32.2	31.36
Cl,	27.8	27.7	28.05	32.2	27.23	28.00

Such calculations have been made for all of Bayer's 14 analyses, but only half of them are given here. These have not been chosen on account of giving better agreements than the others, for the results of the comparisons are very uniform, but they have been selected to show the comparisons in connection with variations in the percentages of silver. The agreements of the calculations with the analyses are remarkably good in all cases, as the greatest differences are 1.2% of cesium and 0.84% of gold.

There seems to be no doubt, therefore, that the two salts under consideration were the chief constituents of Bayer's mixtures. It is to be noticed, however, that in all cases the analyses show less cesium and more gold than the calculated quantities, whereas variations in the opposite directions would be expected on account of contamination of the products with mother-liquors rich in cesium chloride. Therefore it is necessary to assume that the products contained a third constituent, in fairly constant proportion, containing less cesium and more gold than the dark red double salt $Cs_5Au_3Cl_{14}$. The sparingly soluble, yellow double salt $CsAuCl_4$, into which the red one is instantly converted by the action of water, with the loss of cesium chloride by its going into solution, fulfills the requirement in its composition. It is easy to explain the presence of moderate and fairly constant amounts of this yellow salt in Bayer's products in connection with his method of removing mother-liquor from his crops of crystals by suction, presumably with moist air, for I have found that when some of the minute, brilliant crystals of the red salt were placed upon a perfectly clean, dry watch-glass in a closed vessel containing air in contact with water, for a few hours at room temperature, the crystals were changed to droplets of liquid containing clusters of minute crystals of the yellow salt.

The deliquescent character and consequent decomposition of the red double salt, therefore, explains perfectly the presence of the yellow compound in all of Bayer's analyzed products. The proportion of this salt necessary to bring the calculations into perfectly satisfactory agreement with the analyses is from about 2% to about 10% of the whole mixture. One per cent of it in the place of the same amount of the red salt increases the gold to the extent of 0.08% and decreases the cesium about 0.10%. Two calculations are given below where the presence of 5 and 10% of the yellow salt is assumed:

	Cs	Ag	Au	Cl
Calculated for $Cs_2AgAuCl_6$ (A)	33.90	13.77	25.17	27.16
Calculated for $Cs_5Au_3Cl_{14}$ (B)	37.90	....	33.77	28.33
Calculated for $CsAuCl_4$ (C)	28.15	....	41.79	30.06
One of Bayer's analyses, -	34.8	8.50	29.0	27.8
Calculated for 0.617A+0.383B,	35.43	8.50	28.46	27.61
Calc. for 0.617A+0.333B+0.05C,	34.94	8.50	28.86	27.70
Another analysis by Bayer,	35.0	7.47	29.6	27.85
Calculated for 0.54A+0.46B,	35.74	7.44	29.13	27.70
Calc. for 0.54A+0.36B+0.10C,	34.76	7.44	29.93	27.87

In the first of these two calculations very close agreements with the analysis are obtained by assuming 5%

of the yellow salt, while in the second one, with 10%, the result gives lower cesium and higher gold than the analysis, as would be expected from actual mixtures, slightly contaminated.

Similar calculations, based upon three constituents, give very satisfactory agreements with the rest of the analyses made by Bayer, so that it seems to be absolutely certain that his preparations were mixtures of the three things.

The very consistent results that have been obtained here from calculations with Dr. Bayer's analyses show that the latter were undoubtedly very accurate ones, and that he deserves much credit for his analytical skill and reliability. His failure to get a pure triple salt with cesium may be attributed to the fact that the red double salt had not been described at the time that he made the investigation.

Dr. Bayer's conclusion that his results indicated the existence of a variable triple salt in which 3AgCl and $AuCl_3$ mutually replaced each other in their combination with CsCl, was hardly in accord with prevailing chemical views, but it was very astonishing and important if true. His application of the same idea to the rubidium triple chloride which had given him analyses satisfactorily agreeing with a definite, constant formula appears to have been entirely unwarranted.

Immediately following Bayer's paper, Professor Emich published[8] an interesting theoretical discussion in favor of the supposed variable triple chlorides, but he presented no new facts in regard to them.

Somewhat later, E. Suschnig gave[9] an account of an investigation on the triple bromide of rubidium, silver and gold and the corresponding cesium compound. From four analyses of each of the salts he came to the conclusion that they were variable, and that they corresponded to Bayer's formula (certainly uncorrect) for the chlorides. From analogy it seems safe to say that Suschnig also analyzed mixtures, but since these bromides have not been investigated by any one else, it is impossible to decide what the mixtures were.

---

[8] Monatsh. f. Chem., 41, 249, 1920.

[9] Monatsh. f. Chem., 42, 399, 1921.

SUMMARY.

The conclusion has been reached from a consideration of Bayer's statements and from calculations made in connection with his analyses that the triple salt $Cs_2AgAuCl_6$ is a definite, invariable compound, and that Bayer analyzed mixtures of this salt with $Cs_5Au_3Cl_{11}$ and $CsAuCl_4$. It has been concluded also, from Bayer's own analyses, that the rubidium salt is also invariable and has the formula $Rb_6Ag_2Au_3Cl_{17}$ corresponding to that of Pollard's ammonium salt. Finally it has been concluded from analogy that Suschnig's confirmation with the bromides of Bayer's incorrect theory in regard to the chlorides must also be wrong.

New Haven, Conn.,
September, 1922.

Art. XLII.—*The Structural and Stratigraphic Relations of the Great Triassic Fault of Southern Connecticut;* by William L. Russell.

General Geologic Relations and Summary.

The area studied extends from Lighthouse Point, on New Haven Harbor, to the vicinity of Durham, and is over 15 miles in length and several miles broad. The general geologic relations of this tract are quite simple. The Triassic rocks of the Newark series form an eastward dipping homocline, cut off on its eastern border by the Great Fault, where the Triassic rocks abut against the crystallines. The sedimentary rocks are of considerable thickness, and contain three intercalated lava flows,—the lower, main and upper sheets. Normal faults, which tend to repeat the strata, are of frequent occurrence.

The main conclusion of the present paper is in strong support of the hypothesis of Prof. Joseph Barrell[1] that the depression in which the Triassic rocks of Southern Connecticut were laid down was produced by intermittent movement along an eastern fault plane during the course of sedimentation. The evidence for this conclusion is two-fold. In the first place, fanglomerates, composed of huge, angular bowlders, occur at various horizons in the Newark series close to the fault plane, and grade abruptly into finer sediments along the strike to the west. The second line of evidence is furnished by a large quartz lode that occurs along the eastern side of the fault zone. This lode appears to have been formed in pre-Triassic time, and therefore movement had taken place along the present fault zone even before the Triassic. Pebbles of this vein are found in several horizons in the Triassic, indicating that when the rocks in which they occur were laid down, faulting had already taken place, for the lode was formed along a fault that existed before its formation, and also proving that at that time the Triassic did not extend east of its present eastern boundary.

Acknowledgment.—The field work upon the problem under discussion was carried on in the fall of 1921 and the

---

[1] For references see the end of this article.

spring of 1922. The present article is an abridgment of an essay submitted to Yale University for the degree of master of science. The writer is greatly indebted to Prof. C. R. Longwell and Prof. Adolph Knopf, of Yale University, for advice and criticism in preparing the report.

General Description of the Formations.

1. *The crystallines and altered crystallines.*—The rocks to the east and south-east of the great fault consist of granites, gneisses, and schists. At a distance from the fault the granites near Lighthouse Point show little or no evidence of shearing or gneissic banding. Near the fault plane they frequently present a streaky appearance, due to the crushing and drawing out of the minerals by shearing. Under the microscope the normal granites may be seen to be subject to strong cataclastic deformation, but the sheared rocks are much more intensely deformed, and some of them have been reduced to mylonites. The minerals have been crushed and granulated until they are mere lines, and sericite has been developed along shear planes and zones of microbrecciation. These sheared rocks and mylonites are found at intervals along the course of the fault. They were not observed at a distance from it, and the amount of shearing increases irregularly towards the fault plane. The sheared rocks are often cut by quartz veins which are not sheared. North of Branford, where these rocks are best exposed, the shear planes are nearly horizontal, or dip slightly towards the fault.

2. *The quartz lode.*—One of the remarkable features of the region is the presence along the eastern edge of the fault plane of a quartz lode of considerable extent and size, which affords indications of the age of the fault, and the dip of the fault plane. In general this lode consists of white, bluish, or greenish quartz, cut by a network of veins of white, coarsely granular quartz. In addition there are occasionally cubical crystals of pyrite, and rarely fluorite. A composite sample of the lode contained $0.31 of gold to the ton. On its eastern border this vein in many places passes into the crystallines by a gradual transition from the quartz of the lode to altered crystallines partly replaced by quartz, and finally to

unreplaced granite. In other places the transition is of another type. As the fault plane is approached, a network of small quartz veins cutting the crystallines is encountered, which forms a larger and larger percentage of the whole rock, until near the quartz lode the rock has the appearance of a breccia. The fragments of crystallines become more altered and silicified and less numerous towards the lode. Where the crystalline rocks

Fig. 1.

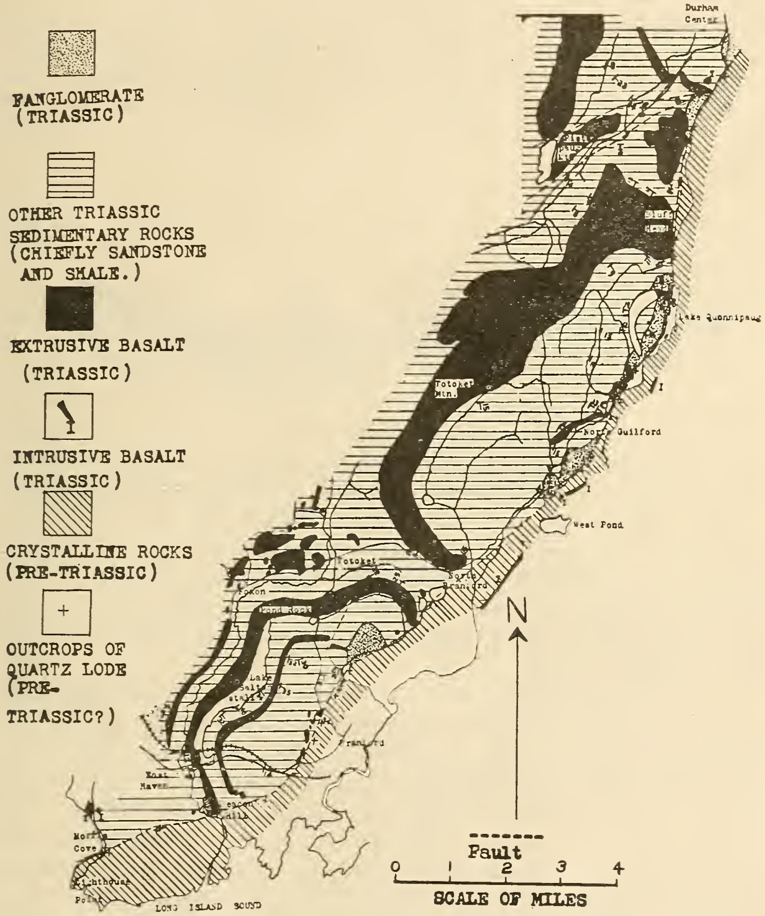


Fig. 1.—Geologic map of the region of the Great Triassic Fault between Lighthouse Point and Durham, Conn.

contain abundant dark minerals, the lode is apt to have a bluish or greenish tinge, apparently derived from their alteration. A thin section of this bluish portion shows remnants of unreplaced minerals. Besides angular altered inclusions of the crystalline rocks, the lode occasionally contains small angular or rounded pebbles of quartz, produced by brecciation and grinding.

This lode is apparently due chiefly to replacement, though parts of it may be actually fissure fillings. As shown by the map (fig. 1), it outcrops at nearly every point where the crystallines and the Triassic are found close together, and its largest exposure, north of Branford, is over half a mile long, and averages over 150 feet wide, not including the slopes of quartz talus. Other outcrops, beyond a concealed stretch, indicate that it is probably over 3,500 feet long.

3. *The fault zone and brecciation.*—Near the course of the Great Fault, and for some distance to the west of it, there are zones of shattered and crushed rocks. Breccias are of frequent occurrence, and there are zones of rounded basalt fragments embedded in crushed or quite firm basalt. Veins or dikes of sandstone and shale occur in the basalt, and sometimes reach a width of several feet. Large basalt blocks, sometimes hundreds of feet long, have been brought up by distributive faulting from lower horizons, and occur at intervals along the course of the fault. These features are a striking testimonial to the great movement and shattering that affected the region in post-Newark time.

4. *The fanglomerates.*—For convenience in mapping, rocks largly composed of pebbles over three inches in diameter, some of which are somewhat angular, have been considered fanglomerates. These rocks are unlike anything else observed in the Triassic trough. They are composed of angular bowlders of various sizes, cemented by sandstone. In some places the bowlders are sharply angular, though usually the larger ones are somewhat rounded. The bowlders reach several feet in diameter in several places, and in one place the rock was chiefly composed of hugh bowlders of basalt, several reet in diameter, some of which are vesicular. Both the size and angularity of the bowlders increases quite rapidly towards the Great Fault, though in an irregular manner. The rock is quite variable, contains numerous finer

lenses, and here and there gives place to a sandstone within a few feet of vertical distance.

As shown by the accompanying map (fig. 1), the fanglomerate never extends more than about half a mile from the fault plane. To the west it interfingers with the sandstones and conglomerates. Long lenses of the fanglomerate run out into the finer rocks. It outcrops at a number of different localities, some of which may have been originally continuous. The actual thickness of each mass is difficult to determine, two or three hundred feet being the maximum thickness actually measured. The fanglomerate is found below the lower basalt flow, immediately below the main sheet, below the upper basalt flow, and above all the flows. The rocks close to the Great Fault are all concealed in the horizons much below the lowest trap sheet, and therefore there is no direct evidence as to whether or not fanglomerates exist in them or not. The rocks immediately above the main sheet are usually fine-grained even close to the Great Fault.

FIG. 2.

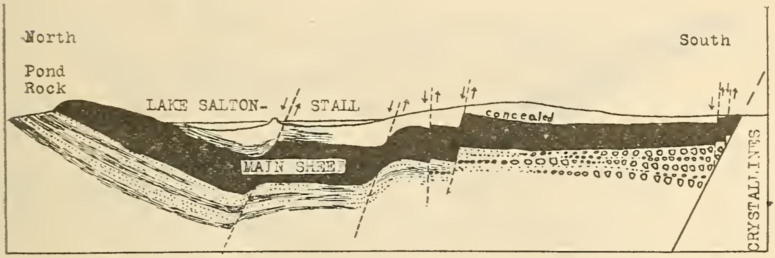


FIG. 2.—Generalized section from Beacon Hill to the South end of Pond Rock, showing the gradation from fanglomerate to shale with increasing distance from the Great Fault.

The pebbles of the fanglomerate consist of all the crystalline rocks found to the east of the Great Fault, pegmatites, masses of vein quartz and feldspar several inches long, large bowlders of basalt, some of which are vasicular and highly angular, and pebbles of the quartz lode. Sometimes abundant pebbles of a rock are found in the fanglomerate, though there is no such rock in the vicinity on the crystalline side of the fault plane. This may mean that the rock once occurred east of the fault, but has been removed by erosion. The basalt bowlders were not found below the lower trap flow. They will be referred to later. The pebbles of the quartz lode were of its most characteristic type—whitish or bluish granular quartz traversed by a network of veins, and altered inclusions cemented by quartz—and some of them were angular and a foot in diameter. They occur between the main and upper basalt flows, and above the upper basalt flow.

FIG. 3.

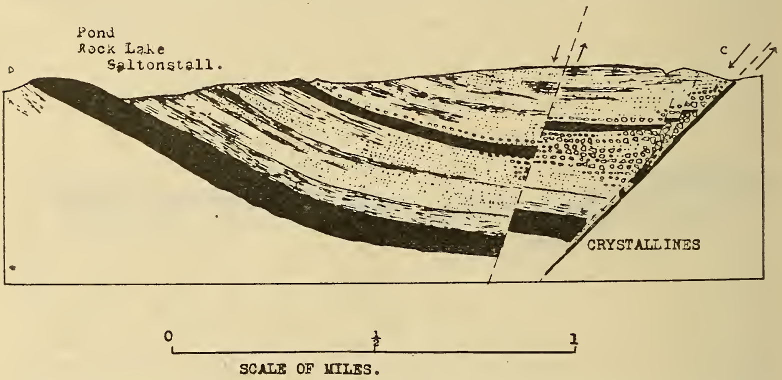


FIG. 3—Generalized section westwards from the neighborhood of the Branford Water Company's Pond north of Branford.

5. *The other sedimentary rocks.*—The sedimentary rocks west of the fault plane and the fanglomerates consist of conglomerate, sandstone, and shale in frequent alternation. The folds or warps enable one to follow the same horizon away from the fault, and when this is done it is found that the rocks in general become finer and finer for a mile or two away from the fault plane. In some places the gradation can be traced along the same horizon from a fanglomerate to a conglomerate, then to a sandstone, and finally to a shale. These relations are shown in figs. 2, 3 and 4.

THE LARGER FAULTS OF THE TRIASSIC TROUGH.

That the larger faults also have a general northeast-southwest strike is apparent at once from Davis's map of the Connecticut Triassic. He considered that the fault separating Bluff Head and Pistapaug Mountain uplifted the strata on the north about 2,500 feet, and cites as proof of this the fact that the main sheet outcrops considerably eastwards to the north. Nevertheless, the strata to the north must have sunk, the amount of sinking increasing eastwards, for near Pistapaug Mountain the upper surface of the main sheet is brought close to the horizon of the lower basalt sheet, with the latter on the south, while near the Great Fault the upper and lower basalt sheets are brought nearly opposite each other, with the lower sheet on the south. The former case corresponds to a throw of about 1,500 feet, the latter to a throw of about 2,500 feet. The displacement of the main sheet to the east on the north is not due to the fault, but to a warp or fold, like that between Pond Rock and Totoket Mountain.

Fig. 4.

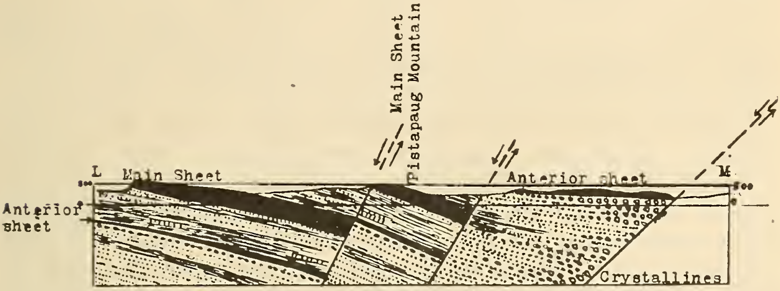


Fig. 4.—Section west-northwest through Pistapaug Mountain.

THEORETICAL CONSIDERATIONS: THE GREAT FAULT.

The Dip of the Plane of the Great Fault.

Davis[2] believed that the fault plane was nearly vertical, and cited as supporting evidence the fact that the outcrop does not advance to the west in the great anticlinal folds or warps. In another publication[3] he says that the folding probably came before the faulting. If this is the case it is evident that the fault plane could not have been warped by it. However, it will be shown later that part of the movement probably took place before the warped sediments were laid down.

The great half-saucer-like folds which give the outcrops of the basalt flows their crescentic outline are one of the most remarkable features of the structure of the region. They vary in diameter from about 1,000 feet, in the vicinity of North Guilford, to many miles. As they all have the same relations to the Great Fault, and all die out rapidly west of it, they appear to be connected with its formation. Possibly they are due to unequal subsidence along the fault plane. If this were the case, there would be no tendency for the fault plane to advance to the west in the upwarps.

A normal fault, such as the one under consideration, probably had some dip to the west at its origin, and this would probably be increased by the tilting of the region. The faults of the central portion of the Triassic dip both northwest and southeast, while those near the Great Fault, which are probably shear faults more or less parallel to it, dip only to the northwest, and dip steeper where the dip of the fault was not affected by the tilting. The occurrence of a precipitous eastern slope and a gentle western slope in the great outcrop of the quartz lode north of Branford, together with the apparent banding dipping west at about 30°, all point strongly to a westward dip of the fault plane. Moreover, in the actual exposure of the fault plane found by Davis at Highland Park the dip was 55° W. It is also reported that a well drilled in the Triassic near the fault penetrated the crystallines. For these reasons it is believed that the fault plane dips to the west at an angle of from 30° to 60°.

THE RELATIVE DATES OF FAULTING AND SEDIMENTATION.

The evidence of the Quartz Lode and the Fanglomerates.

The fact that the quartz lode follows closely the outcrop of the Great Fault indicates that it was formed by solutions that travelled along its plane. The great size of the quartz lode along the fault; the total absence of anything resembling it in the Triassic; its general character and striking similarity to the great quartz mass at Lantern Hill, Connecticut, which is thought to have been formed by heated magmatic waters,[4] all render it probable that the quartz lode was also formed by heated magmatic waters, most likely at the close of the Appalachian Revolution.

The occurrence of pebbles of this quartz lode in the fanglomerates between the main and upper trap sheets shows that by the time these fanglomerates were laid down three separate events must have taken place: first, there must have been movement along the fault plane; second, this fault plane must have been sealed by the formation of the quartz lode; third, there must have been further movement to bring the lode to the surface again. These bowlders also show that during the formation of these fanglomerates the Triassic did not extend more than a few feet east of the outcrop of the fault. If there were any previous Triassic deposits, they must have been already eroded away.

The lowest horizon at which fanglomerates were found is just below the lower basalt sheet. The bed rock of the horizons below this is all concealed for considerable distances from the fault, so that it is impossible to tell whether fanglomerates occur in them or not. They were found at various horizons from below the lower basalt sheet to well above the upper. In one place the upper flow dies out against the fanglomerate, indicating that the surface slope of the alluvial fan was probably several hundred feet per mile. The bowlders are of such great size and so angular that they could not have been transported far. Therefore, their source in the crystallines must have been nearby, and the contact with the Triassic rocks must have been a fault at that time, for the Newark strata at that time were very thick immediately west of the fault, but did not exist close to the east of it.

THE BASALT BOWLDERS OF THE FANGLOMERATE.

The occurrence of huge, angular bowlders of vesicular basalt in the fanglomerates tends to support the foregoing conclusions. These basalt fragments do not occur solely in or near the same horizons as the basalt flows as Davis believed they did. They are found in between them, and above them all. They might be supposed to have been derived from volcanoes in the hills or mountains east of the fault, or they may have been derived from basalt flows that had spread over on the east side of the fault, and then been uplifted. The bowlders are so huge and angular that it is difficult to see how they could have been carried far, and moreover their occurrence follows the fault plane. The flows are sometimes quite thick near the fault, and the scarp could not have remained a steep slope during the whole of Newark time. It seems probable, therefore, that the bowlders were derived from portions of basalt that were lifted up by the faulting.

Fig. 5.

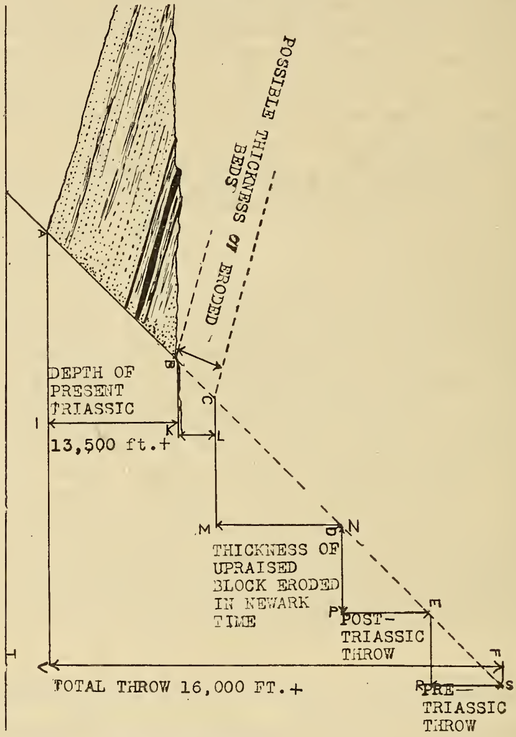


Fig. 5.—Diagram to illustrate the discussion of the throw of the Great Fault.

The Throw of the Great Fault.

Any estimate of the throw of the Great Fault must be based on the thickness of the Triassic to the west. There appears to be great uncertainty about the thickness of the lower sandstones. Davis estimated their thickness to be 5,000 to 6,000 feet. The wells drilled in the Triassic near its western border give a definite indication that these lower sandstones are thicker than this. The facts about these wells may be listed as follows:

Location	Depth in feet	Distance from crystallines to west in miles	Distance expressed as a fraction of that from the crystallines on west to the outcrop of the lower sheet
Near Northampton..	3.700	not over 2 or 3	not over 1/2
Winchester Arms Co. New Haven	4,000	about 2	about 1/3
Near Cheshire, about	4,000	about 1-1/2	less than 1/2

None of these wells penetrated the crystallines. In view of these facts the thickness of the lower sandstones may be estimated at 8,000 feet or more. Their thickness in the Pomperaug Valley, about 15 miles to the west, is only 1,200 feet, which may indicate that they thicken to the east.

The accompanying fig. 5 shows the various elements which enter into the estimation of the throw of the fault. The throw is the sum of the following values:

The thickness of the lower sandstones.......	8,000 feet or more
The thickness of the remainder of the Triassic now remaining	5,500 feet or more
(The sum of these two is shown as HK on the diagram. The movement along the fault plane was AB).	
The thickness of possible Triassic sediments above the highest beds now exposed (Movement BC, Throw KL)	Unknown
Thickness of upraised block worn down during Triassic to provide sediments for the Triassic strata (Movement CD, Throw MD)	Probably at least several thousand feet; may have been greater than the whole thickness of the Triassic.
Post-Triassic Faulting (Movement DE, Throw PE)	The tilting of the sediments; the apparent appearance of lower and lower horizons of the metamorphic rocks in going west towards Derby; and the great shattering of the highest Triassic horizons exposed indicate that this was great.

Possible throw before the Newark deposition (Movement ES, Throw RS)	Unknown.

If part of the Newark strata accumulated a warped or folded depression, this would introduce a correction which should be subtracted from the sum of the foregoing values. However, as the quartz lode probably indicates that there was faulting before the formation of the Newark strata, and as the fanglomerates and the pebbles of the quartz lode occurring in them show that faulting had begun again at least by the time when the trap sheets were extruded, and that the Triassic did not then extend east of the outcrop of the fault plane, it seems unlikely that any appreciable part of the depression was produced by warping.

Taking all the foregoing facts into consideration, the minimum throw of the fault may be estimated at 16,000 feet. However, it may well have been 20,000 feet, and it is possible that it was as much as 30,000 feet.

THE PROBLEM OF THE CROSS FAULTS.

Where the three great northeast-southwest faults of the Triassic intersect the Great Fault, the latter turns and runs along the cross fault in a northeast direction. As this happens three times it can hardly be a coincidence. Davis explained this by assuming that the cross fault brought down the sandstones which he thought existed east of the Great Fault.[5 and 6] The relations as he imagined them are shown in fig. 6. There is definite field evidence for the faults AB, BC, CD and CF. (5 and 6) Davis believed that fault KB continued to the north to form BE, while CF continued to the south to form HC, though no field evidence for the existence of these faults is given. The cross faults, according to Davis, have a throw of about half a mile, and this he believed to be sufficient in each case to bring the base of the Triassic below the surface of block EBCF. Assuming that the base of the sandstones in this block was originally nearly on a level with the present surface of the upland, Davis estimates the depth of the lower sandstones on the eastern side of block EBCF to be about 1,600 feet in the case of the South Manchester Fault block, and 1,400 feet in the case of the South Glastonbury block. It would be quite a coincidence if in the case of each one of the cross faults the base of the Triassic were near enough to the present surface of the upland to be brought down below the level of the lowland by such small faults; and, as the South Manchester Block is over two miles wide, and the South Glastonbury Block is 4 or 5 miles wide, it is still more remarkable that the crystallines are not brought to the surface by the normal 10 to 15° dip of the Triassic.

If, as has been shown previously, the Triassic did not extend east of the Great Fault, we must seek some other method of explaining the offsets. Three hypotheses may be considered: (1) The main fault may have been displaced to the east on the north side of the offsets by great horizontal movement; (2) The apparent displacement may be caused by the westerly dip of the fault plane; (3) The cross faults may have been lines of weakness when the course of the great fault was determined, and where it met one of these lines of weakness it may have followed it for some distance before continuing its northward course.

Fig. 6.

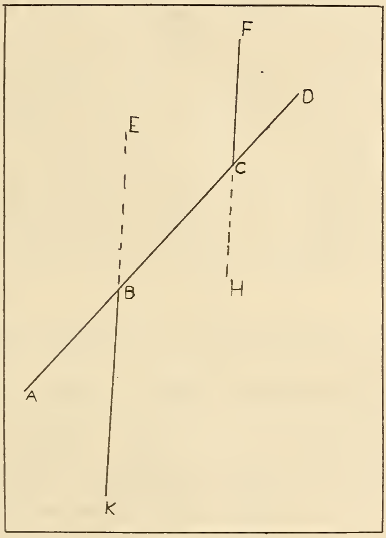


Fig. 6.—Diagram to illustrate Davis's theory of the cross faults.

The first theory need not be considered further, for there is no evidence of such a tremendous horizontal displacement. The second theory would be reasonable, if it could be shown that the dip of the plane of the Great Fault were as small, or the throw of the cross faults as great, as is demanded. The throw of the Paug-Bluff Head fault is about 2,500 feet where it intersects the Great Fault, and possibly 3,000 feet further northeast, and the Great Fault seems to be offset between a mile and a half and two miles. A dip of the fault plane of 14° to 21° would be required to produce this offset. This difficulty is more serious even farther north, where the offset seems to be several miles. The throws of these faults are given by Davis as about half a mile, and even if it be assumed that they increase to the northeast, an extraordinarily low dip of the fault plane must be assumed to account for the offset.

The question might be settled by finding fanglomerates and the pre-Triassic quartz lode along the cross-faults where they bound the Triassic. Near Durham, where the portion of the fault examined ended, there was an outcrop of the fanglomerate and the quartz lode which were apparently associated with the cross fault. This interesting problem cannot be settled without further investigation, but the evidence seems to favor the third hypothesis.

THE PHYSIOGRAPHY OF NEWARK TIME.

During the deposition of the Newark sediments of the region periods of movement along the fault plane alternated with times of relative repose. This is shown by the fact that at some horizons fanglomerates occur near the fault plane, while at others fine shales and sandstones are found. The average rate at which the fault scarp rose above the plains to the west during Newark time was probably not rapid, perhaps something like one foot in a thousand years. It is probable, therefore, that the scarp was at times reduced to a gentle slope. If the same horizon is followed till it intersects the fault plane in several places, it is sometimes found that fanglomerates are developed in the horizon at some of these places and not in others. The rivers may have caused this by building alluvial fans only where they issued on to the plains, or it may be due to unequal movement of different portions of the fault.

The topography of Newark time was, of course, quite different on the two sides of the fault. To the east there were the hills or mountains whose erosion supplied material for the strata near the fault. These mountains were bounded on the west by a scarp, the height and steepness of which varied from time to time. Bordering the scarp on the west was a belt of alluvial fans, the slopes of which were occasionally as high as several hundred feet a mile. Farther west were the flat, featureless plains, diversified only by occasional lakes or playas.

SUMMARY OF GEOLOGIC HISTORY.

Probably during the closing stages of the Appalachian Revolution, almost certainly by the middle of Newark time, movement began along the Great Fault. The crystallines along the fault plane were first sheared and crushed, and later they were partly replaced by a quartz lode, and the fissure was temporarily healed up. During this time the larger cross faults of the Triassic were probably either faults or zones of weakness. During Newark time the sediments accumulated in a depression formed by intermittent movement along the Great Fault. Alluvial fans were built into the plains to the west by streams draining from the fault block range formed at this time. Three or more lava flows were poured out, one of which at least thinned out against the fans. Portions of the flows that had spread over east of the Fault Plane were raised up and their fragments washed into the trough. After the deposition of the sediments, further movement took place along the great fault, and the sediments were tilted, shattered, faulted, and, near the Great Fault, warped into saucer-like folds.

LIST OF REFERENCES.

1. Joseph Barrell: Central Connecticut in the Geologic Past, Conn. State Geol. Survey, Bull. No. 23, 1915.
2. William Davis: The Triassic Formation of Connecticut, U. S. G. S., 18th Ann. Report, pt. II, p. 126, 1896-7.
3. William Davis: The Eastern Boundary of the Connecticut Triassic, Geol. Soc. Am., Bull., Vol. 5, p. 526, 1894.
4. G. F. Loughlin: The Gabbros and Associated Rocks at Preston, Connecticut, U. S. G. S., Bull. 492, p. 143, 1912.
5. William Davis: The Triassic Formation of Connecticut. U. S. G. S., 18th Ann. Report, pt. II, p. 129, 1896-7.
6. William Davis: The Eastern Boundary of the Connecticut Triassic, Geol. Soc. Am., Bull. vol. 5, p. 528, 1894.

SCIENTIFIC INTELLIGENCE.

I. Chemistry and Physics.

1. *The Presence of Cobalt and Nickel in Vegetables.*—Bertrand and Mokragnatz have worked out a process for the quantitative determination of very minute amounts of these two metals in complex mixtures, and they have thus examined the ashes of twenty vegetables, selecting preferably the parts used as food, and including carrots, onions, potatoes, spinach, lettuce, the fleshy part of apricots, tomatoes, beans, several grains such as wheat, oats, buckwheat, maize, and a single fungus, the chantarelle. The amounts of the fresh substances employed for the analyses were one kilogram of the grains and two kilograms of the softer materials. The cobalt and nickel were obtained as potassium cobaltic nitrate and nickel dimethylglyoxime. The results were positive for nickel with all of the plants, while cobalt was found in all but two of them, the carrots and the oats. The amounts for a kilogram of fresh substance varied for cobalt from less than 1/200 milligram up to 0.3 mg. (in buckwheat), and for nickel from 0.01 mg. (tomatoes) to 2.0 mg. (peas).

These results are interesting, since heretofore there have been but a few, perhaps uncertain, statements in regard to the presence of cobalt in the ashes of plants, and still less information concerning nickel. It as yet unknown whether the presence of these metals in vegetables is merely accidental, or whether they are a physiological requirement.—*Comptes Rendus* **173**, 458. H. L. W.

2. *Standard Methods of Chemical Analysis*; by Wilfred W. Scott. 8vo. Volume I. pp. 714; Volume II. pp. 616. New York, 1922 (D. Van Nostrand Company. Price $10 net).—This very important work of reference now appears as a revised and much enlarged third edition, which, on account of its size, has been divided into two volumes. On the title-page Mr. Scott designates himself as the editor of the work and gives a list of thirty-six principal collaborators, but by far the greater part of the book has been prepared by him.

The work is a very impressive one in furnishing a vast amount of reliable information in regard to analytical chemistry. The first volume takes up the elements in alphabetical order and discusses their detection, their separation from other elements, and the gravimetric, volumetric, and other methods for their estimation. This volume also gives an elaborate and excellent series of tables of useful data, including a very extensive one dealing with conversion-factors. The second volume deals particularly with technical analysis, for instance, the examination of acids and alkalies, alloys, soaps, paints, coal, rubber, gases, waters, etc.

It appears that all practical analytical chemists should find this work very useful. H. L. W.

3. *Outlines of Theoretical Chemistry;* by Frederick H. Getman. 8vo, pp. 625. New York, 1922 (John Wiley & Sons, Inc.). This is the third edition of this well-known textbook. A large part of the preceding edition has been rewritten, and much new material has been added on account of the recent advances in the science of physical chemistry. It is an excellent advanced presentation of the subject and it treats the modern developments very satisfactorily.

It may be observed that while the treatment of the topics is decidedly and extensively mathematical, the calculus has been employed in only a few places where it seemed unavoidable, and the author believes that the book should be intelligible to students of moderate mathematical attainments. It is supplied with numerous numerical problems which are undoubtedly very serviceable in enabling students to attain a mastery of the fundamental principles of the subject. H. L. W.

4. *The Formation of Colloids;* by Th. Svedberg. 12mo, pp. 127. New York, 1921 (D. Van Nostrand Company. Price $2 net. Printed in Great Britain).—This is the first of a proposed series of monographs on the physics and chemistry of colloids by the same author. It presents a systematic survey of the processes by which colloids are formed, with particular attention to the conditions which determine the degree of subdivision of the products.

This book is very interesting in showing very clearly the present aspects of this rapidly developing branch of chemistry, and it is also valuable in giving an excellent list of references to the literature of the subject. H. L. W.

5. *Physikalische Chemie der Zelle und der Gewebe,* by Rudolph Höber. I Hälfte, 8vo, pp. 544. Leipzig, 1922 (Verlag von Wilhelm Engelmann).—This is the fifth edition of a very remarkable book. It is to be issued in two volumes of which only the first has appeared.

The titles of the six chapters of part I give an excellent idea of the scope of the book. They are: Theory of solutions and osmotic pressure; electrolytic dissociation; determination of hydrogen ions and their physiological significance; surface phenomena; colloids; and velocity of reaction and the effect of ferments. In every chapter, there is an excellent presentation of the physical chemistry of the subject including theory and methods of work, followed by applications to biology. The book should be of the greatest interest to biologists and physiological chemists. The physical chemistry is so clearly presented that the book may be recommended to chemists as well. H. W. FOOTE.

6. *Spectral Determination of Temperature.*—Mr. Irwin G. Priest has recently described in the Bureau of Standards Scientific Paper, No. 443, a method by which the temperature of an artificial light source may be determined by the process of color matching. The light from a chosen source is passed through a quartz plate between nicols, and so arranged that the spectral distribution of the emergent energy for all needed positions of the second nicol shall be that characteristic of a complete radiator, or the so-called black body. As the temperature of the latter may be calculated by Planck's formula any source which emits light which is capable of evoking a color of the same hue and saturation as the Planckian radiator may be regarded as having the same temperature. As to the precision of color comparisons, quite apart from this particular method, it was found that when the color fields of two lamps were matched by varying the voltage of one of them, the probable error of a single observation, when translated into temperature, was about 6° at 2850° absolute.

With the apparatus as designed, the change of color by rotation of the nicol was equivalent to the variation of black body temperature so that one scale can be calibrated in terms of the other. Various tests of the reliability of the method were made. It was found e. g. that a certain 500 watt lamp had a temperature of 3086°K as determined radiometrically, that is, by the spectral energy distribution, but was measured as 3082°K by the color temperature apparatus. In the case of a 900 watt stereopticon lamp the two methods gave respectively 3087° and 3085°. The color matching method was also applied to the estimation of the temperature of the crater of a 65 volt 10 ampere carbon arc for which the author found mean values of 3780°K with solid carbons, and 3420°K for cored carbons, with errors possibly in the neighborhood of 50°.

A widely different method for the estimation of the temperature of a source is reported by R. T. Birge in the May number of the Astrophysical Journal for the current year, as a result of the study of the variation in intensity of certain series lines in band spectra. By means of the recent formulation of the law of such a series, it is possible to express a relation between the temperature of the source, the convergence separation of the lines, and the parameter of the line of the series for which the intensity is a maximum. From a study of the spectrogram of a carbon arc using 13 amperes at 170 volts this author estimates the temperature of the vapor to be $4500° \pm 300°$K. The same method applied to the reversing layer of the sun indicates a temperature of $4000° \pm 500$K. F. E. B.

7. *Vector Calculus;* by JAMES BRYNE SHAW. Pp. V, 314.

New York, 1922 (D. Van Nostrand Company).—It is to be expected that a mathematician trying to teach physics would write a very different book from that of a physicist teaching mathematics. The present work may fairly be said to come within the former category. The author being primarily interested in the field of associative algebra is disposed to view the method of quaternions as preferable to other systems of vector analysis, but for those who are contrary-minded he has been to considerable pains to explain the characteristics of a variety of systems and the notations employed in them.

The introductory chapter sketches the history and character of vector analysis. The second and third chapters are intended to be explanatory of scalar and vector fields, but as expositions of the meaning of physical quantities they are occasionally sadly lacking. For example, on p. 14 we read:

"Action. This quantity is much used in physics the principle of least action being one of the most important fundamental bases of modern physics. The dimensions of action are [ΘΦ]," (i. e. the unit of electricity times the unit of magnetism) "and the unit might be a *quantum* but for practical purposes a *joule-second* is used." Now waiving the question whether there is any occasion for bringing dimensional equations unto a vector calculus, the obvious meaning of the expression quoted is that the unit of action is the product of the unit charge by the unit pole. But there is no known action of a magnetic charge on an electric charge, which reduces the whole statement to an absurdity.

Chapters IV, V, and VI explain the rules of the game for that particular complex of hypernumbers called a quaternion, after which the author proceeds to the main purpose of the book which is to familiarize the student by easy gradations with the profundities of mathematical physics. Chapter VIII is devoted to derivative and integral theorems and their physical applications. Chapter IX is given to the linear vector function; Chapter X to homogeneous strains and Chapter XI to hydrodynamics.

As a discussion of physical subjects from the vectorial standpoint the book will be found perhaps the greatest mine of examples and illustrations since Tait's Quaternions. Issue must be taken with the author's statement that Gibbs considered scalar and vector multiplications as functions of the dyadic rather than as multiplications (v. Scientific Papers Vol. II, p. 20), and that he considered the dyadic as a quantity.

In dissent from the author's view that, in comparison to other vector methods, the use of quaternions is by far the simplest in theory and practice, one has only to run his eye over the equations in the physical applications to see how readily intelligible they would be to one understanding the function $S\alpha\beta$ and $V\alpha\beta$

but having no conception of the quaternion $\alpha\beta$ (cf. Gibbs), l.c. p. 162).

The author is certainly mistaken in ascribing the invention of the complex operator in the theory of alternating currents to Steinmetz. It was used by Heaviside as early as 1886 and possibly before.

8. *The Origin of Spectra;* by PAUL D. FOOTE and F. L. MOHLER. Pp. 250, New York, 1922 (The Chemical Catalog Company).—From the avalanche of speculations, equations, photographs, and tables of spectral lines which has been precipitated by the Bohr Theory of the atom, the authors, who are research physicists at the Bureau of Standards, have attempted to separate the main lines of argument and in particular to present a systematic correlation of the experimental facts. The present volume is the ninth to appear in the Monograph Series of the American Chemical Society.

The character of the contents may be judged from the titles of the chapters, viz., The Quantum Theory of Spectroscopy, Energy Diagrams, Ionization and Resonance Potentials, Atomic Line Emission and Absorption Spectra, Cumulative Ionization, Thermal Excitation, Thermochemical Relations, X-Ray Spectra, Photoelectric Effect in Vapors, Determination of Planck's Constant from Line Spectra.

The presentation is such as to make the volume more suitable as a handbook for the investigator than for a text-book. As is proper to a monograph, the chapter and verse for the authorities are given for every statement of importance. Illustrations of spectra and tables of data are liberally provided as are also complete subject and author indexes. F. E. B.

II. GEOLOGY AND MINERALOGY.

1. *Pottsville Fauna of Ohio;* by HELEN MORNINGSTAR. Geol. Survey of Ohio, 4th ser., Bull. 25, 312 pp., 16 pls., 1 text fig. (map), 1922.—The Pottsville series of Ohio has an average thickness of about 255 feet, with ten marine fossiliferous zones alternating with as many brackish- or fresh-water deposits, three of which have fossils. Iron ores were laid down in both the fresh and marine waters. Throughout the extent of the exposures the author has brought together fossils from ninety-three places, and these localities are fully described, along with lists of the individual faunules. Then follows the description of all the invertebrate forms, numbering about 200, of which 31 are not specifically determined. The new forms are the genus *Bascomella,* and 20 species. As is to be expected, the bulk of the fauna is made up of Bryozoa, Brachiopoda, and Mollusca.

The monograph is a statement of facts, and all of the species are illustrated, making the work an easily usable one of reference for the Pottsville fauna of Ohio. It is a pleasure to note so promising an initial contribution from a new woman worker in Paleontology. C. S.

2. *Earth and Sun: An Hypothesis of Weather and Sunspots* (in press). *Climatic Changes, their Nature and Causes,* by ELLSWORTH HUNTINGTON and STEPHEN S. VISHER. New Haven (Yale University Press), 329 pp., 13 text figs., 10 tables, 1922.—The first volume treats of the causes of weather, and is introductory to the second, more philosophical one on climatic changes, past and present. The underlying theme is the senior author's "solar cyclonic hypothesis," which holds, briefly, that "the changing temperature of the sun," as revealed in sunspots, alters the storminess and temperature of the earth, and that these factors, along with those of a changing earth's surface, bring about the climatic changes on the earth. It is a most interesting, very intricate, and far-reaching hypothesis, and one that weaves all Nature into a web of consequences. The theory is not only presented fully in "Climatic Changes," but in a style easily readable.

The first main hypothesis is "that the earth's present climatic variations are correlated with changes in the solar atmosphere. This is the key-note of the whole book" (311).

The second main hypothesis is "that variations in the solar atmosphere influence the earth's climate chiefly by causing variations not only in temperature but also in atmospheric pressure and thus in storminess, wind, and rainfall" (312).

The above two causes are balanced in that "many climatic conditions are due to purely terrestrial causes, such as the form and altitude of the lands, the degree to which the continents are united, the movement of ocean currents, the activity of volcanoes, and the composition of the atmosphere and the ocean. Only by combining the solar and the terrestrial can the truth be perceived" (312).

"Finally, the last main hypothesis....holds that if the climatic conditions which now prevail at times of solar activity were magnified sufficiently and if they occurred in conjunction with certain important terrestrial conditions of which there is good evidence, they would produce most of the notable phenomena of glacial periods" (312). C. S.

3. *Seventeenth Report of the Director of the New York State Museum and Science Department:* N. Y. State Mus., Bulls. 239-240, 209 pp., pls., maps, and text figs., 1922.—The head of this great state museum, Doctor John M. Clarke, describes here in an interesting way the work of its various departments during the year 1920-1921. We are glad to note the accession of a

most excellent mastodon skeleton from Orange County, a region that has furnished more specimens than any other, this being the thirty-first. Also the very true-to-nature restorations of glass sponges after those of the Upper Devonian of New York. Ruedemann presents a far-reaching paper on "The existence and configuration of Precambrian continents," attacking the problem from all sides but chiefly from the internal structure or grain of the present continents. The work evinces much reading and study.

Miss Golding describes the local distribution and specific peculiarities of the shell faunas in the Champlain Sea of late Pleistocene time, and their relation to the marine faunas of the St. Lawrence embayment. Out of a possible fauna of 138 species, only 32 entered the freshened Champlain Sea, and but one attained its southern limits. The few marine discoveries in the Hudson Valley are also described. C. S.

4. *Sveriges Olenidskiffer;* by A. H. WESTERGARD. Sver. Geol. Undersökning, Ser. Ca., No. 18, 205 quarto pp., 16 pls., 39 text figs., 1922. With English summary.—This monograph describes most carefully and in great detail the various local successions of the Olenid beds and their faunas throughout Sweden. The strata are alum shales replete with lenses of stinkstone abounding in trilobites. The series is about 40 meters thick and is divisible into six faunal zones, together yielding less than a hundred species. Of this number, 80 are trilobites (28 new), and all are fully described and beautifully illustrated in photogravure. It is a work of the first import and of the greatest valut to students of this time. So far the faunal province of which it treats is known only in Scandinavia, Great Britain, eastern Canada, and Alabama. A few of the species are also known in Bolivia. C. S.

5. *The Geology of the Broken Hill District;* by E. C. ANDREWS. Memoirs, Geol. Survey New South Wales, Geology, No. 8, 432 quarto pages, 124 pls., 41 text figs., 1922.—This sumptuously illustrated volume on the world's greatest lead and zinc mine, describes not only the ore occurrences but as well the geology of the highly deformed strata (silts and shale) which "probably are several miles in thickness." While being folded, the strata were at four different times intruded by igneous rocks and more or less intensely metamorphosed. They make up the Willyama series, from which the Broken Hill mines have taken far more than one half a billion dollars' worth of ores.

Unconformably above these older formations, whose age is unknown but thought to be of Archean time, occurs a series of quartzites, tillites, and laminated claystones, some hundreds of feet thick, the claystones having lentils of marble and limestones "crowded with foreign fragments." The marbles were deposited in clear waters, while the limestones with conglomeratic materials were laid down "during periods of glacial action." These formations comprise the Torrowangee series. The tillite series with its striated boulders is thought to be of the same age as that of South Australia, referred by Howchin to the Cambrian. Andrews, however, after reviewing this matter, concludes that the Torrowangee series is clearly Pre-cambrian in age, "and may be compared with Coleman's Huronian tillites." The next younger strata, which originally covered all, are Cretaceous in age. It is to be hoped that the Australian geologists will now determine the age of the tillites of South Australia, which are known to underlie marine and fossiliferous Lower Cambrian, because it may turn out that these southern tillites are not contemporaneous with those of the Broken Hill area, but that the one series occurs near the base of the Proterozoic, the other toward the close of the same era. If Andrews' surmises are correct, and the tillites of the region about Broken Hill are of the age of Coleman's Huronian tillites in Canada, then there will be established the supposition that in early Huronian time the world had a glacial climate. No finer historical problem in all Australia awaits the discerning geologist, since the tillites of glacial climates are, when properly dated, the most exact criteria for the dating of intercontinental geologic events. C. S.

6. *On the Eclogites of Norway*; by PENTTI ESKOLA. Videnskapsselskapets Skrifter. I. Mat.—Naturv. Klasse. 1921. No 8, pp. 118, with 14 figures and 3 plates. Christiania, 1921.—The eclogites of Norway are found to be of igneous origin, in agreement with the conclusions previously reached by Norwegian investigators. At Nordfjord and More the eclogites occur as lenses in protoclastic granite-gneiss, where they appear to be of the nature of cognate xenoliths, and other masses are enclosed in dunite. In the Bergen area eclogite occurs as segregations in anorthosite. The author has investigated the eclogites quantitatively in careful detail: by bulk chemical analyses; by determination of the mode, generally by mechanical separation of the constituents by means of Clerici's solution; and by chemical analyses of the component minerals and determination of their refractive indices and specific gravities. The garnets of the eclogites prove to be calcium-bearing members of the pyrope-almandite series, of rather wide range in composition. The purpose of this detailed investigation is to obtain fundamental data for what the author calls facies petrology (or heteromorphism, if that term is used in a somewhat more generalized sense than Lacroix has given it).

ADOLPH KNOPF.

7. *New Deposits of Radium in Africa.*—It is announced by the U. S. Geological Survey (Nov. 17) that important deposits of minerals carrying radium have recently been discovered at Luiwishi and Kasolo, near Elizabethville, in the extreme southern part of Belgian Kongo. The veins carry pitchblende, which is in large part altered to gummite, uranophane, and other uranium minerals. A subsidiary company has been formed to extract the radium, and a considerable quantity of ore carrying many times as much radium as the carnotite ores that have heretofore governed the world's markets has been shipped to Belgium. It is uncertain whether these deposits will eventually yield as much radium as the deposits in the plateau of the United States, though a considerable quantity can be produced from the Katanga deposits at a much lower cost. Hence the price of radium has now dropped from $120,000 per gram to $70,000.

8. *United States Geological Survey.*— Dr. Philip S. Smith was appointed, on November 1, acting director of the U. S. Geological Survey, succeeding Dr. George Otis Smith, who resigned to facilitate his work in connection with the Federal Coal Commission.

III. Miscellaneous Scientific Intelligence.

1. *National Academy of Sciences.*—The Autumn meeting of the National Academy was held in New York City from Nov. 14 to 16 in accordance with the plans announced in the preliminary program (see November number, pp. 422, 423). The attendance was large, sixty-four members being present, and the list of papers included some sixty-six titles. It was found of convenience to the members and the public to have these papers divided into three groups read at different points in the City as already planned.

Among the papers falling most closely in line with the general scope of this Journal were the following: An interesting illustrated paper on the Structure of the Jura Mountains in France read by E. de Margerie. Prof. J. C. Merriam discussed the recent evidence as to the age of the Sierra Nevada; the work on the subject had been done in part by R. W. Chancey and C. Stock; the conclusion reached was that the last mountain movement took place after the Pliocene. Prof. W. M. Davis gave new and interesting facts as to the drowned coral reefs of the Liu Kiu Islands of Japan. Dr. H. S. Washington described jade from Yucatan, also Mexico and Honduras. This was in part in the form of beads, also disks and other small objects. The petrographic study by Prof. Tozzer showed these to be in part pure diopside-jadeite (*tuxtlite*) while others contained feldspar (albite) often in large amount. The unexpected conclusion has been reached that these jadeitic rocks are American, not Asiatic, in origin, probable localities being in Guerrero or Oaxaca, Mexico and Costa Rica, or in both. The first habitation of man and of the giant land mammals of prehistoric time is indicated to have been on the Asiatic continent by results of the recent expedition to China and Mongolia of the American Museum of Natural History under Prof. Ray Chapman Andrews as described by Dr. W. D. Matthew.

The U. S. Navy's recently developed device for measuring ocean depths by the echoes from the sea bed of sounds sent from a transmitter on board ship was described by Dr. Harvey C. Hayes. "If we had measured ocean depths where the sinking of the ocean bed caused the Chilean earthquake, we could measure the spot now and perhaps learn something of value." The manufacture and use of electronic tubes for the transmission of high power were described by H. D. Arnold. Other speakers discussed the gyroscope's uses for stabilizing ocean steamers and airplanes, and the methods of carrying multiple telephone and telegraph messages on a single wire. Dr. C. G. Abbot described the spectrum energy curves of the stars.

2. *Nobel Prizes for 1921 and 1922.*—The physics prize for 1921 has been awarded to Professor Albert Einstein of Zurich; that for 1922 to Prof. Niels Bohr, Copenhagen. The chemistry prize for 1921 has been awarded to Professor Frederick Soddy of the University of Oxford: that for 1922 to Francis William Aston, research fellow of Trinity college, Cambridge.

OBITUARY.

MAJOR-GENERAL JAMES WATERHOUSE died on September 28 at the age of eighty years. His contributions to photography were most important and won for him recognition from many photographic societies in England and elsewhere.

WILLIAM HENRY WESLEY, the English astronomer and for forty-seven years assistant secretary of the Royal Astronomical Society, died on October 17 at the age of eighty-one years.

Professor CHARLES MICHIE SMITH, of the Christian College, Madras, and later Government Astronomer at Madras, died on September 27, at the age of sixty-eight years.

PROFESSOR LEV A. TCHUGAIEV, the eminent Russian chemist of the Petrograd University and also director of the Institute for the study of platinum, died on September 23 at the age of forty-nine years.

ROBERT WHEELER WILSON, emeritus professor of astronomy in Harvard University, died in Cambridge on November 1 in the seventieth year of his age.

DR. C. W. WAGGONER, head of the department of physics in West Virginia University, died recently at Shreveport, Louisiana.

INDEX TO VOLUME IV.*

---

*This Index contains the general heads, BOTANY, CHEMISTRY, GEOLOGY, MINERALS, OBITUARY, ROCKS, under each the title of Articles referring thereto are included.

The American Journal of Science

ESTABLISHED BY BENJAMIN SILLIMAN IN 1818.

THE LEADING SCIENTIFIC JOURNAL IN THE UNITED STATES.

Devoted to the Physical and Natural Sciences, with special reference to Physics and Chemistry on the one hand, and to Geology and Mineralogy on the other.

Editor: EDWARD S. DANA.

Associate Editors: Professors WILLIAM M. DAVIS and REGINALD A. DALY, of Cambridge; Professors H. L. WELLS, C. SCHUCHERT, H. E. GREGORY, W. R. COE and F. E. BEACH, of New Haven; Professor EDWARD W. BERRY, of Baltimore; Drs. FREDERICK L. RANSOME and WILLIAM BOWIE, of Washington.

Two volumes annually, in **MONTHLY NUMBERS** of about 80 pages each.

This Journal ended its *first* series of 50 volumes as a quarterly in 1845; its *second* series of 50 volumes as a two-monthly in 1870; its *third* series as a monthly ended December, 1895. A FIFTH SERIES commenced in 1921.

CONTRIBUTORS are requested to revise their manuscript with special care with reference to the use of the linotype machine; changes involving overrunning are expensive. In general, the publisher cannot undertake to assume the cost of more than minor corrections in the proof. All corrections should preferably be made in ink.

Foot notes should be numbered consecutively from 1 up.

The following is an example of the system of references employed, the volume being given in heavy faced type:

Am. J. Sci., **44,** 249, 1917. The year should be given in every case; this renders a series number unessential.

Thirty separate copies of each article will be furnished to the author free of cost and without previous notice from him. They will be provided with a plain cover (but with reference to volume and year). If the author orders separate copies, they will be understood to be in *addition* to the thirty mentioned above, and he will receive a bill for the extra expense involved, as also for that of a printed cover (with title, etc.), when this is *specially ordered.* These charges will be as moderate as possible; the rates will be increased if the article is accompanied by plates, or involves unusual expense.

Subscription price $6 per year, or 50 cents a number, postage prepaid in the United States; $6.25 to Canada; $6.40 to foreign subscribers of countries in the Postal Union. A few sets on sale of the early series. *Ten-volume index numbers* on hand for the second, third and fourth series.

☞ Ten-volume Index, Vols XL–L, Fourth Series, price two dollars each.

Address,

THE AMERICAN JOURNAL OF SCIENCE,
New Haven, Conn.

FINE MINERAL SPECIMENS

CRYSTALLIZED GOLD.

Beautifully crystallized specimens from Transylvania.

Crystals, individuals or in delicate fern-like groups; ¾ x 1½ x 2 inches, $3.50; 1 x 2 x 2 inches, $4.00; ½ x 2 x 2½ inches, $6 00; 1 x 2 x 3 inches, fine crystals, $10.00.

Leaf Gold, 1 x 1 x 1¾ inches, $3.00; ½ x 2 x 2 inches, $3.00; ¾ x 2 x 2 inches, $3.50; 2 x 2 x 3 inches, $15.00.

Wire Gold, 1 x 1½ x 3 inches, $6.00; 1 x 2 x 2 inches, $4.00.

ORTHOCLASE.

Transparent golden yellow cleavages from Madagascar; uncut material priced at 15 cents per gram, as follows: specimen ½ x ½ x 1 inch, $1.50; ¾ x ¾ x 1½ inches, $2.75; 1¼ x 1¾ x 2 inches, $13.20; cut stones priced at $3.00 per carat, ranging from small brilliant at $1.80 to a very large one with exceptionally deep topaz color weighing 34.5 carats, priced at $103.50.

WERNERITE.

Transparent yellow crystal fragments from Madagascar; uncut stones priced at $1.00 per gram, as follows: specimen ¼ x ⅜ inches, 10 cents; ½ x ¾ x 1 inch, $6.00; ¾ x ¾ x ¾ inch, $6.75; ⅝ x ¾ x 1⅛ inches, $11 50; cut stones of wonderful beauty at $4.00 to $6.00 per carat, ranging from .74 carat stone at $2.96 to one of 6.35 carats at $38.10.

ZIRCON.

Small blue transparent crystals, waterworn, from Australia; ¼ x ¼ x ⅜ inch, $2.00; ⅜ x ⅜ x 1 inch, $10.00; ½ x ¾ x 1 inch, $15.00; cut gems (brilliant cut), priced at $8.00 to $14.00 per carat; stones of all sizes, from $2.00 to $60.00.

KRANTZ CRYSTAL MODELS

Crystal Models manufactured by Dr. F. Krantz, of Bonn, Germany, made of Pear-wood, glass or metal, are being imported by us for our customers as usual. The models may be imported free of duty for educational institutions which furnish free entry oath at our request. Duty on all these materials has been raised considerably by the revised tariff schedule.

WARD'S NATURAL SCIENCE ESTABLISHMENT

DEPARTMENT OF MINERALOGY AND PETROGRAPHY

Alfred C. Hawkins, Ph.D., *Manager*

84 College Avenue, Rochester, New York

CONTENTS.

SCIENTIFIC INTELLIGENCE.