THE

AMERICAN

JOURNAL OF SCIENCE.

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FOURTH SERIES

VOL. XXIX—[WHOLE NUMBER, CLXXIX.]

WITH FIVE PLATES.

NEW HAVEN, CONNECTICUT.

1910.

CONTENTS TO VOLUME XXIX.

Number 169.

SCIENTIFIC INTELLIGENCE.

Number 170.

SCIENTIFIC INTELLIGENCE.

Number 171.

SCIENTIFIC INTELLIGENCE.

Number 172.

SCIENTIFIC INTELLIGENCE.

Chemistry and Physics—Detection of Sodium, Cæsium, and Rubidium, W. C. BALL, 360.—Volumetric Determination of Sulphates, MITCHELL and SMITH: Action of Metals on Fused Caustic Soda, LEBLANC and BERGMANN, 361.—Transformation of Diamond into Graphite, VOGEL and TAMMANN : The Johns Hopkins University Circular, No. 2 : Meteorologische Optik, F. M. EXNER, 362.

Geology and Mineralogy—Publications of the U. S. Geological Survey, G. O. SMITH, 363.—Geological Survey Canada, Department of Mines, R. W. BROCK, 365.—Kilauea and Mauna Loa, Hawaiian Volcanoes, W. T. BRIGHAM : Deviations from the Normal Order of Crystallization in Granite, MACKIE, 366.—New Occurrence of Lujavrite : Mercury Minerals from Terlingua, Texas, HILLEBRAND and SCHALLER, 367.—The Rochester Collection of Meteorites ; Descriptive List of Specimens, K. S. HOWARD : A new Meteorite from Georgia, G. P. MERRILL, 368.

Miscellaneous Scientific Intelligence.—Carnegie Institution of Washington : Publications of the Allegheny Observatory of the University of Pittsburgh, 368.

Number 173.

SCIENTIFIC INTELLIGENCE.

Number 174.

SCIENTIFIC INTELLIGENCE.

Established by **BENJAMIN SILLIMAN** in 1818.

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No. 169—JANUARY, 1910.

NEW HAVEN, CONNECTICUT.

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Announcement of New Arrivals.

Iceland Minerals.

I have just received after considerable delay a new lot of Iceland Zeolites consisting of one hundred specimens. The species represented are Heuland-ite, Stilbite, Epistilbite, Scolecite, Ptilolite and Quartz geodes in both Museum and cabinet size specimens, which I have priced at far below former values placed on these choice trap rock minerals. Their beauty, brilliancy and the quality of the crystals is finer than any former lot brought to this country.

Minerals from Franklin Furnace, N. J.

I have also been fortunate in obtaining a very old collection from a gentle-man who specialized in Franklin Furnace minerals and which contains many duplicates of finely crystallized specimens. For instance, several of the ex-tremely rare crystallized Zincites as well as Franklinites, Rhodonites, Troost-ites in very large crystals; also Gahnite, Tourmaline, Calamine, Garnet and Spinel. An exceptional lot of choice Phlogopite in Calcite of the largest size found.

Minerals from Colorado.

Recent additions to my large stock of the desirable Cripple Creek Tellur-ides include specimens of the very best quality obtainable. such as Tellu-rium, Sylvanite, Calaverite, Gold, etc. With these came Amethyst in parallel growth of exquisite quality and a crystallized Calciovolborthite and Carno-tite from Telluride, Col.

Minerals from New Mexico.

A number of Vanadinites have been received from New Mexico, which show crystals distributed over Barite matrix forming desirable specimens of beautiful contrast. Also a number of fine native Silvers from the same locality.

Desirable and timely gifts for Christmas of cut gems, gem crystals, antique cameos, opal carvings, with semi-precious stones cut and polished and adapt-able for mounting in pins, brooches, etc.

The large stock carried places me in the best position to cater to the many requirements of my patrons for either minerals, rare or common gems, as well as the highest quality of reconstructed Rubies, Sapphires, blue or white, and the beautiful new pink Topaz.

I would be pleased to send on approval for inspection and selection any-thing that would interest my patrons.

Information as to special lists and prices of individual specimens cheer-fully furnished.

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THE

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[FOURTH SERIES.]

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Art. I.—*Dinosaurian Distribution;* by Richard S. Lull.

[Contribution from the Paleontological Laboratory, Peabody Museum, Yale University.]

Dinosaurian Distribution.

I. Introductory.

The significance of terrestrial vertebrates of bygone days as aids to geological interpretation, and especially in throwing light upon the isolation and connection of continents, is becoming more and more appreciated.

The dinosaurs, with their known geological range throughout nearly the entire Mesozoic period, and of almost worldwide distribution, are the most significant vertebrates of Secondary times. Add to this their great numbers both of individuals and kinds and the amazing range in their adaptations and one can appreciate the importance of the line of research of which this paper is the first fruit. It constitutes the further elaboration of a presidential address delivered before the American Society of Vertebrate Paleontologists at Baltimore, December, 1908.

As such a work is of necessity to a certain extent a compilation, I can but express my indebtedness to the various authors listed in the Bibliography, of whom my confrère, Professor v. Huene, is the one to whom I owe the most. I am also

grateful to my colleagues Professors Schuchert and Barrell for helpful criticisms and suggestions.

II. Classification.

The dinosaurs, because of their great adaptive radiation throughout their long career, seem to be a very heterogeneous group, so much so that Baur (1891) emphatically denied any relationship on the part of the several orders which are included within the group.

They exhibit two distinct lines of cleavage, dividing the super-order into three orders, of which two, the carnivorous, bipedal Theropoda and the herbivorous, quadrupedal Sauropoda, may be grouped together, in spite of great adaptive differences; while the herbivorous, bipedal or quadrupedal Orthopoda stand more aloof and show a vastly greater range of intra-ordinal variation. To the first two orders collectively the name Saurischia has been given by Seeley (1888), while the Orthopoda have been designated by the corresponding title of Ornithischia.

A further differentiation of the Theropoda points to two distinct races. The heavier megalosaurs, typified by *Megalosaurus* of Europe, *Allosaurus* of the American Morrison, and culminating in the huge *Tyrannosaurus* of the Laramie, were the more conservative group, the evolution of which consists mainly in an increase in size, accompanying a relative diminution of the fore limbs, which were never used for locomotion, and an assumption of the prehensile function by hind feet and mouth armament as in birds of prey.

The other carnivores, the compsognathoid forms, were of an aberrant nature, not increasing so markedly in size; but of a more agile character, better fitted to prey upon feebler reptiles, birds and mammals than upon other dinosaurs. Typical members of this sub-order are *Compsognathus* from the lithographic stone of Bavaria and *Ornitholestes* of the American Morrison beds.

The Sauropoda appear and disappear with startling suddenness in the northern hemisphere, though lingering in the southern until the close of the Mesozoic. During this time they undergo but little evolution, and that mainly in the line of a marvelous adaptation for lightness coupled with great strength, especially in the elongated vertebral column. Perhaps the best-known representatives of this group are *Apatosaurus* (*Brontosaurus*), a huge, unwieldly beast, and *Diplodocus*, a lighter, more slender form; both from the Morrison of Wyoming and Colorado. It is a significant fact that the most generalized (*Haplocanthosaurus*) and the most specialized

(*Diplodocus*) among sauropods occur in the same quarry and were therefore contemporaneous. (Hatcher 1903, p. 57).

Of the plant-feeding Orthopoda there are three main types, which have differentiated from the original stock ; one, the unarmored Ornithopoda, paralleling the carnivores in general bodily contour and bipedal gait, though bringing the fore feet to the ground when occasion demanded. Like the carnivores they too included a greater and a lesser race. The former, like *Iguanodon* of the Wealden of Europe and *Camptosaurus* of the American Morrison, culminated in *Trachodon* of the late Cretaceous ; while the latter are represented by the fleet *Laosaurus* of North America and *Hypsilophodon* of Europe.

On the other hand, two groups of armored, secondarily quadrupedal dinosaurs arose, possibly derived from the same branch of the Orthopoda, possibly of independent origin. These were the Stegosauria, the defensive sort with small head and heavy body armor sometimes forming, over part of the body at least, a veritable cuirass or carapace ; and the more aggressive Ceratopsia with huge armored skull, but, so far as our knowledge goes, bereft of any special body mail. The first are represented by the British *Polacanthus* and the American *Stegosaurus*, while the last have a splendid representation in that most grotesque of dinosaurs, *Triceratops* from the American Laramie.

V. Huene (1907–1908, p. 351) derives the Sauropoda from the early Theropod dinosaurs of the Trias, seeing in the genus *Plateosaurus* the annectant type. In his scheme of relationships (v. Huene 1909, p. 22), however, he seems to defer the divergence of the Sauropoda from the Plateosauridæ until the Lias, which would hardly give time for the profound change shown by either *Cetiosaurus* or *Dystrophæus* of the Dogger. It is my impression that the divergence occurred earlier in Triassic time.

Of annectant forms, linking the Theropoda and Orthopoda, none is suggested by v. Huene among known types, as our known record of the latter does not go back far enough in time. Of the Stegosauria, *Scelidosaurus* of the English Lias seems to be the most primitive as it surely is the oldest ; it is, however, still removed from the Ornithopoda and a common ancestor must again be sought in more remote strata.

The Ceratopsia may have their earliest representative in *Stenopelix* of the Wealden of Brückeburg. V. Huene (1907–1908, p. 374) has shown strong points of resemblance between the pelvis of *Stenopelix* and that of *Triceratops*. Whether, as he suggests, one can derive the phylum from the Scelidosauridan stem, or whether the group represents an independent offshoot from the Orthopod stock, is not quite clear.

These relationships are expressed in the table (figure 1), which is largely compiled from lesser ones by v. Huene (1907–1908, pp. 340, 375, 377; 1909, p. 22).

III.   Habitats and Adaptations.

In order to comprehend the remarkable geographical distribution of the dinosaurs, it is necessary to investigate the character of their various habitats, the conditions they were forced to meet and the marvelous degree of adaptation to the environment which they underwent.

I imagine the conditions which gave to the dinosaurs their initial evolutionary trend were such as are thought to have prevailed, beginning in the Permian, throughout Triassic time.   This is well shown in the region now known as the Connecticut valley.   The older notion of the estuarine origin of these deposits has been abandoned in favor of the idea that they were of terrestrial origin, the climatic conditions being those of semi-aridity with areas here and there which were subject to inundations occurring in times of torrential rains such as are observed to-day under similar climatic conditions in different portions of our globe.   This lends color to the view that the early dinosaurs were truly terrestrial types, with marked cursorial adaptation, indicated in the free, bipedal stride and compact, bird-like foot which is shown by the fossil footprints.

V. Huene (1907–1909, pp. 396–401) derives the Theropoda and Parasuchia from one stem, the supposition being that the distinguishing characteristics were developed during the oldest Trias through adaptation.   Increasing aridity of climate would render it necessary for an animal to go farther afield for water and possibly for food and thereby place a premium on good powers of locomotion, so that selection would be very active in weeding out the unfit or inadaptable lines.   This locomotor adaptation in the quadrupedal stage is beautifully shown in the Parasuchian genus *Stegomus* (Lull 1904 B, pp. 147–148) from the Connecticut valley Trias (Rhætic), evidently a persistent type which, possibly because of the retention of armor, remained a quadruped though long of limb and with the greater portion of the weight borne on the hinder extremities. *Stegomus*, I imagine, though belonging, morphologically, to a very different race, represents a stage in the adaptation of the dinosaurs which was reached early in the Trias.

Many modern lizards are amazingly swift of movement, but their journeys are brief and the rapidly moving types are small.   It is a well known fact that a number of lizards, notably *Chlamydosaurus*, when startled, rise on the hinder limbs

and run with a truly bipedal gait (Sayville-Kent 1898, p. 341). It is significant that the bipedal lizards, so far as my knowledge goes, are all found in semi-arid climates—Australia, Southwestern United States. This tendency toward bipedalism, with a consequent profound alteration of the hind limbs and pelvis, both in bone and musculature, seems therefore to have developed to meet the need of greater range of movement necessitated by increasing aridity, and was the prime factor in the early evolution of the dinosaurian race.

So strongly was this feature impressed, that the main lines of dinosaurian evolution, whether plant or animal feeders, were cursorial, terrestrial types, though, as new conditions arose, or were met with during their forced migrations, aberrant types of marvelous complexity and range of specialization developed. These aberrant forms, from the fact that their remains were more readily preserved, are the ones best known to us and have colored our whole conception of the dinosaurian race.

When the plant-feeding Orthopoda arose we do not know. *Nanosaurus* (v. Huene and Lull 1908) is known from the upper Trias (or lower Jurassic) of Colorado, while in the possibly contemporaneons beds of the Connecticut valley there have been found many footprints which Lull (1904 A, pp. 499–509) has shown to belong to plant-feeding types of general proportions not unlike those of their theropod allies, but differing mainly in the feebly prehensile character of the little, blunt-toed manus, the imprint of which is sometimes seen. The Theropoda, on the other hand, had a strong, grasping hallux, as a rule rotated to the rear of the foot so as to be in opposition to the other toes, and a manus with powerful claws, which had already sacrificed fully the function of locomotion to that of prehension. The Orthopoda could give rise to secondarily quadrupedal (Dollo 1905) forms, the Stegosauria, the Ceratopsia; the Theropoda, on the other hand, had cast the die in favor of absolute bipedalism and stalked on upon the hind limbs to the end of their career.

While both small and large forms prevailed at the close of the Trias, the differentiation, if we except the character of the pubis, is largely owing to opposite habits, acquired apparently in the remote Trias, very early in the dinosaurian evolution.

The carnivores, as has been said, are relatively conservative in their evolution, except for the differentiation into the greater megalosauroid forms and the lesser compsognathoid types. The Theropoda were evidently the most mobile of all dinosaurs, free to migrate wherever other creatures lived which could possibly be utilized for prey, for not only do we find them the world over, with the exception of Asia (vide

infra p. 31) north of India, but practically wherever dinosaurs of whatever sort are found.

The Sauropoda.

During the Triassic, the carnivores had spread to other conditions and had given rise to a new order, the Sauropoda, no longer truly terrestrial, but inhabiting the bayous and swamps of the numerous deltas which fringed the continental shores. This change of habitat was far-reaching in its effects, for rapid locomotion was no longer necessary and a certain degeneracy resulted—whether the carnivorous ancestors had attained bipedalism or whether the Sauropoda were primitively quadrupedal I cannot say. Increase in size was accompanied by an elongation of the neck to get a greater range of feeding with as little bodily movement as possible and it necessitated as well a diametric change in diet, for with increasing bulk, no longer finding the animal food of their forbears adequate or readily obtainable, they took to an herbivorous feeding habit which required but little change in the mouth armament.

The modern Iguanidæ show a certain parallelism with the Sauropoda, for while the primitive diet is carnivorous (insectivorous) "some of the most striking forms are herbivorous, e. g. *Iguana, Amblyrhynchus,* and *Basiliscus.*" (Gadow 1908, pp. 528, 533.) Moreover, one finds within the family not only semi-aquatic adaptation, but even semi-marine. The last is shown by *Amblyrhynchus cristatus,* which "inhabits the rocky and sandy strips of coast of most of the Galapagos Islands, feeding on certain kinds of algae, which it has to dive for, since these plants grow below tide-marks."

The precise food of the Sauropoda is a matter of doubt. Dr. Hay (1908, p. 674), in discussing that of *Diplodocus,* the most highly specialized member of the order, sums up the expressions of opinion as follows : " Hatcher suggested that the teeth might have been useful in detaching from the bottoms and shores the succulent aquatic and semi-aquatic plants that must have grown there in abundance. Osborn [1889, p. 214] says that the ' food probably consisted of some very large and nutritious species of water plant. The anterior claws may have been used in uprooting such plants * * * The plants may have been drawn down the throat in large quantities without mastication.' * * * Holland [1906, p. 240] thinks that the teeth were better adapted for raking and tearing off from the rocks soft masses of clinging algæ than for securing any other forms of vegetable food now represented in the waters of the world.

"To the present writer [Hay] the suggestion of Dr. Holland has in it more of probability than any of the others presented. If the food-plants sought by *Diplodocus* had been large and such as required uprooting by the great claws of the reptile, the prehension and manipulation of the masses would have been liable to break the slender teeth and would certainly have produced on them perceptible wear.   * * *

"It is more probable that the food consisted of floating algae than of plants that were loosely attached to the bottoms of stagnant bayous and ponds. . . . In addition to various algae were probably other floating plants."

The teeth of the Sauropoda, notably *Morosaurus* and *Apto-saurus* (*Brontosaurus*), are much more robust and frequently show decided wear. This wear, however, is along the edges on either side of and sometimes including the apex; which could readily be accounted for by abrasion of the alternating teeth of the opposing jaw and which could not be due to scraping of vegetation from the rocks. The food of these animals may have been more in keeping with the character of that mentioned by Osborn.

It is interesting to note in this connection, à propos of the question of the digestibility of huge masses of unmasticated vegetation, the occurrence of "stomach stones" or "gastroliths" (Wieland 1906) which seem to have had an important function in aiding in the trituration of the food. Wieland records the occurrence of such polished flint pebbles in immediate association with the remains of a large sauropod observed at the northern end of the Big Horn Mountains. Pebbles, presumably gastroliths, were also found by Wieland with the type of the Sauropod genus *Barosaurus* from near Piedmont, South Dakota.

Dr. Hay (loc. cit., p. 673–674) further says: "Hatcher has discussed at length the nature of the region in which the species of *Diplodocus* and their allies lived, as well as the habits of the Sauropoda in general; and the present writer [Hay] agrees with him on most points. Hatcher believed that the Atlantosaurus [Morrison] beds were deposited, not in an immense freshwater lake, as held by some geologists, but over a comparatively low and level plain which was occupied by perhaps small lakes connected by an interlacing system of river channels. The climate was warm and the region was overspread by luxuriant forests and broad savannas. The area thus occupied included large parts of the present states of Colorado, New Mexico, Utah, Montana and the Dakotas. In his memoir on *Diplodocus* Hatcher compares the conditions prevailing in that region during the Upper Jurassic [Lower Cretaceous] to those now found about the

mouth of the Amazon and over some of the more elevated plains of Western Brazil.

"In such regions the rivers, fed from distant elevated lands, must have been subject to frequent inundations. The beds of the streams were continually shifting, and there existed numerous abandoned channels that were filled with stagnant water. An animal that lived in such a region would be compelled to adapt itself to a more or less aquatic life, and this adaptation would be reflected to a greater or less extent in the structure of the animal."

Through the courtesy of Dr. Holland, I have been able to study somewhat critically an undoubted sauropod footprint from the Morrison dinosaur quarry at Cañon City, Colorado. Hatcher figures a cast of this track in his memoir on the osteology of *Haplocanthosaurus* (1903, fig. 23, p. 161). The figure is somewhat deceptive, however, in that it was taken from a plaster cast of the specimen which in turn is a natural cast of the original impression made by the living animal and which is therefore in relief. The surface of the specimen itself is covered with deep pits caused by a solution of the calcareous cement which bound the grains of sand together, thus allowing the latter to be washed out. In the photograph the casts of these pits, being in relief, give the impression of pebbles, whereas the rock in the quarry is a fine-grained, cross-bedded sandstone of uniform texture, without appreciable clay, and not gravelly at all. A microscopic study of the sand-grains themselves show them to be angular with slightly abraded corners, sand of aqueous deposit; but apparently laid down in a lake or bayou, rather than in a normal river as indicated by the absence of clay and the presence of a lime cement. The cross-bedding which the rock exhibits could readily have been made by wave action along the shores of a comparatively shallow delta-lake or bay, and the track, which is that of a very young animal, was evidently made under water. The character of the sediment does not give evidence of much vegetable matter at the particular point where the track was made. The footprint is that which one would expect from the known character of the sauropod foot, and is evenly impressed throughout as though the animal's weight were borne equally over the entire sole, evidence in favor of a true walk rather than a sprawling crawl, at any rate when the body was partly water-borne.

I believe these animals to have been truly aquatic though capable of coming ashore where the substratum was sufficiently firm to support the immense weight, and, while they show no trace of swimming appendages, they doubtless could swim as a hippopotamus does or, as Hay (1908, p. 667) has implied, like a

colubrid snake "which makes fair progress in the water, not-withstanding the absence both of a compressed tail and of a vertical fin."

The Wealden formation of England is thus described by Geikie (1903, pp. 1180–1181). "The Purbeck beds bring before us evidence of a great change in the geography of England towards the close of the Jurassic period. They show how the floor of the sea, in which the thick and varied formations of that period were deposited, came to be gradually elevated, and how into pools of fresh and brackish water the land leaves, insects, and small marsupials of the adjacent land were washed down. These evidences of terrestrial conditions are followed in the same region by a vast delta formation, that of the Weald, which accumulated over the south of England, while the marine strata were being deposited in the north. Hence two types of Lower Cretaceous sedimentation occur, one where the strata are fluviatile (Wealden), and the other where they are marine (Neocomian)."

In Wyoming the Morrison beds lie directly upon the marine Baptanodon beds of Marsh in which Belemnites abound. Lying between this and the main dinosaur-bearing layer are about 156 feet (Loomis 1901, pp. 192–193) of variegated sandstones and clays, of which bed No. 13, $82\frac{1}{2}$ feet above that which contains *Baptanodon* itself, seems to represent the first of the freshwater (or brackish) series, as it contains an abandoned dinosaur quarry in Como Bluff. This would seem to indicate that in the Morrison, conditions very similar to that of the Wealden prevailed and that in each instance access to the sea on the part of the sauropod inhabitants was not only possible but actually probable, as the littoral realm seems to have been the highway of immigration of this order of dinosaurs.

The Morrison beds, lying as they do in a great synclinal trough, and at the time of their deposition but little above sea level, probably were drained, in the southern portion at least, into the sea, which lay some two hundred and fifty miles (Schuchert 1909, Late Upper Jurassic Chart) to the southward. This drainage outlet because of its very low gradient may again have given conditions similar to those of the Amazon (vide supra p. 8), so that the passage of the Sauropoda across the area included in the present state of New Mexico would appear to have been perfectly feasible. Evidence which may be corroborative is found in Madagascar, in a locality east of the bay of Narinda, wherein were discovered the remains of *Titanosaurus* in a matrix containing the marine *Mytilus madagascarensis* and foraminifera (Boule 1896, p. 348).

Orthopoda.

The Orthopod dinosaurs were adapted to a very different kind of food from that of the Sauropoda, developing in the course of their evolution a more and more perfect dental mechanism for chopping into short lengths the relatively firm terrestrial vegetation. The toothless anterior part of the mouth was sheathed in a leathery or horny beak which reached its highest perfection in the Ceratopsia and which constituted the prehensile, while the teeth, borne in the posterior portion of the jaws, formed the masticatory part of the mouth ; best developed in the Ceratopsia (Hatcher 1907, pp. 43–46) on the one hand and the Trachodontidæ (Brown 1908, pp. 52–53) on the other.

The Sauropoda and Theropoda had only prehensile teeth and did not masticate their food at all. This shows quite clearly that, so far as feeding habits go, none of the three great groups of dinosaurs came into competition with each other, except that the carnivores did occasionally devour the others, and that, in so far as the Sauropoda and Orthopoda were concerned, the habitat was necessarily different ; the latter being in the main terrestrial, the former amphibious. In no other way can we account for the marked differences in distribution of the two orders which, reduced to its final analysis, has gone so far that the two groups are rarely found in the same quarry even within the same region and geological formation. For example, " Quarry 13 " (Gilmore, 1909, p. 299) in Como Bluff, Wyoming, from which several of Professor Marsh's more important type specimens came, contains almost entirely the remains of Orthopoda, *Camptosaurus, Dryosaurus, Stegosaurus ;* of Carnivores, *Allosaurus* and *Cœlurus,* while but a single Sauropod, the type of *Morosaurus lentus,* an extremely young individual, was found in association. On the other hand, the famous Bone Cabin Quarry, situated but a few miles distant, had yielded up to 1904 (Osborn, 1904, p. 694) sauropods, 44 ; stegosaurs, 3 ; smaller herbivorous dinosaurs, 4 ; large carnivorous dinosaurs, 6 ; small carnivorous dinosaurs, 3 ; showing the Sauropoda to be vastly more numerous than the other plant-feeding varieties, and evidently implying a distinct habitat from that represented by " Quarry 13."

Within the Orthopoda the marked differentiation into Ornithopoda, or unarmored types, and the Stegosauria and Ceratopsia, or armored forms, seems to have been due to their different modes of defence, presumably against the omnipresent carnivores, though the existence of enemies other than dinosaurs, such as the crocodile *Goniopholis,* is not unlikely. The Ornithopoda, which were the most conservative in their evolu-

tion among the Orthopoda, retained the cursorial character of their ancestry, relying evidently upon celerity and speed rather than upon weapons or armor for defence against their sanguinary foes. The ideal of this type of dinosaur was perhaps *Laosaurus* of North American Morrison and its old world representative *Hypsilophodon* of the English Wealden. Later *Trachodon*, and probably its ancestor *Claosaurus*, the remains of which are found repeatedly in marine rocks, became in their turn semi-aquatic, possibly in their search for food because of competition with the great armored forms. They did not, however, rely on increasing bulk for immunity against attack as did the Sauropoda; but, by means of a powerful, laterally compressed swimming tail may have been as active as crocodiles in the water while still retaining a means of comparatively rapid locomotion on land. The defencelessness of these creatures, so far as armor is concerned, has been beautifully shown in the "mummified" specimen of *Trachodon*, discovered in 1908 by C. H. Sternberg, in Converse County, Wyoming, and now preserved in the American Museum of Natural History. Professor Osborn (1909, pp. 793–795) says of it: "The first and most surprising impression is that the epidermis is extremely thin, and that the markings are excessively fine and delicate for an animal of such large dimensions. There is no evidence in any part of the epidermis either of coarse tubercles or of overlapping scales. In all parts of the body observed it is entirely composed of scales of two kinds: (1) larger pavement or non-imbricating scales, (2) smaller tubercular scales." Osborn speaks not only of the "vigorous use of the tail as a balancing, and perhaps partly as a swimming organ," but also tells us that the "manus is completely encased in the integument, and was thus web-footed." Evidence for aquatic or semi-aquatic life.

The armored dinosaurs make their first appearance in *Scelidosaurus* of the English Lias, the possible ancestor of all of the subsequent mailed types. The earliest forms were probably bipedal, but, as time went on, and the armor increased in bulk and weight, we find these dinosaurs becoming secondarily quadrupedal (Dollo 1905), losing all celerity of movement and becoming sluggish, slow moving, living citadels of well-nigh impregnable character. In habitat they were doubtless terrestrial, as in the case of the earlier Ornithopoda with which their remains are found associated. A curious differentiation of armored dinosaurs occurred, correlated with a marked difference in the mode of defence, in that the more aggressive, mentally alert Ceratopsia used the head both for offence and defence, while the stegosaurs seem to have used the tail. *Stegosaurus* proper, which developed to an extreme this method

of defence as well as a remarkable body armament of huge probably upstanding plates, became too highly specialized to survive and apparently died out early in the Lower Cretaceous. Its allies, however, still lived on until the close of the Mesozoic, developing over the rear of the body in *Polacanthus* of the English Wealden, and later in *Ankylosaurus* of the Laramie, a veritable cuirass, glyptodon-like in its perfection, covering what seemed to be the most vulnerable portion of the body.

That the Ceratopsia were aggressive fighters among themselves, as the cattle are to-day, is known from the frequent punctures of skull and frill, broken horn-cores, and such sanguinary evidences. That they held their own against the terrible carnivores of their time is shown by their survival until the close of dinosaurian history.

The environment of the Cretaceous Orthopod dinosaurs and of the attendant carnivores is described by Stanton (1909, pp. 280–282) as consisting of great areas but slightly elevated above the level of the sea and occasionally actually beneath it, wherein are found fresh-water, brackish water, or marine deposits. Upon these great marshes vegetation became established, and land animals, and those of the streams and lagoons as well as the bays and estuaries, sought their appropriate habitats.

In speaking of the conditions prevailing toward the close of the Cretaceous, Hatcher (1893, p. 142; Hatcher, Marsh, Lull 1907, p. 194) says: "The Ceratops beds are thought to afford evidence in themselves of having been deposited not in a great open lake, but in a vast swamp with occasional stretches of open waters, the whole presenting an appearance similar to that which now exists in the interior of the Everglades of Florida. This condition would account for the frequent changes from one material to another in the same horizon.* * *

"The conditions that prevailed over this region during the period in which the Ceratops beds were deposited were probably those of a great swamp with numerous small open bodies of water connected by a network of water courses constantly changing their channels. The intervening spaces were but slightly elevated above the water level or at times submerged. The entire region where the waters were not too deep was covered by an abundant vegetation, and inhabited by the huge dinosaurs (*Triceratops*, *Torosaurus*, *Claosaurus*, etc.), as well as by the smaller crocodiles and turtles and the diminutive mammals, all of whose remains are now found embedded in the deposits."

For the terrestrial Orthopoda, such as *Camptosaurus* and *Iguanodon*, the cycads and ferns which grew in such profusion during their time would supply ample nourishment. *Stegosau-*

rus, however, has relatively feeble teeth, and must have fed upon the most succulent of terrestrial plants. The Ceratopsia, living as they did toward the close of the Upper Cretaceous, were surrounded by a virtually modernized flora, and hence may have had feeding habits very similar to those of the sub-tropical browsing ungulates of to-day.

Trachodon, however, presents more of a problem on account of its undoubted aquatic habits. Here the anterior, toothless part of the mouth in the most highly specialized types became broadened and depressed into a duck-like form, and, while undoubtedly sheathed with a horny or leathery integument, probably did not have the shearing mechanism so perfectly developed as in the true terrestrial plant-feeders. On the other hand, the dental battery reaches its greatest perfection in *Trachodon,* consisting as it does of "from 45 to 60 vertical and from 10 to 14 horizontal rows of teeth, so that there were more than 2,000 teeth altogether in both jaws." (Brown, 1908, p. 53.) The immense number, especially of those in reserve, implies a very rapid wear and consequent replacement of the teeth ; which, together with the sharp, serrated, shearing edge which the collective teeth of a jaw present, argues strongly in favor of the idea as expressed by Brown (loc. cit., p. 55) that some species of Equesetæ, the remains of which are the most abundant among the plant relics entombed with these dinosaurs, supplied them with food. The broad duck-like muzzle would be admirable for dislodging the rhizomes from their resting place, while the abundance of silica in the cuticle of the plant would necessitate just such a dental battery as the Trachodonts possessed for its proper mastication.

IV. Geological Distribution.

Both geologically and geographically the dinosaurs show a peculiar discontinuous distribution, due in large measure to the imperfection of our records, but also to the fact that they were principally terrestrial types and that the preservation of their remains in water-laid rocks is largely the result of accident.

Theropoda.

Geologically the Theropoda have the greatest range, as they are first found in the Lower Muschelkalk of Europe and continue on until the end of the Mesozoic.

Triassic.

Of the Triassic forms, a very complete series is found in central Europe, of which one of the most primitive genera is *Thecodontosaurus,* which also had the widest distribution both geographically and in time (see fig 2). From the *Thecodonto-*

saurus stem are derived, as side lines, the Newark dinosaurs *Anchisaurus* and *Ammosaurus* of the Connecticut valley; while the first known of these, *Megadactylus polyzelus* from Springfield, Massachusetts, v. Huene (1906, pp. 115–118) refers to the genus *Thecodontosaurus* itself. *Tanystrophœus*, ancestral to the delicate, hollow-boned Cœluridæ, begins also in the Muschelkalk, and while differing widely from *Thecodontosaurus*, its successor *Cœlophysis*, from beds in Colorado equivalent to the Upper Keuper of Europe, converges again toward the Thecodontoid phylum, so that the later representatives, *Cœlurus* on the one hand and the Compsognathoid forms on the other, are closely approximated.

In the Lower Keuper a new genus, *Zanclodon*, appears in Europe, of greater size than its contemporaries, and from which v. Huene (1909, p. 20) would derive *Ceratosaurus* of the Morrison with no annectant forms. There are, however, among the Connecticut valley footprints (Rhætic), besides numerous ones referable to the Thecodontoid types (*Anchisauripus* Lull—1904, p. 468), those of a large carnivore with powerful anterior claws but with a relatively feeble hallux. This track which Hitchcock called *Gigandipus* (Lull, loc. cit., p. 492) because of its great size, may well have been made by a member of the Zanclodon phylum, the bones of which are as yet unknown in these deposits.

The Middle Keuper ushers in another genus in the form of *Teratosaurus;* giving rise, in the Rhætic, according to v. Huene, to two main branches, from one of which arose, through *Gressylosaurus* and *Euskelosaurus*, the great Megalosaurian line, the other giving rise, through *Plateosaurus*, to the Sauropoda. This seems to me, however, to place the divergence of the Sauropoda somewhat too late in time; to the implied phylogeny I take no exception.

The Connecticut valley forms, which had reached great profusion, to judge from the abundance and variety of their footprints, are contemporaneous with the European Rhætic. Footprints apparently of equivalent age and character are found in New Mexico as well.

The lower Keuper beds contain *Thecodontosaurus* and possibly *Massospondylus* in India (Lydekker 1890, p. 22), while the Upper Keuper entombed the former genus in Australia.

The Upper Karoo beds of Africa, referred by v. Huene to the Rhætic and by Broom (1907, p. 161) to the Lower Jura (Stormberg Beds), contain *Thecodontosaurus*, *Euskelosaurus* and *Massospondylus*, all Triassic types.

Jurassic.

During Jurassic time the record is confined practically to England and the adjacent parts of France until the ushering in of the North American Morrison and Potomac toward its close.

While several species of carnivores are found in England and France during this period, they are all referred to the genus *Megalosaurus* with the exception of the Kimmeridgian *Streptospondylus* of England and *Compsognathus* of equivalent age from the lithographic limestone of Solenhofen, Bavaria.

Dr. A. Smith Woodward (1906, pp. 1–3) has recently described a Megalosaurian ungual phalanx from the Lower Jurassic of Victoria, Australia. He does not, however, suggest a more precise correlation of the beds with those of Europe.

Lower Cretaceous.

The American Morrison in the West and the basal Potomac (Patuxent–Arundel) in the East have yielded a number of Theropoda; from the Potomac, *Allosaurus*, the American representative of *Megalosaurus* and *Cœlurus;* while the Morrison has produced, in addition to these forms, *Creosaurus* and *Labrosaurus*, the horned carnivore *Ceratosaurus*, and the agile "bird-catching" dinosaur *Ornitholestes*.

In Europe the Wealden, probable equivalent in part to the American Morrison, has produced numerous remains of *Megalosaurus*. This genus is also reported from the Albian or Gault of France and from the Bellasien of Portugal, considered by Chaffat to be midway between the Aptian and Cenomanian.

Upper Cretaceous.

In the Upper Cretaceous, ushered in by the Cenomanian, the European species of Theropoda are, almost without exception, referred to the genus *Megalosaurus*, a well-nigh incredible range, Lias to Danian, for a single genus, even of a relatively conservative type. Depéret (1899, p. 692) has referred a carnivore from the Danian (Rognac) of Montagne-Noire, France, to the genus *Dryptosaurus*, first made known from the Upper Cretaceous of New Jersey.

The New World carnivores, on the other hand, have been given various names; of these the principal types are *Dryptosaurus* of the New Jersey Greensand and the Judith River (Senonian) of Montana and Alberta and *Tyrannosaurus* of the Laramie (Danian) among the huge Megalosaurs; while the lesser race is represented by *Ornithomimus* of the Judith River beds, a probable derivative from *Ornitholestes* of the

Morrison. From the Guaranitic beds (Danian) of Patagonia two genera of carnivores, *Genyodectes* (Woodward 1901) and *Loncosaurus* (Ameghino 1900, p. 61), both similar to *Megalosaurus*, have been described.

The Sauropoda.

The oldest undoubted Sauropod dinosaur thus far recorded is *Dystrophœus*, described by Cope (1877), from the Red beds of the Painted Canyon in southeast Utah, which he refers to the Trias, but which v. Huene (1904, pp. 320–321), upon the evidence offered by Whitman Cross, believes to be the equivalent to the Dogger. Doubtless owing to the dearth of Jurassic continental deposits, the American record is a blank from this time until the Morrison and its equivalent, the Lower Potomac of Maryland. Sauropoda appear in England with the Bathonian (Great Oölite) in the form of the generalized *Cetiosaurus*.

The Oxfordian has produced *Ornithopsis*, the Kimmeridgian *Ornithopsis*, *Bothriospondylus* and *Pelorosaurus ;* the Portlandian, the first of these ; while in the Lower Cretaceous Wealden we find *Cetiosaurus*, *Pelorosaurus*, *Morosaurus* and *Titanosaurus* (Lydekker non Marsh). *Cetiosaurus* and *Pelorosaurus*, v. Huene believes, represent parallel phyla giving rise, in the first instance, to the aberrant American *Brachiosaurus* and *Haplocanthosaurus* of the Morrison, while *Pelorosaurus*, through an early *Morosaurus* as a central type, gives rise to *Atlantosaurus* and *Apatosaurus* (*Brontosaurus*) on the one hand, and *Diplodocus* on the other, being succeeded in time by *Titanosaurus* (Lydekker) which ranges as high as the uppermost Cretaceous.

The American basal Potomac beds have produced *Pleurocœlus*, which is also found in the Wealden of England and Purbeckian of France. The Trinity sands of Texas, of probable equivalent age to the upper Aptian, contain the remains of *Morosaurus*, a typical Morrison genus.

In the southern hemisphere, in Africa, Madagascar and India, in beds of an age approximately equivalent to the Cenomanian, there have been found *Titanosaurus* and allied genera, such as *Gigantosaurus*, *Bothriospondylus* and, in Patagonia in the Guaranitic beds, *Titanosaurus*, *Argyrosaurus* and the relatively small aberrant *Microsaurus*.

Depéret (1889, p. 692) has also described *Titanosaurus* from the Rognac, Danian, of Saint Chinian in the south of France, the last record of the Sauropoda in Europe.

Orthopoda— Ornithopoda.

The Ornithopod dinosaurs, which exclude the armored types, make their first appearance in the North American

Upper Triassic, the possible equivalent of the Rhætic, being represented in the bone by *Nanosaurus*, of the Hallopus beds near Cañon City, Colorado, described by Marsh as a carnivore, but which v. Huene and Lull (1908, p. 143) have lately referred to this order. This type comes from the Upper Trias or Lower Jura of Colorado and is absolutely unique.

Williston, in a letter to the author dated Cañon City, Colorado, July 11, 1909, says : " After a careful study of the locality and region the conclusions I reach are : Nothing more definite as to the age of the Hallopus beds can be said than was given by Marsh. In my opinion they are either uppermost Trias or Lower Jurassic, though possibly of Middle Jurassic age. No fossils of any kind have ever been found below them in the Cañon City region. The type [of *Hallopus*] was found between 60 and 70 feet above the Red beds, doubtless of Triassic age. The intervening strata are distinctly conformable with the Red beds. All the known Morrison fossils from Cañon City are from above the Hallopus horizon, from one to three hundred feet, though numerous fragments of sauropods in the hillside suggest the possibility of less interval between them. There is no persistent red sandstone stratum in the Hallopus horizon. * * * my conclusion is that, until other fossils are found to fix more definitely their age, it is unwise to assign definitely either Triassic or Jurassic age to them. Jura-Trias will express this uncertainty."

Impressed upon the rocks of the Newark system, the equivalent of the Old World Rhætic, in the Connecticut valley and New Jersey are numerous footprints which Lull (1904, p. 499) has shown to pertain to ornithopod forms, the genus *Anomœpus* unquestionably. Two other genera may also belong to the Ornithopoda, *Eubrontes* of larger size and the aberrant *Otozoum*, the bipedal tracks of which indicate a foot unlike that of any known dinosaur. The footprints included under the genus *Anomœpus* show a considerable range in size but are all such as could have been made by forms like *Nanosaurus* and *Hypsilophodon*.

England again gives us the only record of Jurassic types, if we eliminate *Nanosaurus* and the Morrison forms, *Camptosaurus prestwichii* described as *Iguanodon* being found in the Kimmeridge clay. The other Jurassic types which have been referred to *Camptosaurus* Gilmore (1909, pp. 289–292) considers as invalid so far as the genus is concerned. The Oxfordian has yielded *Cryptodraco* (*Cryptosaurus*) which v. Huene (1909, p. 21) considers as ancestral to *Camptosaurus*, the central type of this group.

From the American Morrison are *Camptosaurus*, and a lesser form *Laosaurus* and its relative *Dryosaurus*, which, together

with the persistently primitive Wealden *Hypsilophodon*, v. Huene derives from the Colorado *Nanosaurus*. Lull (1910) will report *Dryosaurus* also from the basal Potomac beds of Maryland, and Gilmore (1909, pp. 392-395) has described a *Camptosaurus* from the Lakota in South Dakota.

The Wealden of England and especially of Belgium has yielded remarkably preserved specimens of *Iguanodon*, the successor of *Camptosaurus*. *Iguanodon* is in turn succeeded in the Cenomanian of England by a type referred to the American genus *Trachodon*, but somewhat questionably.

In America, the Niobrara, the equivalent of the European Turonian, has yielded the type of *Claosaurus agilis*, which is followed in the New Jersey Greensand and in probably equivalent beds of North Carolina by *Trachodon* (*Hadrosaurus*).

In the West, *Trachodon* is found in the Judith River beds and again in the Laramie, where it lingers on until the final extinction of the dinosaurian race at the close of the Mesozoic.

The European Cenomanian has produced *Craspedodon* in Belgium and *Mochlodon* from the Gosau formations of Austria. *Rhabdodon*, found in Rognac of southern France and in the Mæstricht beds of Belgium and Holland, both of the Danian period, is probably the closing member of the race in Europe.

Armored Orthopoda—Stegosauria.

The Stegosaurs have their first known representative in *Scelidosaurus* of the English Lias, beyond which the record is blank until we come to *Dacentrus* (*Omosaurus*) of the Kimmeridgian, which appears to be the central type in the evolution of this group. The Morrison yields *Stegosaurus*, which some authors have identified with the European *Dacentrus*, but which appears to be an aberrant side branch derived also from the Scelidosaurian stem. In the basal Potomac beds of Maryland several teeth and more questionably a vertebrum (Lull 1910) are described as *Priconodon* and referred to the Stegosauria.

The Purbeckian of England has also yielded *Priconodon*, while from the Wealden come *Polacanthus* and *Hyælosaurus*, the latter being found in Belgium as well as in England. *Acanthopholis*, from the English Cenomanian, v. Huene makes the connecting link with *Ankylosaurus* of the Laramie.

Intervening forms in the series, however, are probably represented by *Nodosaurus* from the Pierre (Turonian) of Colorado, while *Stegopelta*, recently described by Williston (1905, pp. 503-505) from the Lower Benton of Wyoming, and *Palæoscincus* of the Judith River are closely related if not identical

with *Ankylosaurus* of the Laramie. All three, according to Williston, were derived from *Polacanthus* of the Wealden of Europe.

The Gosau beds of Wiener Neustedt near Vienna, probably equivalent to our Judith River, contain a number of armored forms such as *Struthiosaurus* (Nopcsa 1902) and *Acanthopholis* (Nopcsa 1902) some of which, at least, probably pertain to the same race.

Ceratopsia.

The Ceratopsia have a relatively brief career,—*Stenopelix*, the pelvis of which resembles that of *Triceratops*, being the earliest possible representative among known forms. It is found in the Neocomian of Germany. The remains described by Seeley (1881, pl. xxviii, fig. 4) from the Gosau formation under the name of *Cratæomus* (= *Struthiosaurus ;* Nopcsa 1902) contain what appears to be a ceratopsian left supra-orbital horn-core which would seem to represent a stage of evolution equivalent to *Ceratops* of the American Judith River. Nopcsa (1902, p. 7) is of the opinion, however, that the horn-like bone in question represents a dorsal spine after the manner of those of *Polacanthus*. This, together with the total absence of two-rooted teeth of the ceratopsian sort among the number preserved at Vienna, casts grave doubt upon the existence in Europe of this remarkable group.

The American Judith River (= Belly River of Canada) contains two stages in the evolution of the Ceratopsia, *Monoclonius* and *Ceratops*, as well as the somewhat aberrant *Centrosaurus* described by Lambe (1904). The Laramie deposits which follow later after a hiatus of some 2,000 or more feet of marine strata contain the terminal members of this race, *Triceratops* and *Torosaurus*. The geological distribution and phylogenies are shown in figure 1.

V. Geographical Distribution.

Theropoda.

The geographical distribution of dinosaurs presents some very interesting problems, some of which, at first sight, are difficult to explain.

By far the widest spread forms are the carnivorous Theropoda (fig. 2), evidently the most adaptable and of a nature not so subservient to a peculiar kind of food, which was apt to be local in distribution, as in the case of the plant-feeding forms. These carnivores are reported in practically every locality where herbivorous dinosaurs have been found, as they seem to

Fig. 1.

FIGURE 1. Phylogeny and geological distribution of the principal dinosaurian genera.

have accompanied the latter in all of their wanderings. In addition to this they had, during Triassic times, deployed rapidly before our records give us evidence of the existence of the herbivores.

The oldest recorded Theropoda, those of the Lower Muschel-kalk, are found in Germany, but we have no proof that this was the center of dispersal. Indeed v. Huene (1908, pp. 100-101) is of the opinion that one must go farther west, where a great continent extended from England to America, to find the conditions which, we have imagined, must have given rise to the dinosaurian race. During the Keuper, particularly, "a brackish sea and swamp extended from England to Eastern Germany as far as the Scandinavian, East Prussian and Bohemian borders, where another great northern continent began and extended eastward."

The semi-arid continent of Triassic time would doubtless be the chosen habitat, the swamp regions the place where the remains of wandering individuals might more readily be preserved.

During the Trias, the Theropoda spread in one direction through Germany, France, England, and in the other to eastern and finally to western North America, which was reached not later than the Upper Keuper. On the other hand, they migrated southward in the Old World to the Gondwana continent, for in the Lettenkohle time we find them in India, in the Upper Keuper in Australia, while South Africa was reached at least by Rhætic time.

What the precise line of march was is somewhat doubtful— I imagine, however, it was southward to what is now northern Africa, thence east to India and Australia, and south to the Cape Colony. We have no recorded evidence of Triassic dinosaurs in South America or in New Zealand. I should hesitate to infer that they had not reached South America during this period, though, as we shall see, the first remains to be found are not older than the Wealden. New Zealand, however, has yielded a rich Triassic flora, together with the remains of labyrinthodonts, implying extensive terrestrial deposits though not the ideal dinosaurian habitát; but as Theropoda are found in all sorts of deposits, even marine, that feature is not especially significant. The total absence of the dinosaurs from New Zealand deposits of any age; the presence in the Permian and Trias of labyrinthodonts; the presence to-day of the absolutely unique *Hatteria*, the sole survivor of its order, dating its ancestry also from the Permian; the presence of no tailed amphibia, of one rare species of frog, of a few lizards, which Heilprin tells us cannot pass the sea as adults, but do in the egg as they are found on remote oceanic islands to which they

Fig. 2.

Lower Muschelkalk	Upper Muschelkalk	Letten-kohle	Lower Keuper	Middle Keuper	Upper Keuper	Rhaetic
				NORTH AMERICA		Ammosaurus, Manchester, Conn. Anchisaurus " " Thecodontosaurus, Springfield, Mass. Coelophysis, Gallinas Mountains, N. M.
				ENGLAND		Gresyllosaurus, Wedmore Hill, Somersetshire. Plateosaurus, Brigend, Glamorganshire. Plateosaurus, Leicester.
					Thecodontosaurus, Warwick; Durdham Down; Bristol.	
				FRANCE		Plateosaurus, Provenchère, Hte. Marne; Buerre and Domblans n. Besançon; Bois de Chassagne, Poligny, Jura; Fèchaux n. Lons-le-Saunier. Gresyllosaurus, Provenchère, Hte. Marne; Bois de Chassagne, Poligny, Jura; Lons-le-Saunier.
				Thecodontosaurus, Luneville.		
				GERMANY		Plateosaurus, n. Göttingen, n. Hedeper Schlosslesmühle in Schönhuch, n. Tübingen. Plateosaurus, n. Katzenhof, Pegnitzthal, Unterfranken, n. Nuremberg, n. Bayreuth, n. Tübingen, n. Stuttgart, Balingen. Gresyllosaurus, n. Nuremberg, n. Tübingen, n. Stuttgart. Pachysaurus, n. Tübingen, n. Rottweil, n. Gmünd, n. Löwenstein.
					Teratosaurus, n. Rottweil, n. Stuttgart, n. Brackenheim, n. Nuremberg.	
					Sellosaurus, n. Stuttgart, n. Brackenheim.	
					Tanystropheus, n. Stuttgart.	
					Thecodontosaurus, n. Stuttgart.	
				Zanclodon, n. Ludwigsburg, n. Stuttgart, n. Hall.		
				Thecodontosaurus, Bayreuth, n. Crailsheim.		
				Tanystropheus, Bayreuth, n. Crailsheim, Hall, Oberbronn, Alsatia.		
Thecodontosaurus, Gogolin, Upper Silesia.						
Tanystropheus, Gogolin, Krappitz.						
				SWITZERLAND		
					Gresyllosaurus, n. Basel	
				SOUTH AFRICA		Thecodontosaurus, Barkley-East (Stormberg beds), Aliwal North. Euskelosaurus, Aliwal North. Massospondylus, n. Harrismith, Drakensberg.
				INDIA		
			Thecodontosaurus,	? Ranigansch.		
				AUSTRALIA		
					Thecodontosaurus, North-east Coast.	

FIGURE 2.   Distribution of the Triassic Theropoda (adapted from v. Huene).

Fig. 3.

Lias	Fullonian	Bathonian	Oxfordian	Corallian	Kimmeridgian	Portlandian	Purbeckian
				THEROPODA			
				ENGLAND			
							Nuthetes, Swanage, Dorset.
						Megalosaurus	
					Megalosaurus, Wiltshire.		
				Megalosaurus, Yorkshire.			
			Megalosaurus, Weymouth.				
		Megalosaurus, Stonesfield, Enslow, Oxford.					
	Megalosaurus, Bridport, S.W. England.						
Megalosaurus, Lyme Regis.							
				GERMANY			
					Compsognathus, Solenhofen, Bavaria.		
				FRANCE			
						Megalosaurus, Boulogne-sur-Mer.	
					Megalosaurus(Streptospondylus), Le Havre, Devizes, Boulogne, Cape-de-la-Heve.		
			Megalosaurus, Calvados.				
		Megalosaurus, Caen in Calvados, Saint-Gaulthier.					
Megalosaurus, Franche-Comte.							
				SPAIN			
Megalosaurus, Ruedes(Asturias).							
				PORTUGAL			
						Megalosaurus, Mont Lambert.	
			Megalosaurus(Lusitanien), Pombal, environs of Crasto.				
				AUSTRALIA			
	Megalosaurus, Cape Patterson, Victoria(precise horizon doubtful)						
				SAUROPODA			
				NORTH AMERICA			
		Dystrophaeus, Painted Cañon, S.W.Utah.					
				ENGLAND			
						Pelorosaurus(Ornithopsis), Isle of Portland.	
					Pelorosaurus, Stretham, Cambridgeshire.		
					Pelorosaurus(Bothriospondylus), Swindon, Bradford, Wiltshire.		
					Pelorosaurus(Ornithopsis), Weymouth, Ely.		
			Pelorosaurus, Peterborough.				
			Pelorosaurus(Ornithopsis), Eyebury, Oxfordshire.				
			Cetiosaurus, Peterborough.				
		Cetiosaurus, Oxford, Stonesfield, Blisworth, Bilbury, Enslow, Cogenhoe.					
				FRANCE			
						Pelorosaurus, Boulogne-sur-Mer.	
					Pelorosaurus, Wimille n. Boulogne.		
					Pelorosaurus(Bothriospondylus), n. Havre.		
			?Pelorosaurus(Tooth), Saint-Gaulthier				
		Cetiosaurus, Caen.					
				PORTUGAL			
					Pelorosaurus, Vestaria.		
			Pelorosaurus, Ourem.				
		Morosaurus, Ourem.					
				MADAGASCAR.			
	Pelorosaurus(Dogger)						

Fig. 3. Distribution of the Jurassic Theropoda and Sauropoda (original).

may have found means of introduction by floating timber; the absence of any indigenous mammals other than bats, a rat, and the Maori dog, the introduction of which may be as readily accounted for;—all of these evidences seem to me to point to an utter isolation geographically on the part of New Zealand since the close of the Permian. De Lapparent's maps (1906) indicate a continuous New Zealand-Australian connection into the basal Eocene—long after the breaking up of the Gondwana continent. The biological evidence which I have given strongly opposes this view.

During Jurassic times the record of Theropoda (fig. 3) is practically continuous in England and Europe, and one Megalosaur has been described by Smith Woodward (1906) from the Lower Jurassic of Cape Patterson, Victoria, Australia, about the nearest point toward the unattainable New Zealand.

For Africa, South America, and most strikingly for North America, the known Theropod record is a perfect blank throughout the Jurassic, though the remains of other dinosaurs are sparingly known. This is unquestionably due to dearth of known terrestrial deposits in Africa and North America, for the few which exist have thus far yielded no dinosaur remains. As for South America, it may be that the migrant dinosaurs did not arrive until the beginning of Lower Cretaceous time.

The Lower Cretaceous (fig. 4) saw the Theropoda at their widest extent, the Wealden of England and the Morrison and basal Potomac of North America having yielded a marvelous assemblage of types. In Europe their record is seen somewhat scatteringly throughout the Lower and Upper Cretaceous, indicating that they inhabited the whole area throughout the period. In North America, while there are extensive breaks in the continuity of the record, the great numbers and wide distribution at the beginning and end imply an equally extensive distribution in time and space. Central Africa, near the Tchad See, yields theropod remains during the Cenomanian; Madagascar, India and Australia as well in beds of approximately equivalent age; while in the neighborhood of Bahia, Brazil, in beds of an age equivalent to the Wealden, is found the first positive indication that these forms had reached South America. Having once found a foothold in South America, the Theropoda lingered on until the close of the Cretaceous, as their remains are reported from several localities in Patagonia in the Guaranitic (Danian) strata.

Sauropoda.

The Sauropoda (fig. 5) are also very widespread though evidently local in distribution owing to necessary peculiarities in habitat and food. Their appearance in time is startling, as

FIG. 4.

Wealden Morrison	Aptian	Albian	Cenomani- an	Turonian	Senonian	Danian
			NORTH AMERICA			
						Tyrannosaurus, Hell Creek, Mont.;E.Fork of Little Pow- der R.,Mont.;Ojo Alamo,N.M.; Converse Co.,Wyo. Ornithomimus, Converse Co., Wyo.;n.Denver,Col.
					Ornithomimus, Red Deer River,Alberta, Can.;Mont. Aublysodon, Judith,Mont.;Red Deer Riv- er,Alberta. Deinodon,.Judith,Mont.;Red Deer River, Alberta. Dryptosaurus, Red Deer River,Alberta; Haddonfield,N.J. Coelosaurus, Haddonfield,N.J.	
				?Allosaurus, Kansas.		
Allosaurus, Como,Wyo.;Bone Cabin n.Medicine Bow,Wyo.;Canyon City,Col.;Prince George Co., Md.(Potomac). Labrosaurus, Como,Wyo.;Canyon City,Col. Creosaurus, Como,Wyo. Ceratosaurus, Como,Wyo.;Canyon City,Col. Ornitholestes, Bone Cabin,Wyo. Coelurus, Como,Wyo.;Prince George Co.,Md.						
			ENGLAND			
Megalosaurus, Hastings,Cuckfield,Isle of Wight. Calamospondylus, Isle of Wight. Coelurus, Isle of Wight.						
			FRANCE			
						Dryptosaurus, Saint Chinian.
		Megalosaurus, Boulonnais,Grand Prè,Louppy.				
			PORTUGAL			
						Megalosaurus, Vizo.
		Megalosaurus, Boco do Chapin,Cap d'Espichel.				
			BELGIUM and HOLLAND			
						Megalosaurus, Maestricht.
					Megalosaurus	
			GERMANY			
Megalosaurus, North.Germany.						
			AUSTRIA and HUNGARY			
					Megalosaurus, n.Vienna(Neue Welt)Sie- benhürgen.	
			AFRICA			
			"Ornithomimus-like", Tchad-See,Central Africa.			
			MADAGASCAR			
					Megalosaurus	
		Megalosaurus, Nevarana.				
			INDIA			
		Megalosaurus, Trichinipoli.				
			AUSTRALIA			
		Megalosaurus, New South Wales(Geol.level not given)				
			SOUTH AMERICA			
						Loncosaurus, Rio Rehuen,Pata- gonia. Genyodectes, Patagonia.
Megalosaurus, Bahia,Brazil.						

FIG. 4.   Distribution of the Cretaceous Theropoda (original).

they are found in strata which v. Huene refers in each case to
the Dogger but at points far removed geographically, in England, in Utah, and in Madagascar (v. Huene, 1909, p. 14). If
v. Huene is correct in his derivation of the group from the
Theropod genus *Plateosaurus*, I should look to this swampland extending during the late Trias from England to Eastern
Germany, before alluded to (vide supra p. 21) as the place of
origin of the race. That they reached such remote places
before their very existence is indicated in our records points to
the incompleteness of the latter and good powers of migration
along the swamp and delta formations which fringed the continental shores.

The Sauropoda are abundant in England from the Bathonian
(Dogger) to the Wealden, in France from the Bathonian until
the Aptian, and then, if Depéret (1899) is right, after a lapse
of time during which no Sauropoda left their records elsewhere in the northern hemisphere, they appear again in the
form of *Titanosaurus* at Saint Chinian and Languedoc in
southern France in beds referable to the Danian—the very
close of the Cretaceous period!

In America, with the exception of *Dystrophœus* of the
Dogger of Utah and an unnamed Sauropod reported by Gilmore (1909, p. 300) from the Lakota (Aptian) of Buffalo Gap,
South Dakota, the Sauropoda are confined entirely to the Morrison and its eastern equivalent, the basal Potomac, and in the
South, to the Trinity sandstones of Texas and Oklahoma. A
remarkable feature of the career of the American types is that,
with the exception of the ill-known *Dystrophœus*, the most
generalized *Haplocanthosaurus* and the most specialized
Diplodocus have been found associated in the same quarry,
although Riggs (1904, p. 246) argues for *Haplocanthosaurus*
a terrestrial habitat, on account of the similarity in length of
fore and hind limb and the apparent inflexibility of the vertebral column; while *Diplodocus* shows the highest degree of
aquatic adaptation known within the group.

In the southern hemisphere one finds sauropod remains
from India across Madagascar and East Africa to Patagonia,
almost the entire length from East to West around the south
shore of the old Gondwana continent. There is, however, no
record of their occurrence in Australia, a piece of negative
evidence which can hardly be weighed heavily in view of the
meagerness of the known dinosaur remains in that quarter of
our globe.

The principal southern genus is *Titanosaurus* (Lydekker
non Marsh), the remains of which are found also in the English Wealden. The beds wherein the southern Sauropods
are found are, curiously enough, Upper Cretaceous, probably

FIG. 5.

Wealden Morrison	Aptian	Albian	Cenomanian	Turonian	Senonian	Danian
			NORTH AMERICA			

Atlantosaurus, Canyon City,Col.;Morrison.Col.

Apatosaurus(Brontosaurus), Como,Wyo.;Bone Cabin,Wyo.;Medicine Bow,Wyo..Sheep Creek,Wyo.; Grand River Valley n.Fruita,Col.;Freeze Out Hills,Wyo.;Morrison,Col.;Webster Park,Col.

Morosaurus, Oklahoma(Trinity Sands).

Morosaurus, Como,Wyo.;Canyon City,Col.;Grand River Valley,Col.;Freeze Out Hills,Wyo.

Camerasaurus, Canyon City,Col.

Pleurocoelus, Prince George Co.,Md.(Potomac):Como,Wyo.

Diplodocus, Bone Cabin,Wyo.;Sheep Creek,Wyo.;Canyon City,Col.;n.Morrison,Col.

Barosaurus, Piedmont,S.D.

Brachiosaurus, Grand River Valley,Col.

Haplocanthosaurus, Canyon City,Col.

"Sauropod"(Lakota), Buffalo Gap,S.D.

ENGLAND

Cetiosaurus, Isle of Wight;Cuckfield,Sussex.

Pelorosaurus, Isle of Wight,Sandown,Cuckfield,Sussex.

Pelorosaurus(Ornithopsis), Cowden.

Titanosaurus, Isle of Wight.

Morosaurus, Cuckfield,Sussex.

Pleurocoelus, Hastings,Cuckfield,Isle of Wight.

Hoplosaurus, Isle of Wight.

FRANCE

Titanosaurus, Saint Chinian, Languedoc.

Aepysaurus Mont Ventoux(Vaucluse)Perigord.

Pleurocoelus, Caen.

PORTUGAL

Pleurocoelus, Boca do Chapin,Cap d'Espichel.

AFRICA

Algoasaurus, Port Elizabeth(precise level doubtful).

Titanosaurus, Tendaguru,East Africa.

Gigantosaurus, Tendaguru,East Africa.

MADAGASCAR

Titanosaurus, Nevarana.

Pelorosaurus(Bothriospondylus), n.Bay of Narinda.

INDIA

Titanosaurus(may be Albian), Maleri,Pisdura.

SOUTH AMERICA

Titanosaurus, Neuquen,Rio Che- hut,Patagonia.

Argyrosaurus,Rio Chebut,Pat- agonia.

Microsaurus, Neuquen,Pata- gonia.

FIG. 5. Distribution of the Cretaceous Sauropoda (original).

FIG. 6.

Jura-Trias and Jurassic								
Rhaetic	Lias	Fullonian	Bathonian	Oxfordian	Corallian	Kimmeridgian	Portlandian	Purbeckian

ORNITHOPODA

NORTH AMERICA

Nanosaurus, n. Canyon City, Col.
Anomoepus (Footprints), Mass., Conn., N.J.
Otozoum (Footprints), Mass., Conn.

ENGLAND

Iguanodon
Camptosaurus (Iguanodon), Cumnor Hurst, Oxfordshire.
Iguanodon (Camptosaurus), Peterborough.
Cryptodraco, (loc. unknown)

FRANCE

Iguanodon (Camptosaurus), Boulogne-sur-Mer.

PORTUGAL
Iguanodon, Cap d'Espichel.

STEGOSAURIA

ENGLAND

Echinodon, Swanage.
Omosaurus, Swindon, Wootton Bassett, Wiltshire.
Omosaurus ?
Scelidosaurus, Charmouth, Dorset.

Cretaceous						
Wealden Morrison	Aptian	Albian	Cenomanian	Turonian	Senonian	Danian

ORNITHOPODA

NORTH AMERICA

Trachodon (Laramie), Hell Creek, n. Forsyth, Chalk Buttes 20 mi. W. of Elklaka, E. Fork Little Powder R., n. Glendive, Mont.; Converse Co., N. Platte R. mouth of Medicine Bow, Wyo.; Grand River, S.D.

Trachodon, Red Deer River, Alberta; S. Fork Cheyenne, S.D.; Judith, Missouri R.; Hell Creek (Pierre) Musselshell Basin, Sweet Grass Co., Mont.; Cape Fear R., N.C.; Georgia; Haddonfield, N.J.

Claosaurus (Niobrara) Smoky Hill Valley, Kan.

Camptosaurus (Lakota), Buffalo Gap, S.D.
Camptosaurus, Como, Bone Cabin, Albany Co., Carbon Co., Wyo.; Canyon City, Garden of the Gods, Col.; Custer Co., S.D.
Laosaurus, Como, Bone Cabin, Wyo.
Dryosaurus, Como, Wyo.; Bladensburg, Md. (Potomac).

ENGLAND

?Trachodon
Iguanodon, Isle of Wight, Sussex; Maidstone, Kent.
Iguanodon, Bradfordshire (Neocomian), Hastings, Cuckfield, Isle of Wight.
Iguanodon (Camptosaurus), Isle of Wight.
Hypsilophodon, Cuckfield, Isle of Wight, n. Brixton.

BELGIUM AND HOLLAND

Craspedodon, Maestricht.
Orthomerus, Maestricht.

FRANCE

Rhabdodon, Rognac n. Provence.
?Hypselosaurus, Rognac.

PORTUGAL
Iguanodon (Bellasien Infer.), Boca do Chapin, Cap d'Espichel.

AUSTRIA-HUNGARY

Mochlodon, n. Vienna, Siebenbürgen.
Telmatosaurus (Limnosaurus) Siebenbürgen.

FIG. 6.   Distribution of the Jura-Trias and Jurassic Orthopoda and of the Cretaceous Ornithopoda (original).

not older than Cenomanian time, and, with the exception of the questionable *Macrourosaurus* of the English Cenomanian and the *Titanosaurus* reported by Depéret (vide supra) from the Danian of Southern France, the contained dinosaurs represent by far the latest appearance of the Sauropod group anywhere recorded on the face of the globe.

The last stand of these huge creatures, so far as our present knowledge goes, and again excepting Depéret's *Titanosaurus* (vide supra, p. 26), was in Patagonia, where the remains of three genera, *Titanosaurus*, *Argyrosaurus* and the small aberrant *Microsaurus* are found in the Guaranitic beds correlated by Hatcher (1900, p. 95) with the Laramie (Danian) of North America.

Orthopoda.

Geographically the Orthopoda (figs. 6 and 7) as a whole, with the exception of the Ceratopsia, which are apparently confined to western North America, have a common distribution; and, while paralleling that of the other dinosaurs in the northern hemisphere, are unique in their entire absence from the southern. It can hardly be said that the paucity of our records is responsible for this apparent lack of southern forms, for their preservation and discovery should surely have brought some to light when the Theropoda and Sauropoda are relatively so abundant.

America seems to have been the original home of the orthopod dinosaurs, the first recorded type the bones of which are known being *Nanosaurus* of the Jura-Trias of Utah. In the upper series of the Newark (Rhætic) beds in Massachusetts, Connecticut and New Jersey are indications of numerous species of these plant-feeding forms, so that it is evident that by the beginning of Jurassic time not only were they widespread in North America but they had reached a considerable degree of variation as well, implying a long though unrecorded career. During the Jurassic the record is again a blank as with the American Theropoda, but with the ushering in of Lower Cretaceous time by the great Morrison deposits in the West and the Potomac in the East we find a marvelous assemblage of types, small and large, armored and unarmored. This is especially true in the West, since the Potomac dinosaurs, coming as they do from few localities which are all of one character, reflect the Sauropod rather than the Orthopod habitat, so that while an armored dinosaur, *Priconodon*, and an unarmored *Dryosaurus* (Lull 1910) only have been found in Maryland, others doubtless existed and may some day be brought to light.

All through Upper Cretaceous time the American record is quite complete, especially in the West, though New Jersey,

Fig. 7.

Wealden Morrison	Aptian	Albian	Cenomanian	Turonian	Senonian	Danian
			STEGOSAURIA			
			NORTH AMERICA			
						Ankylosaurus, Hell Creek, Mont.
					Ankylosaurus(Stereocephalus), Red Deer River,Alberta.	
					Palaeoscincus, Red Deer River,Alberta; Judith River,Mont.	
					Nodosaurus, n.Como,Wyo.	
				Stegopelta, Lander,Wyo.		
				Hierosaurus(Niobrara), Gove Co.,Kan.		
		Hoplitosaurus(Lakota), Buffalo Gap,S.D.				
Stegosaurus, Como,n.Medicine Bow,Bone Cabin,Sheep Creek,Wyo.						
Stegosaurus(Diracodon), Como,Wyo.						
Priconodon(Potomac), Prince George Co.,Md.						
			ENGLAND			
			Acanthopholis, Folkstone.			
		Acanthopholis, Cambridge.				
Polacanthus, Hastings,Isle of Wight.						
Hylaeosaurus, Hastings,Tilgate,Cuckfield.						
Vectisaurus, Isle of Wight.						
			FRANCE			
					Struthiosaurus(Crataeomus)St.Chinian.	
		Hylaeosaurus, Boulonnais,Grand Prè.				
			GERMANY			
Hylaeosaurus, North Germany.						
Stenopelix, Brückeburg.						
			AUSTRIA-HUNGARY			
					Struthiosaurus, n.Vienna(Neue Welt).	
					Hoplosaurus, n.Vienna(Neue Welt).	
			CERATOPSIA			
			NORTH AMERICA			
						Triceratops, Converse Co., N.Platte River opposite mouth of Medicine Bow,Wyo.; Hell Creek,Powder River, Chalk Buttes 20 mi.W.of Elklaka,E.Fork Little Powder River,n.Glendive,n. Rosebud,Mont.;Yule,Billings Co.,N.D.;Ojo Alamo,N.M.; n.Denver,Col.
						Diceratops, Converse Co.,Wyo.
						Torosaurus, Converse Co.,Wyo.
						Agathaumas, Black Buttes,Wyo.
					Ceratops(Judith River), n.Judith,Missouri River,Mont.;Red Deer River,Alberta.	
					Monoclonius(Judith River), n.Judith, Mont.;Red Deer River,Alberta.	
					Centrosaurus(Judith River), Red Deer River,Alberta.	
					"Ceratopsians", Musselshell River Basin,Sweet Grass Co.,Mont.	

Fig. 7.   Distribution of the Cretaceous Stegosauria and Ceratopsia (original).

North Carolina and Georgia have yielded Trachodons of Magothy (Senonian) age.

The great culmination of the group, in which the older types were joined by the remarkable Ceratopsia, occurred toward the close of the Cretaceous in the area lying just eastward of the Rocky Mountains and extending from New Mexico on the south to Alberta on the north, perhaps beyond.

In the Old World I have searched in vain for traces of Orthopoda before the Lias. Beasley, Sollas and others have described many fossil footprints from beds ranging from the Bunter to the Upper Keuper, including some undoubted dinosaurian tracks (Sollas 1879, pp. 511–516) resembling those of *Anchisauripus* (*Brontozoum*, part) (Lull 1904, p. 486) of the Connecticut formation. There is none among them in any way comparable with *Anomœpus* (Lull 1904, p. 500) of the New World. Beasley (1907, p. 167–168) is inclined to think that he has in *Chirotherium storetonense* from near Liverpool the footprint of an herbivore. That one may readily consent to, but the foot in no way resembles that of a dinosaur and the tracks are generally referred to unknown labyrinthodonts.

In the English Lias the first Orthopod appears in the form of the armored *Scelidosaurus* followed in the Oxfordian by *Omosaurus* and later by *Echinodon*. Recorded specimens of armored forms are entirely confined to England during Jurassic time and not until the Wealden do we find their remains on the continent. With the Cenomanian they apparently forsake their earlier home entirely for the continent, culminating in *Struthiosaurus* and *Hoplosaurus* of Austro-Hungary and southern France.

The unarmored Orthopoda, the Ornithopoda, begin their Old World career simultaneously in England and Portugal in beds of Oxfordian age, but are not numerous during the Jurassic. The Wealden, however, brings in a great many species, some in wonderful preservation. Their subsequent history is much like that of the armored types, culminating in Austro-Hungary, France and Belgium.

It will be observed that no mention is made of the Asian continent north of India—the ancient Angara-land. Thus far our records show absolutely no trace of dinosaurian remains from any part of this vast area. Professor Marsh (1897, pp. 413–414) says: "In St Petersburg I hoped to find many dinosaurian remains, as here had been brought together an abundance of fossil treasures from various parts of the Russian Empire, which I knew must contain many forms of this group. In the four principal museums of the city, however, I could find no bones of Dinosaurs on exhibition, nor could I learn from any of the museum authorities that such remains had

Fig. 8.
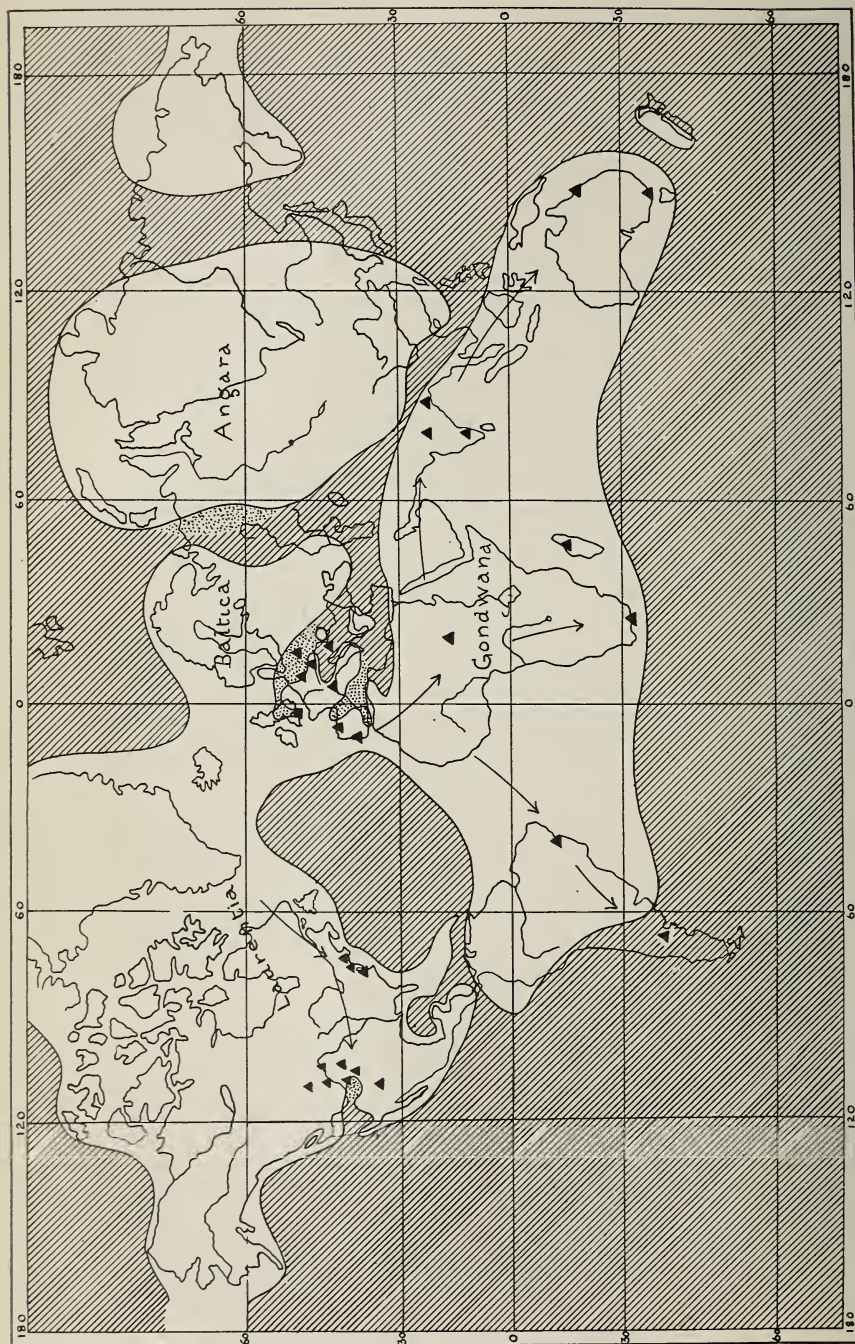
Fig. 8. Map showing the principal localities of the Theropoda with probable routes of migration. Based upon the lower Triassic maps of Schuchert for North America and de Lapparent for the rest of the world. (Dotted areas, terrestrial deposits.)

Fig. 9.
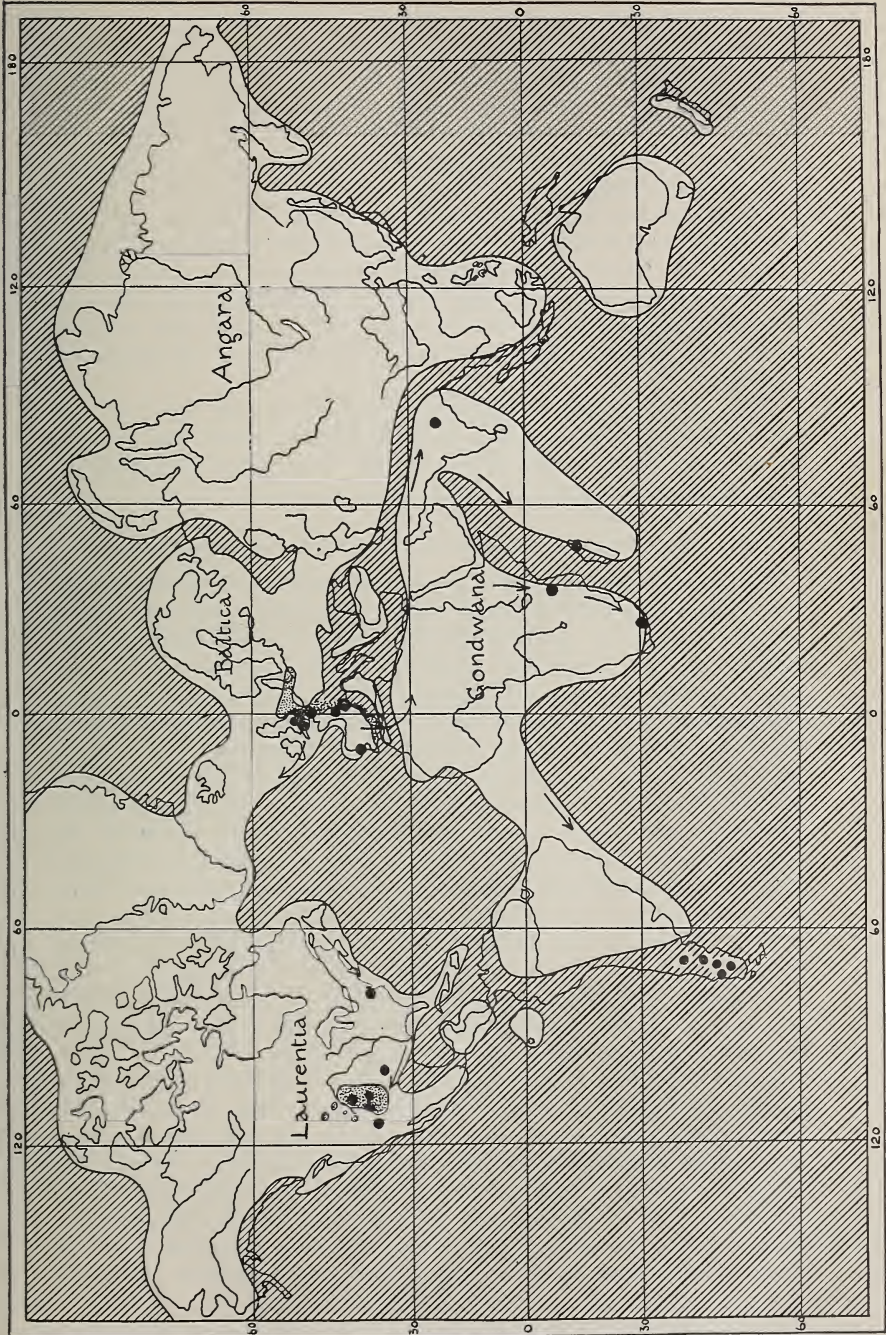
Fig. 9. Map showing the chief localities and probable routes of migration of the Sauropoda. Based upon Schuchert's late upper Jurassic map of North America and de Lapparent's Wealden map for the rest of the world.

been recognized among the specimens received, neither could I find any such fossils myself among the debris of the collections, so often a rich repository for new or inconspicuous specimens. This was true, also, of the smaller collections visited, and I was at last forced to admit that here, at least, the Dinosaurs of Russia like the snakes of Ireland, were conspicuous only by their absence.

"This opinion was not changed by a visit to the rich geological collections of Moscow, which I examined with care; although other fossil vertebrates, including many reptiles, were abundantly represented. I was assured, moreover, by various Russian paleontologists, that in other museums of the empire or in the known localities they had seen no dinosaurian remains."

This evidence can be interpreted again in the light of the fact that Asia is so largely a *terra incognita* from the paleontologist's point of view, or in that of the physical isolation of Angara during the whole dinosaurian epoch.

VI. Summary of Migrations and Paleogeography.

The probable center of evolution and course of migration of the Theropoda has already been sketched. Having their origin apparently somewhere in the northern continent of Laurentia, they deployed southward and westward, covering not only the confines of western Europe but extending into Gondwana, the southern land mass, during Triassic times. New Zealand they never reached and they may have been retarded in their passage to South America until the beginning of the Lower Cretaceous (see fig. 8). The Sauropoda probably had their origin in Europe, migrating early in Jurassic time to the southern as well as to the western continent. Thence in the southern hemisphere both east, south, and west until their range was almost as great as that of their carnivorous allies. Whether the Danian Titanosaur of southern France was a returned migrant or whether suitable conditions caused it to linger long after the death of all of its neighboring allies, like the Steller's sea cow in Behring Sea, I cannot say. The second idea seems the more probable (fig. 9).

The Orthopoda (fig. 10) present at first sight a much more serious difficulty in their entire absence from the southern hemisphere. It would seem as though we had here a group the center of whose dispersal was North America. They were truly terrestrial types, many of marked cursorial adaptation, which should be as capable of migration as the Theropoda. They were, however, dependent upon a peculiar sort of food which was in turn dependent upon certain climatic

Fig. 10.
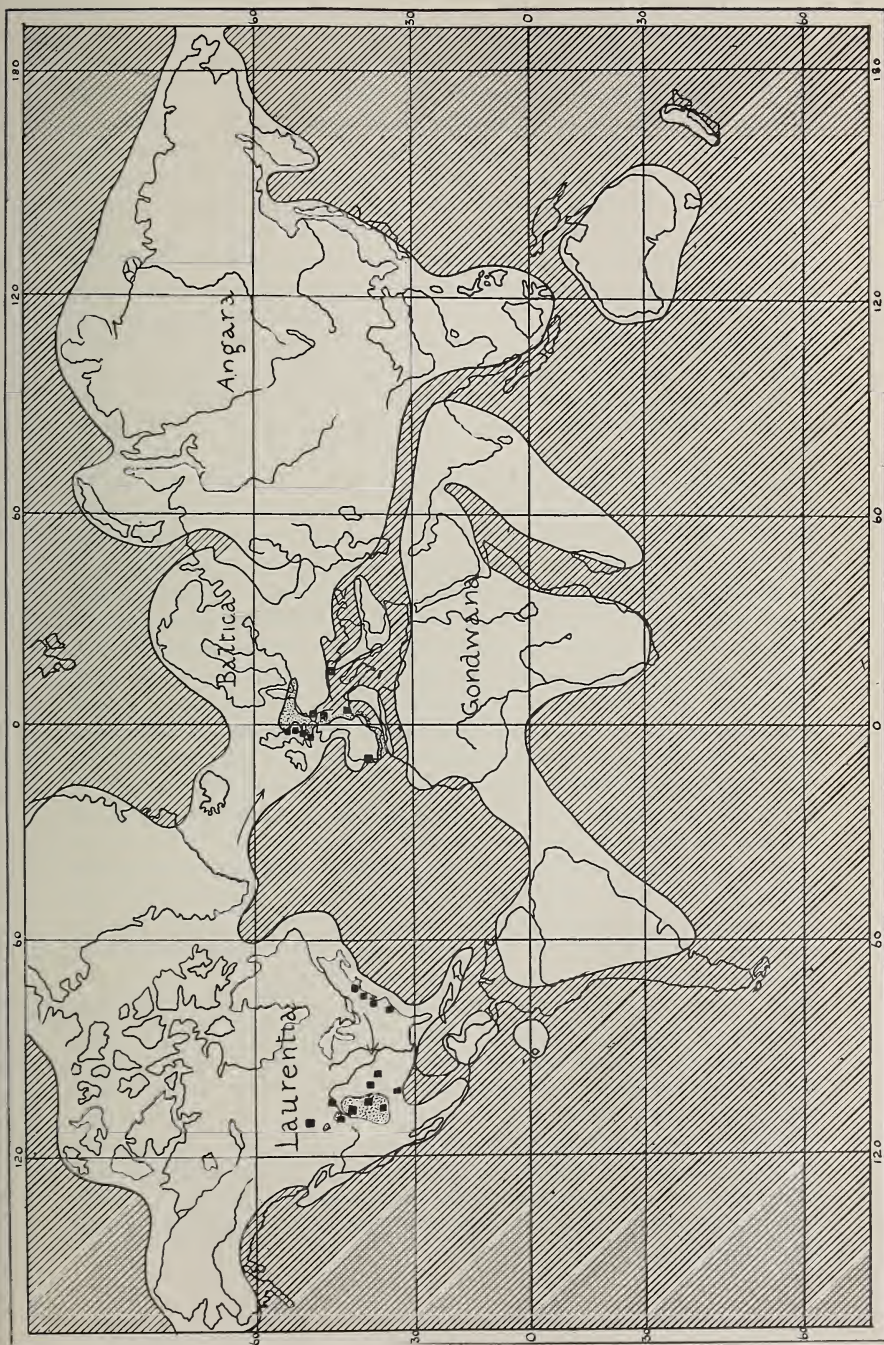
Fig. 10.   The same map as in fig. 9, showing localities and migratory routes of the Orthopoda.

conditions and necessarily went where food was abundant and were checked where it failed.   The opportunity for migration to Gondwana Land from Europe by a dry land route may readily have ceased before the Orthopoda reached the Old World.   The Sauropoda, on the other hand, being amphibious could cross broken land connections provided the water were not of too great an extent.   It is a significant feature that only Theropods, Sauropods and the late Cretaceous Orthopods, *Claosaurus* and *Trachodon,* have been found in marine deposits, indicating a semi-aquatic life on the part of the latter two and at least a fearlessness of water when necessity arose upon that of the carnivores.   By the time the Trachodont dinosaurs reached the Old World the opportunity for southern migration even for an amphibious animal had apparently ceased.

A comparison may well be made with living mammals, the deer on the one hand, the hippopotamus on the other.   The former are world-wide in their distribution except for Australasia, the Arabian peninsula and Africa, save for a single species, *Cervus barbarus,* which inhabits the Mediterranean coast from Tunis to the slopes of the Atlas range.   Schillings (1906, p. 261) says : "In 1896 hippopotamuses were still plentiful in the Nzoia River and the Athi River in British East Africa; they were to be found, too, along the coast between Dar-es-Salaam and Pangani.   I saw them on several occasions in the surf, and I shall never forget my astonishment once, on getting out of a clump of cocoanut palms, to see what I had imagined to be an uprooted tree trunk on the sands suddenly change into a hippopotamus and make its way into the sea.

"Hippopotamuses travel by sea to get from one estuary to another, no doubt ridding themselves at the same time of certain parasites in the salt water."

Hippopotamuses show no more aquatic adaptation than the sauropod dinosaur, *Diplodocus,* if as much.   Hippopotamuses are confined in their present range to Africa south of the Sahara, being found in the Nile only above Khartum.   In former times they extended to Madagascar, northwest India and practically the whole of western Europe including southwest England (Murray 1866, map XXIX).   This shows that certain barriers exist which prove effective against such extremely mobile creatures as the deer and which have debarred them from the Ethiopian realm.   These barriers, however, were not prohibitive in the case of the less mobile hippopotamus.   A similar contrast of conditions might readily have limited the distribution of the Orthopod dinosaurs, while the Sauropoda, as in the case of the hippopotamuses, could easily migrate.

Why the Sauropoda lingered so long in the southern hemisphere after their apparent extinction in the North, is difficult to answer unless it were because of the limitations of food and climate in the North which did not at once prevail in the South. Even though the Trachodontidæ gradually assumed aquatic habits, they were too late to be brought into active competition with the Sauropoda in the northern land mass.

The carnivores being always present doubtless served at first only to limit the plant-feeding forms ; they may, however, have been responsible for the final blotting out of the Sauropoda when weakened in numbers and by the burden of racial old age.

I believe that, all things considered, the degree of moisture, whether atmospheric in accelerating or limiting plant growth, or in the form of actual water barriers, was the most potent factor in the origin, evolution, migrations, and final extinction of the dinosaurian race.

Williston (1909, p. 401) is inclined to think that "there must have been free communication during part or all of the Mesozoic time between North and South America, proof of which is seen in the dinosaurs, mosasaurs, and crocodiles, some of them being, according to competent observers, identical generically even with North American forms." This may be true of the crocodiles and mosasaurs and yet imply no land bridge over which dinosaurs could pass. True, fragmentary remains from Patagonia have been referred to *Allosaurus* so characteristic of the American Morrison, but I seriously question the generic identity of any of the dinosaurs with North American forms. The presence of the earliest recorded remains near Bahia, on the line of march from the East, may be taken at its apparent value. I have found no evidence in favor of a north and south migration in the western hemisphere.

These studies only serve to verify for the most part the paleogeographical maps of de Lapparent and Schuchert, for in every instance, with the exception of Patagonia and where the dinosaur was found in salt water deposits, the locality fell upon a land area as indicated upon the maps. I would, however, differ from de Lapparent in his inclusion of New Zealand in the Gondwana continent after the beginning of the Trias. The finding of similar dinosaurs on either side of the Mozambique Channel during the Cenomanian, after the cleavage of Gondwana Land into an Indo-Madagascar and an Africo-Brazilian mass, has been explained by Depéret (1909, p. 303), who assumes that a temporary closure of the gap occurred. As the Madagascar types are mainly Sauropod, one of which was found associated with *Mytilus* and Foraminifera, the closure may not have been complete. It is not, however, necessary

to assume even a partial closure, as my map (fig. 9) will show. De Lapparent's maps show no connection between Gondwana Land and Patagonia until the Basal Eocene, which is too late for the migration of the Patagonian (Danian) dinosaurs from the northeast. The closure may have occurred not long before, however, so far as dinosaurian evidence is concerned.

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Art. II.—*The Origin of the Crinoidal Muscular Artic-
ulations ;* by Austin Hobart Clark.

The peculiarly complicated type of muscular articulation by
which the post-radial ossicles of the crinoids are joined together
is generally supposed to have been derived from the so-called
loose suture, the connective tissue of which has gradually
become differentiated into two different types of ligaments
and also into true muscle. The steps by which this process
has come about have never been satisfactorily shown.

While there appears to be in the crinoids a direct continuity
between the connective tissue through various types of liga-
mentous attachment to true muscle, yet it does not seem
probable that the differentiation of the connective tissue
between two adjacent ossicles could ever have progressed so far
as to produce the conditions found in the crinoids, where two
bundles of highly specialized muscle fibers occur, histologically,
as well as in their location, sharply differentiated from the
ligaments.

A comparison of the crinoids with the two most nearly related
recent classes, the Echinoidea and the Holothuroidea (Bohad-
schoidea), offers, however, an easy solution of the problem of
the origin of the complex crinoidal muscular articulations.

In the Echinoidea the plates are united more or less closely
by connective tissue, just as are the interradials and the
secondary perisomic plates generally in the recent crinoids, and
this was probably the original mode of union for the primary
ambulacral ossicles of the crinoids as well. Now in all the
heteroradiate Echinodermata (which include the Pelmatozoa,
Echinoidea, and Holothuroidea) wherever the ambulacral ossi-
cles or body wall are at all flexible, as occurs in the crinoids, in
the holothurians, and in the echinothurids among the echinoids,
each ambulacrum possesses a pair of longitudinal muscles one
of which runs along either outer border, and may extend itself
more or less inward. No definite homology has ever been
proved between these five longitudinal ambulacral muscle pairs
which are so constant in all the recent heteroradiate Echino-
dermata possessing the possibility of ambulacral motion ; but
from the uniform presence and location of these muscles it
seems most probable that such homology actually exists.

Now if the ancestral crinoids possessed a longitudinal muscle
along each border of the ambulacral series, as we must infer
from analogy with the echinothurids and the holothurians,
their closest recent relatives, we may assume an ambulacral
structure something like that of the former—a series of

ambulacral ossicles united by connective tissue with a longitudinal muscle band running interiorly along either side of the ambulacral series as a whole. It is easy to imagine that at first the muscle bands were fanlike in arrangement and broad as in the echinothurids, but later, with increased flexibility of the test, became narrow, and finally resolved themselves into longitudinal muscles more like those of the holothurians. With increased scope of motion between the ambulacral ossicles, beveling was induced, whereby the apposed faces of adjacent ossicles were in close apposition in the median line (perpendicular to the line between the center of the ossicle and the center of the calyx) but sloped away from each other both inwardly and outwardly. The connective tissue along this median line, the prototype of the so-called transverse ridge, now became very short and dense, forming what is practically a very narrowly linear close suture; while the connective tissue on the remainder of the articular surfaces was more or less lengthened, and gradually became ligamentous in nature, at the same time, through the separation of the internal edges of adjacent ossicles, the longitudinal muscle bands were, by pressure from within the calyx, pushed in between them, and certain of the fibers came to be inserted on the apposed faces of the ossicles instead of only on the ventral (interior) surface. This would give the ambulacral ossicles a joint face consisting of two equal oblong ligament fossæ, separated by a narrow transverse ridge, with a small muscular fossa at each outer corner of the inner ligament fossa. Now the calyx of the crinoids is remarkable for its very small size, and hence in the development of the race we may assume that this decrease in size has caused it to press more or less upon the internal organs. This pressure would not be equal at all points on the inner surface of the ossicles because of the existence of various radial vessels which run along the center of the ambulacra, chief among which is the axial nerve cord. These vessels would, by this pressure, encroach upon the area of the inner ligament fossa, and would tend to excavate it in the form of a more or less broad V, at the apex of which would be the axial nerve cord; at the same time the muscles would encroach more and more upon the articular face, and the part of the original muscular band which originally ran along the inner side of each individual ossicle, having now become useless, would disappear. The ventral ligament fibers, as a result of the decrease in the area of the fossa occupied by them through the encroachment of the " soft parts," not being able to migrate past the close suture along the transverse ridge, would come to lie more and more closely together, and would form two masses each more dense and compact than that of

the outer (dorsal) ligament mass, which remains unchanged. The muscles, unable to penetrate into the area occupied by the two resultants from the originally single inner (ventral) ligament mass, would gradually creep inward along their outer edge toward the center of the joint face. When the encroachment of the "soft parts" had progressed so far as to cause the axial nerve cord to lie upon the transverse ridge, we would find a condition as follows: first a large undivided dorsal ligament fossa occupied by more or less scattered contractile ligament, and bounded ventrally by the transverse ridge; just ventral to the transverse ridge would be found two triangular fossæ, one on either side, lying with their apices just under the center of the axial cord and one of their sides coinciding with the transverse ridge; these fossæ would lodge ligament masses similar to the dorsal ligament mass, but much more dense; on the outer distal corners of each of these two triangular fossæ would be found muscular fossæ, which would extend more or less inward toward the center of the joint face, but which would never meet in the median line. Thus we have arrived at the type of muscular articulation characteristic of the crinoid arm, comprising a single dorsal ligament fossa, two interarticular muscular fossæ, and two ventral muscular fossæ. This theory of the genesis of the crinoidal muscular articulations (1) explains the peculiar denseness of the interarticular ligament masses, and (2) does away with the necessity of assuming that the muscles are the specialized connective tissue of an original loose suture.

I have already shown how the peculiarly modified non-muscular articulations, the syzygy and the synarthry, are derived from the muscular type of articulation; so that now we are enabled to derive every known type of union between the ossicles of the crinoid crown from the simple connective tissue union known as the loose suture.

A few words in regard to the syzygy may not be out of place. Minckert, like all his predecessors except Sars, believes that the syzygies are joints of especial weakness in the crinoid arm where fracture takes place in case the arm is seized, due to this especial weakness. He also believes that in adolescent autotomy the arm is voluntarily cast off by the animal at the first syzygy. My experience with living crinoids has led me to agree with Sars; the syzygy is at least as strong as the muscular articulations, as anyone may prove for himself by breaking up crinoid arms. Under certain conditions, however, the syzygy becomes peculiarly weak, and often breaks of itself. I believe that this is susceptible of ready physiological explanation. Bosshard has shown that the fibers of the dorsal ligament and of the syzygy are histologically the same, the only

difference being that the latter are extremely short. Now since the fibers of the dorsal ligament and of the syzygy are identical except in length, we should expect that they both would possess the same physiological characteristics, and, therefore, that the fibers of the syzygy would be contractile in the same way that those of the dorsal ligament are, though their possible loss or gain in length, owing to their shortness, would be very slight. As the fibers of the syzygy are continuous in substance through the organic base of the ossicles with those of the dorsal ligaments preceding and succeeding, it is probable

FIGS. 1–5.
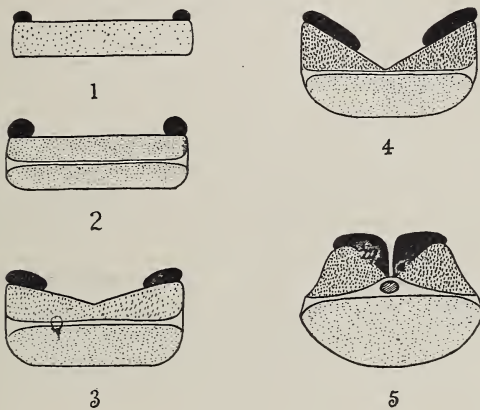
Diagrams illustrating the origin of the muscular articulations of Crinoids.

FIG. 1. The primitive joint face, with connective tissue binding ; the two longitudinal ambulacral muscles are seen on the outer angles.

FIG. 2. A joint face differentiated by the development of a transverse ridge ; the connective tissue on either side has become ligamentous, and the muscles have increased in size.

FIG. 3. A joint face showing reduction of the internal fossa by pressure of the " soft parts :" the ligament of the internal fossa is becoming denser ; the muscles have increased in size.

FIG. 4. The internal fossa has now become divided into two interarticular ligament fossæ, lodging dense ligament bundles ; the muscles have become still larger.

FIG. 5. Radial face of one of the Zygometridæ.

that they act in sympathy with them, expanding and contracting, in their small way as they do. It may be readily supposed that the tension of the fibers in the syzygy is adjusted to the ordinary movements of the crinoid arm. The dorsal ligaments are normally always antagonized more or less by the powerful ventral musculature and ordinarily never contract to their furthest capacity. If for any reason the ventral muscles are rendered inert, as by the panic incident to capture, then

the dorsal ligament would contract to the farthest limit, and the fibers in the syzygies, through sympathetic action, would also contract, but, being normally under more or less tension, would not be able to take up this contraction within themselves, but would be pulled apart, thus breaking off the arm at the syzygy. Fracture of the arms at the syzygies, then, would appear to be an entirely involuntary act on the part of the crinoid, due solely to the physiological effects of panic; this panic may, of course, be more or less general, or localized, so that stimulus of the calyx would induce fracture at the first brachial syzygy, stimulus on the arms at the neighboring syzygies.

During the growth of most of the oligophreate comatulids the ten original arms are cast off, often at the first syzygy, and from the stumps axillaries arise bearing several arms. Minckert supposed that this was a voluntary action; but it is noticeable that all the comatulids which have more than ten arms have short brachials which are correlated with a corresponding shortness in the muscle fibers and dorsal ligament fibers uniting them. Now it seems probable that during growth the dorsal ligament fibers are able to accommodate themselves gradually to their decreasing length through their contractile power; but this would have exactly the same effect upon the syzygies as panic—they would be torn apart—so that the casting off of the arms of the ten armed young of the oligophreate comatulids appears to be, not a voluntary action, but a direct result of the gradual change from the juvenile to the adult type of brachial.

Art. III.—*On the Substitution of Bromine and of Iodine for Chlorine in the Separation of Cerium from the other Cerium Earths;* by Philip E. Browning and Edwin J. Roberts.

[Contributions from the Kent Chemical Laboratory of Yale Univ.—ccvi.]

One of the best known processes for the separation of cerium from lanthanum and didymium is that of Mosander.* This process consists in passing chlorine gas into a mixture of the hydroxides suspended in a distinct excess of a fixed alkali hydroxide, until the solution is saturated and the reaction of the liquid is no longer alkaline to litmus. Under these conditions nearly all the cerium remains undissolved as the ceric hydroxide, while the other cerium earths go largely into solution. In treating mixed material the residue of ceric hydroxide generally retains some of the cerium earths so that the treatment with chlorine must be repeated. Two disadvantages associated with this method therefore are, the preparation and use of chlorine gas, and the solvent action of the hydrochloric acid formed in the reaction upon the ceric hydroxide

$$2Ce(OH)_3 + Cl_2 = 2CeO_2 + 2HCl + 2H_2O.$$

The work to be described was undertaken to study the effect of substituting bromine or iodine for chlorine in this process. A preliminary experiment was made by suspending a precipitate of the washed hydroxides of the cerium earths in water, adding a little liquid bromine, and allowing the action to go on for several hours with occasional stirring. The precipitate took on the color of the ceric hydroxide, and on filtering the filtrate was found to contain a considerable amount of cerium earths free from cerium.

In the following experiments solutions of known amounts of the mixed oxides, composed of about 50 per cent of cerium and 50 per cent of the cerium earth oxides other than cerium, were treated with a slight excess of sodium or potassium hydroxide. To these hydroxides suspended in the alkaline solution, liquid bromine or bromine water was added in distinct excess, and the mixture was placed upon a steam bath until the greater part of the free bromine was expelled. The residue was then filtered off, washed, and treated as before. This process was repeated twice, and the filtrate after each treatment was found to contain the amounts of cerium earth oxides, free from cerium, indicated in the table. The residue from the last treatment on being dissolved in acid showed only

* J. prakt. Chem., xxx, 267.

faint didymium bands. In experiment (6) the indication of the presence of didymium was very faint. In another experiment the same amount of material used in (5) and (6), 10 grams, was subjected to a fourth and fifth treatment with bromine, the fourth treatment yielding a small fraction of a gram of the oxides, and the fifth only a few milligrams. In both cases these oxides were free from cerium. The oxides from the first filtrates were much lighter in color than those obtained from the last, which, of course, indicates that the lanthanum is dissolved by the action of the bromine more readily than the didymium. The results follow in the table :

	Mixed oxides taken grm.	Oxides found in first filtrate grm.	Oxides found in second filtrate grm.	Oxides found in third filtrate grm.	Total oxides found grm.
(1)	1·0000	0·3310	0·0720	0·0190	0·4420
(2)	1·0000	0·2900	0·1010	0·0420	6·4330
(3)	1·0000	0·2250	0·1290	0·0640	0·4180
(4)	1·0000	0·2750	0·0860	0·0740	0·4350
(5)	10·0000	3·1360	1·0050	0·5930	4·7340
(6)	10·0000	3·4590	0·5240	0·8560	4·8390

So it has been shown that by substituting bromine for chlorine in the Mosander process about 50 per cent of the other cerium earths can be separated from ceric hydroxide in one treatment, and that after three treatments practically all the other cerium earths are removed without any solvent action upon the ceric hydroxide. The advantages of the method are, the convenience in the use of the bromine, and the apparent lack of tendency of the hydrobromic acid to dissolve the ceric hydroxide.

An experiment was made, using iodine in place of bromine, as follows : The precipitated and suspended hydroxides from 2 grams of the mixed oxides were treated with 1 gram of solid iodine. After standing for about two hours on a steam bath, the excess of iodine was removed by boiling, and the residue of hydroxides was filtered off. The filtrate gave 0·0980 grm. of oxides, free from cerium, and of a slight brown color. This shows that the action of iodine is the same, in a general way, as that of chlorine and bromine, but is too incomplete to be of any practical value.

Art. IV.—*New Fossil Coleoptera from Florissant, with Notes on some already described;* by H. F. Wickham.

Calosoma Web.

C. cockerelli n. sp.   A piece of a wing cover lacking both base and apex is referred to this genus.   It represents a species about the size of *C. calvini* m., from the same shales.   The elytron is marked with sixteen well impressed punctured striæ, besides an indeterminate number (perhaps two) closer to the outer margin.   The interspaces are nearly four times as wide as the diameter of the punctures in most parts of the area, but in the neighborhood of the apex of the tenth and eleventh striæ the punctures are much larger than elsewhere and are equal in diameter to the interstitial width.   In general, the punctures are rounded or slightly elongate and they are separated longitudinally by spaces about equal to their own diameters.   The elytral surface shows no indication of the coarse imbricate scabrosity of the interstrial spaces which is evident in our recent North American *C. calidum*, nor are any series of interstitial punctures visible.   The interspaces are apparently slightly convex.   Length of fragment about 9·25^{mm}, greatest width 6·15^{mm}.

Station number not given.   Collection number 232, Florissant Expedition 1906.   Received from Prof. Cockerell.   Holotype in Peabody Museum of Yale University.   Cat. No. 10.

Pterostichus Bon.

P. pumpellyi Scudder.   An elytron showing obverse and reverse is referred here with fair certainty.   The elytral striæ are nine in number and are more clearly exhibited on the reverse.   They are fine, sharp, fairly deep, perfectly smooth, the interspaces moderately convex.   The scutellar stria joins the first at about 1·75^{mm} from the base.   Length 9·75^{mm}, width 3·40^{mm}.

Station number 13.   Collection number, obverse 87, reverse 65, Florissant Expedition 1906.   Received from Prof. Cockerell.

Platynus Bon.

A specimen in obverse and reverse, believed to belong to this genus, is among the material sent by Prof. Cockerell. The elytra are 6·20^{mm} in length, and have a conjoint width of 4·10^{mm} at middle.   They are finely striate, about as in our recent *P. placidus*, and are apparently almost or quite impunc-

tate.   Compared with *P. tartareus* Scudder, from the Floris-
sant shales, the specimen in hand has the humeral angles less
rounded and the elytral apices decidedly less truncate.   The
remainder of the body is too poorly preserved for study, and
it seems scarcely wise to impose a specific name.

Station number 13a.   Collection numbers 114 and 155,
Florissant Expedition 1906.   Collected by Mrs. W. P.
Cockerell, and received from Professor Cockerell.   Specimen
in the Peabody Museum of Yale University, Cat. No. 11.

Peltis Illiger.

P. laminata n. sp.   Form oblong-elliptical, similar to that
of the recent North American *P. pipingskœldi*.   Head larger
than in that species, somewhat dilated by pressure.   Prothorax,
as preserved, broader shortly in front of the base, sides arcu-
ately narrowed to apex which is broadly emarginate, front
angles a little greater than right, hind angles obscure but
apparently obtuse and rounding, a faint basal marginal line
somewhat as in Colorado specimens of the recent *P. ferruginea*.
Elytra slightly broadest at base, where they are a little wider
than the prothorax, scarcely perceptibly narrower to a point
behind the middle, thence rapidly arcuately narrowed to the
apices, which are nearly pointed and (through distortion)
dehiscent.   The disk shows traces of having been finely striate
but the sculpture of the entire surface is now scabrous and
obscure.   The sexual organs are protruded from the tip of the
body but show no definite structure.   Length, including
extruded sex organ, $12 \cdot 50^{mm}$; of prothorax along median line,
$2 \cdot 25^{mm}$; of elytra, $6 \cdot 60^{mm}$; width of prothorax, 5^{mm}; of elytra
conjoined, $6 \cdot 25^{mm}$.

In outline, this insect quite closely recalls several recent
species of *Peltis*, though the form of the thorax is slightly
nearer that of *Calitys scabra*.   However, the thoracic and
elytral margins are perfectly clear-cut and entire as in *Peltis*,
while in our *Calitys* they are coarsely serrate.   The antennæ
and legs are not shown.

Station number R. 4.   Collection number 145, Florissant
Expedition 1906.   Received from Prof. Cockerell.   Holotype
in the Peabody Museum of Yale University, Cat. No. 12.

Atœnius Harold.

A. patescens Scudder.   One specimen, in reverse, exceeding
Scudder's measurements by about $\cdot 50^{mm}$, is included in the
collection.   The state of preservation is only fair and no
important characters can be added to the original description.

Station number 14.   Collection number 207, Florissant
Expedition 1906.   Received from Prof. Cockerell.

Aphodius Illiger.

A. laminicola n. sp.   Form stout, evidently a little more so than in the recent *A. fimetarius*, head narrowed anteriorly, clypeus almost squarely truncate at middle, the angles rounded. Prothorax broadest about the middle, sides apparently regularly arcuate but not alike in the specimen and therefore incapable of exact definition. The appearance is that the base was distinctly broader than the apex. Sculpture obliterated by the impressions of the underside, which show through. Scutellum (?) large, almost equilaterally triangular, the basal (anterior) angles obliquely truncate, basal region rugosely punctate, middle finely carinate. Elytra subparallel to an indeterminate distance behind the middle, regularly conjointly rounded at tip, striæ fine, single, finely and not closely punctured, interspaces broad and very nearly or quite flat with a few scattered fine punctures, sutural interval narrower than the next. Legs stout, middle tibia slightly bent at base, tip moderately expanded, median oblique ridge faintly indicated. Length 9.70^{mm}, of elytra 5.75^{mm}, of middle femur about 1.70^{mm}, of middle tibia 1.35^{mm}, of middle tarsus about 1.35^{mm}, conjoint width of elytra about middle 4.80^{mm}.

Station number 14. Collection number 231, Florissant Expedition 1906. Received from Prof. Cockerell. The type is in the Peabody Museum of Yale University (Cat. No. 13); a second, poorer specimen, a reverse, from the same station and with the catalogue number 140, is in the Museum of the University of Colorado.

The type specimen is very puzzling, on account of the peculiar state of preservation; the parts of the under side are largely shown through and interfere with the view of the upper surface. Thus I am not sure whether the structure described as the scutellum may not be the mesosternum, and on account of similar confusion I have not tried to give measurements for the head and prothorax. Of the legs, the two middle femora show plainly, the front and hind ones indistinctly. One middle tibia and the tarsus of the opposite leg are distinct.

Amphicoma Latr.

A. defuncta n. sp.   The specimen shows only the tips of the elytra, with ill-defined exposed portions of the abdominal apex, some traces of hind wings, a well preserved hind tibia and tarsus and poorly indicated portions of the other leg of this pair. Elytra strongly dehiscent and tapering to the tip, which is rounded, surface clothed with hairs which are apparently longer and sparser than in the recent California *A. ursina*. The outer edge of each elytron shows a fine marginal bead, as in that species; the sutural bead is less strongly marked. No

indication of discal sculpture, aside from the fine piligerous punctures, can be seen. The exposed tibia of the hind leg is perhaps a trifle stouter than in *A. ursina,* about equally broadened to the tip, the lateral margins (perhaps accidentally) irregular; one terminal spur shows, which is more than half as long as the first tarsal joint, but the extreme apex is concealed so that the exact length cannot be determined. Tarsi rather stout for this genus, the first joint longest (about one third longer than the one following) third and fourth joints nearly equal to each other and slightly longer than the second, claw joint again longer but ill defined, claws not in condition for study. Apparently, the first, second and third tarsal joints were finely longitudinally carinate above, a feature that I cannot detect in any recent *Amphicoma* at my disposal. Neither do I find any certain evidence that the legs were hairy, though I believe that certain sculpturings on the tibia represent piligerous punctures. The tarsal joints surely bore short stiff hairs on their margins, as in the recent *A. vulpina* from the New England coast. Width of elytral fragment, at 5^{mm} from tip, 3^{mm}; length of tibia, 4·75^{mm}; of tarsus, entire, 7·25^{mm}; of first joint about 1·75^{mm}.

Station number 14. Collection number 186, Florissant Expedition 1906. Received from Prof. Cockerell. The holotype is in the Peabody Museum of Yale University, Cat. No. 14.

Lema Fabr.

L. evanescens n. sp. Form similar to that of the recent *L. collaris* and equally stout. As the type is largely in profile, it is not possible to give comparative measurements of the length and breadth of different parts of the body, though the head, with greater portions of the eyes and antennæ, the prothorax, elytra, abdomen, and parts of the legs are more or less clearly shown. The antennæ are very nearly approximate at base and are stout, the intermediate joints but very little longer than broad; the eyes are large and prominent, legs stout. The specimen is a reverse, and lines of small elevations indicate that the elytra were punctured in rows similarly to most of our recent North American species. Total length, 5·60^{mm}; of elytron, 3·60^{mm}.

Station number not given. Collection number 86, Florissant Expedition 1906. Received from Prof. Cockerell. Type in Peabody Museum of Yale University, Cat. No. 15.

A second specimen, collected at Florissant in 1906 but with no station designated though bearing the collection number 107, is less in profile than the first and indicates that the prothoracic constriction was slightly antemedian and fairly deep. In this the broader elytron is 3·65^{mm} in length and about 1·30^{mm} in width.

Ologlyptus Lacordaire.

O. primus n. sp.   The rather poorly preserved specimen indicates a species of moderate size and probably flattened form, approximating that of our recent *O. anastomosis.* The prothorax is broadest near the middle, sides regularly rounding, apex considerably narrower than the base but owing to incompleteness of the specimen the exact proportions cannot be given.   Head obscured, antennæ with the median joints about as broad as long.   Elytral sculpture apparently rough, but no details can be made out.   Legs wanting.   Length of specimen, which lacks a small portion of the tip of the elytra, 7.25^{mm}; of prothorax about 2.15^{mm}; width of elytra, conjoint, 3.65^{mm}; of prothorax (distorted ?), 2.75^{mm}.

Station number 13.   Collection number 154, Florissant Expedition 1906.   Received from Prof. Cockerell.   Holotype in the Peabody Museum of Yale University, Cat. No. 16.

The generic reference is not made with any great certainty, but the facies is decidedly that of several recent species of *Ologlyptus*, with which it has been directly compared.   The prothorax appears to have the basal margin extending farther backwards than the points of the hind angles, much as in the Mexican *O. sinuaticollis* but to an even greater degree.

Macratria Newm.

M. gigantea n. sp.   Form elongate, head small, short, prothorax very long and narrow, elytra conjointly much broader than the prothorax, sides subparallel, apices rounded, surface finely, distinctly and rather closely striate, the striæ finely, not closely punctured, interspaces flat.   Middle leg not elongate and only moderately stout.   Antennæ showing only a few intermediate joints which are sufficiently well preserved to indicate that they are longer than wide, but not greatly elongate.   Length from front of head to tip of elytra, but exclusive of projecting abdominal organs, 8^{mm}.   Length of head, as preserved, 1^{mm}; of prothorax, 2.10^{mm}; of elytra, 5.10^{mm}. Width of prothorax about 1.50^{mm}, of elytra, conjointly, 2.50^{mm}. The articulations of the leg joints are not well enough defined to permit of accurate measurements.

Station number 14.   Collection number 9, Florissant Expedition 1906.   Received from Prof. Cockerell.   Holotype in the Peabody Museum of Yale University, Cat. No. 17.

The specimen has a decidedly Anthicide look, and in build as well as sculpture resembles our recent North American species of *Macratria* though far exceeding them in size. Possibly it may represent an extinct allied genus, but no characters are evident upon which to base a separation.

Iowa City, Iowa.

Art. V.—*A Feldspar from Linosa and the Existence of Soda Anorthite (Carnegieite)*; by Henry S. Washington and Fred. Eugene Wright.

The mineral described in this paper was found as loose crystals, together with crystals of kaersutite, at a small parasitic cinder cone of the volcano Monte Rosso, on the island of Linosa, east of Tunis.[*] The chemical investigation was undertaken by the senior author and the optical by the junior.

Physical Characters.

The dark brown, pumiceous, basaltic lava clings so tenaciously to the crystal faces that it was not possible to obtain satisfactory material for crystallographic measurements.   The crystals vary much in size, the largest one measuring 3.5^{cm} in length and about 2^{cm} in width.   While some are fragmentary, others are wholly bounded by crystal faces.   They are elongated parallel to the a axis, and are of simple crystal habit, being bounded by the forms (001), (010), (110), and (1$\bar{1}$0), on the assumption that the mineral is a triclinic feldspar.

Although the crystal faces do not lend themselves to goniometric measurement, the basal cleavage is highly perfect, and albite twinning lamellæ are occasionally well developed.   On such a cleavage flake the angle between the basal cleavage planes of two adjacent albite lamellæ was measured on a two-circle goniometer with reducing attachment, and found to be $8°\ 3'$.   From this the angle $(001) \wedge (010) = 85°\ 59'$ can be deduced, this angle for albite being $86°\ 24'$, for anorthite $85°\ 20'$, and for labradorite $86°\ 12'$.   The cleavage after (010) is very imperfect, as is often the case with the soda-lime feldspars, and only indications of cleavage after the prism faces (110) and (1$\bar{1}$0) were noted.   When the cleavage does not control, the fracture is highly conchoidal.   Viewed along certain directions, especially about normal to the front pinacoid, a peculiar, milky, opalescent sheen, resembling that of moonstone, can be seen in some of the crystals.

Fine polysynthetic twinning lamellæ after the albite law are not uncommon, and occasionally cross polysynthetic twinning lamellæ, probably after the pericline law, were observed.   On a plate nearly normal to the obtuse bisectrix the angle between the albite and the pericline twinning lamellæ was found to be $94°$.

The specific gravity was determined (by H. S. W.) with the pycnometer on two separate portions of the carefully selected

material used for the chemical analyses, and was found to be 2·692 at 3° and 2·693 at 17°. The latter may, therefore, be considered to be the specific gravity of the mineral, or, rather, correcting for about 0·75 weight per cent, or 0·35 volume per cent, of included magnetite, the true specific gravity of the mineral would be 2·684. The hardness is slightly less than that of adularia, but not far from 6.

Except for ferruginous stains derived from the inclosing basaltic scoria on the exterior portions of the crystals, and the very small and rare inclusions of magnetite to be described later, and which did not interfere with the optic determinations, the material is remarkably fresh, colorless and transparent, and admirably adapted for optic work. Zonal structure was not evident.

The refractive indices were measured in sodium light on an Abbé–Pulfrich total refractometer, the probable error of the values being less than ± ·001, with the following results:

$$\alpha_{Na}=1·5549, \quad \beta_{Na}=1·5587, \quad \gamma_{Na}=1·5634,$$
$$\gamma-\alpha=0·0085, \quad \gamma-\beta=0·0047, \quad \beta-\alpha=0·0038$$

According to these values the measured crystal plate was optically positive and $2V_{Na}=82° 48'$. On a second, less perfect plate slightly higher values were obtained, but the observed differences were only a little greater than the probable error.

The optic axial angle was measured directly on a Wülfing axial angle apparatus in sodium light, the plates being immersed in a liquid of the refractive index 1·559, the observed readings giving, therefore, at once the true optic axial angle $2V_{Na}$. Five plates normal to the bisectrix c and one plate normal to α were measured. The values thus obtained did not agree well, and several of the plates were remeasured with practically the same results.[*] The probable error of the values in the following table is certainly less than ±30'.

Crystal plate	$2V_{Na}$	Dispersion	Optical character	Extinction angle,[†] $\alpha \wedge a$
1	78° 0'	$\rho > v$	+	28·0°
2	78° 29'	- - - -	+	12·0°
3	84° 29'	$\rho > v$	+	6·2°
4[‡]	85° 41'	- - - -	+	33·0°
5	89° 27'[§]	- - - -	—	11·9°
6	88° 59'[‖]	- - - -	—	13·0°

[*] We are indebted to Mr. E. S. Larsen, jr., of the Geophysical Laboratory, for an independent measurement of the optic axial angles of the entire set. His results are practically the same as those in the table, the greatest differences being 20' on a less favorable plate.

[†] Too much stress cannot be placed on these extinction angles, since the plates were cut only approximately normal to the bisectrices and were out a number of degrees in certain instances.

[‡] Plate cut normal to the obtuse bisectrix. 94° 18' measured.

[§] 90° 33' measured.   [‖] 91° 1' measured.

These variations are of considerable magnitude and the values seem to differ from crystal to crystal rather than within a single crystal. This phenomenon of variation in optic axial angle might possibly be explained as a result of unequal cooling of the different crystals, as is the case with orthoclase and sanidine; but other evidence, particularly that of the extinction angles, shows that the composition probably varies slightly from crystal to crystal.

The extinction angles were measured both on cleavage flakes after (001) and on (010). In each case the angles were measured as accurately as possible, with the aid of the circularly polarizing bi-quartz wedge,* and the probable error is less than 15′.

On (001) the values for $a \wedge \mathfrak{a}$ ranged from $-0 \cdot 6°$ to $-4 \cdot 5°$, and on basal cleavage flakes from one crystal the angles averaged $-2 \cdot 0°$, and from a second $-4 \cdot 5°$. Other pieces showing polysynthetic lamellæ were observed occasionally with very high extinction angles; but the examination in convergent light, and also the determination of the ellipsoidal axis, whether $\mathfrak{a}$ or c, proved that either the cleavage fragment was not parallel to the base or that pericline lamellæ were being examined.†

Extinction angles were also measured on the brachypinacoid (010), both on the rhomb-shaped cleavage flakes and also on a section ground parallel to the brachypinacoid. Different values were obtained for different flakes, although in the larger ground plates no marked indications of wavy extinction or zonal structure were observed. The values ranged from $a \wedge \mathfrak{a} = -2 \cdot 5°$ to $-11°$. Since, however, the cleavage parallel to (010) is not perfect, it is possible that part of this variation was due to the fact that the surfaces were not precisely parallel to (010) at the place of measurement, but were inclined because of minute irregularities of the cleavage. Flakes parallel to (010) often show in white light the peculiar interference phenomena characteristic of minerals with slight dispersion of the bisectrices.

In convergent polarized light the optic normal emerges near the center of the field on plates parallel to (001); while the bisectrix c is nearly normal to the brachypinaoid, and appears near the center of the field on flakes parallel to (010).

Taken collectively, these results indicate that the present material is a plagioclase feldspar, of somewhat variable composition and with slightly modified characters. Taken alone,

* Cf. F. E. Wright, this Journal, vol. xxvi, p 391, 1908.

† A series of measurements on 12 different cleavage flakes from one of the crystals was also made by Mr. E. S. Larsen, with the result $a \wedge \mathfrak{a} = 2° \ 2' \pm 6'$, a value well in accord with Wright's observations.

the extinction angles on (001) would indicate a feldspar composition ranging from about $Ab_{11}An_5$ to $Ab_{21}An_{20}$, while from those on (010) a composition from $Ab_{11}An_5$ to $Ab_{13}An_{10}$ and higher might be inferred. The values of the optic axial angle alone indicate variations from $Ab_{37}An_{20}$ to Ab_6An_5, according to the most accurate measurements of the different members of the plagioclase series. As a whole, therefore, the optic characters would show that we have an andesine feldspar of a composition somewhat more sodic than Ab_1An_1, on an average about Ab_3An_2, while the specific gravity is almost exactly that of a labradorite of the composition Ab_1An_1, or (corrected) of an andesine Ab_5An_4.

Chemical Composition.

The material used for the chemical analyses was obtained by coarsely crushing several of the crystals and fragments and very careful hand-picking under the lens. It was found to be impossible to separate the portions contaminated with adherent basaltic scoria by means of heavy solutions. Because of the similar specific gravities, particles with and without attached scoria floated and sank together. In the heavy solution the material used for analysis seemed to be homogeneous.

All the material analyzed was perfectly fresh, colorless, and water-clear, and consisted of but one mineral, so far as could be ascertained by examination under the microscope. While the greater portion was entirely free from inclusions, it was impracticable not to use some fragments containing inclusions, and as these have a bearing on the chemical discussion, they may be briefly described here. Apart from them the material was perfectly pure and admirably suitable for chemical analysis.

The inclusions are never very abundant, especially in the fragments used for the analyses. They are very minute in size, the largest being 0.5^{mm} long by 0.1^{mm} wide, and the great majority are much smaller. They are of uniform character, in the form of narrow, spindle-shaped bodies or thin cylinders with rounded ends. They are black, with metallic luster, and perfectly opaque, so that they may be regarded as essentially magnetite, a conclusion also indicated by the results of the analyses.

The feldspathic mineral is only slightly acted on by hot, dilute hydrochloric acid, even after prolonged treatment, so that the main portion was brought into solution by fusion with mixed sodium and potassium carbonates. In this, as in other respects, the analyses were made by the methods advocated by Hillebrand and by Washington, the alkalies being determined by the Smith method.

An analysis was made in duplicate (except for FeO, the alkalies and H_2O) on one lot of selected fragments, portions of which also served for the specific gravity determinations, the material being dried at 110°. As the results were decidedly unexpected, especially in view of the preliminary optic work, a second lot of fragments was analyzed, special care being taken to select, so far as possible, only those showing cleavage surfaces, so as to exclude any possible nephelite. The results of the three analyses, with the average and the molecular ratios of this last, are given below.

	I	II	III	Average	
SiO_2	52·73	52·75	52·83	52·77	·874
TiO_2*	trace	trace	trace	trace	
Al_2O_3	29·34	29·54	29·63	29·50	·290
Fe_2O_3	0·67	0·75	0·53	0·65	·004
FeO	0·17	(0·17)	(0·17)	0·17	·002
MgO	0·03	0·05	0·07	0·05	·001
CaO	10·73	10·59	10·67	10·66	·190
Na_2O	5·40	(5·40)	(5·40)	5·40	·087
K_2O	0·74	(0·74)	(0·74)	0·74	·008
H_2O	0·38	(0·38)	0·34	0·36	
	100·19	100·37	100·38	100·30	

The very small amounts of iron oxides and magnesia are evidently derived from the small, opaque inclusions. Ferric oxide is in excess of ferrous, but in the determination of such small amounts the fact is not of much significance, so that the figures bear out the microscopic examination in the conclusion that the inclusions are of a (non-titaniferous) magnetite. They also probably contain the magnesia. We may, therefore, safely reject the small amounts of ferric and ferrous oxides, magnesia and water, which last is to be ascribed to adsorption of atmospheric moisture† by the powder. On this basis the composition deduced from the analysis will be as follows :

	Linosa mineral			$(\frac{4}{5}Na_2\frac{3}{5}Ca)Al_2Si_3O_{10}$	Ab_1An_1	Ab_3An_2
SiO_2	53·26	·882	9·09	52·84	55·67	58·24
Al_2O_3	29·78	·291	3·00	29·94	28·26	26·53
CaO	10·76	·192	1·98	10·96	10·34	8·32
Na_2O	5·45	·088	} 0·99	6·26	5·73	6·91
K_2O	0·75	·008		0·00	0·00	0·00
	100·00			100·00	100·00	100·00

* The color produced by H_2O_2 in the solution used for the titration of iron as Fe_2O_3 was barely perceptible, so that only faint traces of titanium can be present.

† Cf. Day and Allen, Carnegie Publication, No. 31, 1905, p. 57.

The ratios of the Linosa mineral are very close to whole numbers, though there is a slight excess of silica. Calculating the small amount of potash with the soda, the figures of the analysis correspond to the formula $Na_2O.2CaO.3Al_2O_3.9SiO_2$, which, simplified, becomes $(\frac{1}{3}Na_2,\frac{2}{3}Ca)Al_2Si_3O_{10}$. The percentage composition of this molecule is given above.

No anhydrous silicates with formulas corresponding to this appear to be known independently, but several zeolites are analogous, namely: wellsite, $(K_2,Ca,Ba)Al_2Si_3O_{10}+3H_2O$; edingtonite, $BaAl_2Si_3O_{10}+3H_2O$; natrolite, $Na_2Al_2Si_3O_{10}+2H_2O$; and a potassium natrolite observed by Pirsson[*] in missourite with the approximate composition $(K_2Ca)Al_2Si_3O_{10}+2H_2O$. Indeed, the composition of the Linosa mineral is exactly that of a mesolite, $(mNa_2Al_2Si_3O_{10}.2H_2O+nCaAl_2Si_3O_{10}.3H_2O)$, with $Na_2O:CaO=1:2$, and lacking the water.

Compounds of this type can be regarded as salts of the alumo-trisilicic acid $(H_2Al_2Si_3O_{10})$ of Morozewicz,[†] the potassium salt of which he considers as present in nephelite, with varying proportions of the sodium alumo-disilicate, $(Na_2Al_2Si_2O_8)$. Reduced to still simpler terms they would be salts of the acid $H_8Si_3O_{10}$, for which Vogt[‡] proposes the name pyrosilicic acid. He refers akermanite and gehlenite to this simple formula, as does Tschermak[§] the mineral melilite.

Comparing the composition of our mineral with those of the two plagioclases, Ab_1An_1 and Ab_3An_2, which it closely resembles in its physical properties, it will be seen from the table above that Ab_1An_1 shows closely concordant figures for lime and soda, while silica is distinctly higher and alumina lower; and that, on the other hand, Ab_3An_2 shows much higher silica and slightly higher soda, but lower lime and alumina. In fact a composition satisfactorily close to that of the Linosa mineral as regards all the constituents, and furnishing like ratios, cannot be calculated from mixtures of the albite and anorthite molecules.

The relations may be better seen in the respective ratios, as shown when the formulas are compared, as follows:

Linosa mineral $= Na_2O.2CaO.3Al_2O_3.9SiO_2$.
Labradorite $(Ab_1An_1) = Na_2O.2CaO.3Al_2O_3.10SiO_2$.
Andesine $(Ab_3An_2) = 3Na_2O.4CaO.7Al_2O_3.22SiO_2$.

Discussion.

The data given in the preceding pages make it clear that the physical and chemical characters of our mineral are at variance. The crystal system, twinning laws, cleavage, and hardness are

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[*] Weed and Pirsson, this Journal, ii, p. 320, 1896.
[†] Morozewicz, Bull. Acad. Sci. Cracov., p. 999, 1907.
[‡] Vogt, Mineralbildung in Schmelzmassen, p. 162, 1892.
[§] Tschermak, Lehrbuch der Mineralogie, p. 523, 1905.

those of the lime-soda feldspars. The specific gravity, the crystallographic angles measured and the birefringences are those of a labradorite of about the composition Ab_1An_1. Although the optic axial angle and the extinctions are decidedly variable, they correspond to those of andesines somewhat more sodic than Ab_1An_1, on the average about Ab_3An_2. On the other hand, the chemical composition is not that of any possible member of the normal plagioclase series, or mixtures of albite and anorthite. The ratios of Al_2O_3, CaO and Na_2O are those of Ab_1An_1, but the amount of SiO_2 is lower than that demanded for these by the known feldspar formulas, and the mutual ratios of this with those of the other constituents indicate a composition which corresponds to that of an anhydrous mesolite, or a salt of the acid $H_2Al_2Si_3O_{10}$, with $Na : Ca = 1 : 1$. Our mineral is, therefore, physically closely allied to labradorite and andesine, but chemical distinctly different in the ratios of the constituents.

The possibility that the material analyzed was a mechanical mixture of particles of two minerals, such as labradorite and nephelite, and that only fragments of the former were subjected to optic investigation, is rendered untenable by the following facts. Careful examination of the unbroken crystals, as well as microscopic study of the crushed fragments and cleavage flakes, by both of the authors independently, revealed the presence of but one mineral, colorless, transparent, cleavable and feldspar-like. Apart from the small, opaque inclusions, each crystal appeared to be homogeneous, and all appeared to be of identical material, except for the optic variations. The action of hydrochloric acid showed that no readily decomposable mineral was present as separate individuals. The very close agreement between separate portions in specific gravity and in chemical composition renders the mathematical chances against the hypothesis of a mechanical mixture of particles of two minerals so great that it may be safely eliminated from consideration. Finally, the lavas of Linosa are all typical feldspar basalts, and only a few very small amounts of nephelite possibly existent as a glassy base. Assuming, therefore, that the material was homogeneous, two hypotheses present themselves to account for the anomalies observed.

One is that the Linosa mineral is to be regarded as a distinct species, chemically, of the formula $Na_2Ca_2Al_6Si_9O_{33}$, but with physical properties which correspond very closely to those of a plagioclase of the composition Ab_1An_1 to Ab_3An_2. The uniformity of the material as shown by the specific gravity and the chemical analyses and, above all, the very close approach to exact rationality of all the ratios, are in favor of this view. But the peculiarities of chemical composition are explicable in

another way, and as it would be contrary to our notions of the definitions of mineral species to consider two chemically similar minerals as distinct which possess essentially identical crystallographic form and physical and optic properties in so many respects, we may also disregard this hypothesis.

The alternative view is that the mineral is a labradorite of abnormal optic characters and chemical composition, due to the presence of another mineral in intimate molecular mixture as a mixed crystal or solid solution. The amount of this must be small, and in its optic characters the subordinate mineral should presumably resemble a plagioclase, since the optic constants of the Linosa mineral are essentially those of a lime-soda feldspar, but indicate a composition somewhat more sodic than that indicated by the specific gravity.

The range of possibilities as to the mineral molecule which may be supposed to be admixed molecularly with the labradorite is very limited, as it must be, chemically, an aluminosilicate of either soda or lime, or of both of these, with alumina equal molecularly to the basic oxide or oxides, and with the ratio of silica to bases less than in labradorite. Furthermore, it seems necessary to assume that the base is soda alone, because if the subordinate mineral is purely calcic, all the soda entering albite, the lime must be equally distributed between the molecules $CaO.Al_2O_3.2SiO_2$ (anorthite) and $CaO.Al_2O_3.SiO_2$, to obtain the ratios and percentages shown by our mineral. This calcic subsilicate is not known to occur either in nature or artificially, its nearest analogue being kornerupine, $MgO.Al_2O_3.-SiO_2$, and its existence does not seem probable. Also no mineral in which $CaO + Na_2O = Al_2O_3$ is known which suits the requirements of the case.

The sodium-aluminum metasilicate, $Na_2O.Al_2O_3.4SiO_2$, occurs in nature as jadeite, and might also presumably exist as an isometric and isotropic soda-leucite. The presence of this molecule would yield a composition identical with that of our mineral, if soda is equally distributed between this and albite, the whole forming the mixture: $Na_2O.Al_2O_3.6SiO_2 + Na_2O.Al_2O_3.-4SiO_2 + 4(CaO.Al_2O_3.2SiO_2)$. But the presence of either of these mineral molecules may be considered as impossible here, on crystallographic as well as on optic grounds.

The most probable mineral molecule, therefore, is the orthosilicate $Na_2O.Al_2O_3.2SiO_2$. Assuming this to be present, the composition of the Linosa mineral in terms of mineral molecules can be calculated to be as follows :

$KAlSi_3O_8$ ---- ·016 ⎞	·154	7·84	4·48
$NaAlSi_3O_8$ --- ·137 ⎠			36·16
$CaAl_2Si_2O_8$ ---------- ·192		9·84	53·78
$Na_2Al_2Si_2O_8$ --------- ·019		1·00	5·58

Reckoning the small amount of potash as orthoclase with the albite molecule, the ratios of albite, anorthite and sodium alumino-metasilicate approximate closely to whole numbers, and are almost exactly $8:10:1$. The labradorite would thus have the composition Ab_4An_5, while we have seen that the optic data indicate that the mineral is actually somewhat more sodic, from about Ab_1An_1 to Ab_3An_2.

The molecule $Na_2Al_2Si_2O_8$ is that of potash-free nephelite, which does not seem to occur in nature, but which has been made artificially in small hexagonal crystals, much like those of nephelite, and with a specific gravity of 2.555.[*] If this mineral were present it would necessarily be as a mechanical mixture or as what has been termed [†] an "anomalous solid solution," since it is not crystallographically isomorphous with the triclinic albite and anorthite, and true solid solution or a mixed crystal, containing such an amount of the subordinate mineral as shown above, would hardly be expected in such dissimilar minerals.

True solid solution could take place, however, if the molecule $Na_2Al_2Si_2O_8$ is dimorphous, and a second form exists whose symmetry relations approximate those of anorthite and albite. The two formulas

$$\text{Anorthite, } CaO.Al_2O_3\ 2SiO_2$$
$$\text{Nephelite, } Na_2O.Al_2O_3.2SiO_2$$
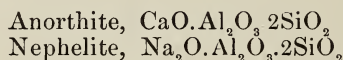
are identical, except that in the second Na_2O replaces the CaO of the first, and it is not out of the range of possibility that a soda anorthite should exist. This mineral is not yet known to occur in nature, but its presumable characters would harmonize the conflicting data. Thus, it should be triclinic and isomorphous with albite and anorthite, and therefore capable of forming mixed crystals with these analogous to the ordinary plagioclase series. Similarly, it would presumably possess optic characters more sodic, that is, more like those of a soda-lime feldspar, than those of purely calcic anorthite; so that we would thus have an explanation of the fact that, while the relations of CaO and Na_2O in our mineral are those of Ab_1An_1, certain of the optic characters are those of a more sodic plagioclase. Since the specific gravity of nephelite, and presumably also of the soda anorthite, is less than that of anorthite, the density of the mixed crystal should be less than that of the equivalent plagioclase in which no soda anorthite occurs, and we have seen that, while the normal plagioclase present is about Ab_4An_5, which would have a density of 2.698, the density of our mineral is that of Ab_1An_1 or Ab_5An_4.

[*] Cf. Hintze, Mineralogie, vol. ii. p. 97.
[†] A. Johnsen, Neues Jahrbuch, 1903, ii, p. 93.

From the above data on the percentage composition in terms of the different mineral molecules (Or, Ab, An, Ne), the specific gravity of the mineral can be calculated on the assumption that no great volume change in the component molecules has taken place, a condition which experience has shown to hold true for practically all cases of solid solution. The weight per cent of each molecule present, divided by its density in crystallized condition, furnishes its specific volume or its volume compared with water of equal weight. The sum of these specific volume values for all the molecules present denotes in turn the specific volume of the substance, the reciprocal of which is the density required. In this calculation the most accurate density determinations of the components were used, namely: Or = $2 \cdot 55$, Ab = $2 \cdot 605$, An = $2 \cdot 765$, and Ne = $2 \cdot 571$ (the last determined on artificial triclinic Na_2Al_2-Si_2O_8). The resulting density, $2 \cdot 685$, approximates very closely the measured density, $2 \cdot 693$, and is almost identical with this as corrected for the magnetite inclusions, $2 \cdot 684$. This in itself is a strong proof that the Linosa mineral is a mixed crystal of feldspar and soda anorthite.

This complex mineral would belong logically to the group of feldspars, just as do the barium-bearing members of the orthoclase-celsian series, some intermediate members of which are called hyalophane, and which contain the molecule $BaAl_2Si_2O_8$. In this connection it is interesting to note that a sodium-barium plagioclase, described by Des Cloiseaux,[*] was crystallographically similar to albite-oligoclase, optically like a labradorite, and with the oxygen ratios of andesine. Mentioning this mineral, Rosenbusch[†] points out that, as celsian is monoclinic, the barium alumino-silicate must be dimorphous.

The Linosa mineral would thus be a representative of a distinct and hitherto unrecognized triclinic feldspar series, characterized by the joint presence of molecules of albite, lime anorthite, and soda anorthite. Reckoning in with the soda the small amount of potash present, and distinguishing the lime and soda anorthites as Can and Nan respectively, our feldspar would have the composition $Ab_8Can_{10}Nan_1$.

Regarded as a feldspar of such abnormal character, and especially if the assumption is verified that soda anorthite is present and that we are dealing with a representative of a new feldspar series, the Linosa mineral is deserving of a new name. For this we propose *anemousite*, after the ancient Greek name of the island. The term anemousite would imply, of course, not only a feldspar with the exact composition given above, but, like hyalophane, oligoclase, labradorite, etc., could be

[*] Tscherm. Min. Mitth., p. 99, 1877.
[†] Mikr. Phys., vol. i, part ii, p. 313, 1905.

applied to feldspars composed of the three molecules mentioned in somewhat varying ratios. If more representatives of the series are discovered, these limits might be more sharply defined, centering round the composition of the present case.

The very close approach to stoichiometric ratios of the oxides may seem to be inconsistent with the view that the mineral is an isomorphous mixture or solid solution. It is, however, in harmony with the well known fact that solid solutions tend to form with their elements in simple ratios, in which case they possess greater stability, giving rise to the substances known as molecular compounds. This is exemplified in many mineral groups, such as the plagioclases, pyroxenes, olivines, nephelite, and the calcite group, the intermediate members of which are very apt to show simple ratios of the end components.

The fact that soda anorthite is not known to occur independently in nature cannot be brought up against the hypothesis of its presence in this case, as the assumption of the presence of a molecule unrepresented by itself in nature is not uncommon in explaining the constitution of many complex mineral groups. Its non-existence as a mineral may be best explained on the ground that the conditions necessary to its formation seldom obtain, the physical conditions being generally such that the more stable nephelite is formed in its stead.

Assuming the presence of the soda-anorthite molecule, it is certainly remarkable that it does not appear to have been detected as yet among the hundreds of chemical analyses which have been made of the feldspars. It would seem to be certain, at least, that it does not enter into the composition of many of these, so far as known, and that, if present at all, it forms only a very small percentage of the feldspar substance, so that its effect in altering the silica ratios would either be overlooked or attributed to impurities or analytical error.

It is a plausible, and indeed reasonable, supposition that we have to do here with a case of imperfect isodimorphism or limited miscibility, as it is termed,[*] instances of which have been investigated by Retgers and others. As stated by Groth: " If the temperature intervals for the stability of the individual modifications of two substances differ so widely that, under the conditions ruling during the crystallization, the corresponding state of the one substance is metastable, then as a rule this substance can crystallize along with the other in the form which is stable for it [the other], but only to a limited extent." This is illustrated by monoclinic $FeSO_4.7H_2O$ and

* Cf. P. Groth, Introduction to Chemical Crystallography, New York, 1906, p. 92.

orthorhombic $MgSO_4.7H_2O$. Monoclinic mixed crystals with the form of the former can be obtained with up to 54 per cent of magnesium sulphate, indicating the existence of a monoclinic form of this salt. Then a gap occurs, until we obtain orthorhombic mixed crystals with 81 to 100 per cent of the magnesium salt, showing the existence of an orthorhombic ferrous sulphate. Very unstable monoclinic crystals of the magnesium salt have been prepared, but orthorhombic ferrous sulphate is as yet unknown in the free state. An analogous case is that of rhombohedral sodium nitrate and. orthorhombic silver nitrate. Rhombohedral mixed crystals have been prepared containing up to 52·5 per cent of silver nitrate, while orthorhombic crystals containing only up to 4·5 per cent of sodium nitrate have been obtained. In accordance with these results, no orthorhombic modification of sodium nitrate is known, but the pure rhombohedral silver salt is formed from fusion on cooling.

Analogously we can suppose that $Na_2Al_2Si_2O_8$ and $CaAl_2Si_2O_8$ are isodimorphous, each forming hexagonal and triclinic modifications. Of these, however, only the hexagonal form of the sodium salt and the triclinic form of the calcium salt are stable under ordinary pyrogenetic conditions, while the converse forms are metastable and capable of existence in mixed crystals with the other only in small amount and within a very narrow range of temperature or other physical conditions. The calcium almost always present in nephelite, up to about two per cent, may be thus regarded as existent as hexagonal calcium nephelite,[*] which must possess a very limited degree of stability, while the stability of the triclinic modification of the sodium salt is apparently somewhat greater, to judge from the percentage shown by anemousite.

It is obvious that the existence of soda anorthite and its presence in the lime-soda feldspars, or the possibility of the assumption by these of other molecules in solid solution, would have a very important influence on determinative mineralogy and petrography. The optic characters of such an abnormal feldspar would not indicate its true chemical composition in accordance with the tables and diagrams in use at present, as the feldspar would be apparently more sodic than it is in reality. The optic determination of the soda-lime feldspars in thin section would thus not be the comparatively simple and unerring matter that it is now supposed to be, as the possibility of the presence of soda anorthite and its influence on the optic constants would have to be taken into consideration. The recognition of celsian introduces a similar uncertainty.

[*] Morozewicz (op. cit., p. 988) and others consider the calcium as replacing the sodium in nephelite.

Again, assuming the possibility of existence of soda anorthite, it would presumably depend on the conditions controlling during crystallization, whether the sodium-alumino orthosilicate would crystallize as nephelite in separate individuals, or as soda anorthite in mixed crystals with albite and anorthite. With identical chemical composition of the rock, we would have in the one case a nephelite tephrite, and in the other a feldspar basalt, but the norms of both would be the same and would show normative nephelite, since nephelite and soda anorthite are normatively the same molecule. We might explain in this way the anomaly of certain holocrystalline rocks containing plagioclase, the norms of which show considerable nephelite, though none of this mineral is present in the mode; and this may be applied to the normatively nephelitic feldspar basalts of Linosa itself. In some cases, of course, the discrepancy is to be attributed to the readjustments of the normative molecules due to the formation of other modal minerals. and the case is mentioned as illustrating some of the petrographic possibilities consequent on the existence of soda anorthite.

The points brought out in the preceding paragraphs indicate the importance and necessity of the verification of the assumed existence of soda anorthite, before any modification is called for of our ideas in regard to the composition and constitution of the soda-lime feldspars, based as these are on the large amount of accurate work by Tschermak, Schuster, Fouqué, Michel Lévy, Fedorow, and others. The very general agreement of the observations of all these workers with the theory that only mixtures of $NaAlSi_3O_8$ (albite) and $CaAl_2Si_2O_8$ (anorthite) are involved is strong evidence in favor of its general truth, and points to the conclusion that, if present at all, the amount of soda anorthite must be very small in most feldspars so far examined. On the other hand, the occasional very notable divergences from the figures demanded by the premises and the variability of the feldspars optically, indicate the possibility of the presence of some modifying constituents one of which might well be the molecule suggested by us.

The Formation of Soda Anorthite.

Fouqué and Michel Lévy* succeeded in 1880 in producing oligoclase, labradorite, and anorthite containing strontium, barium and lead, instead of calcium, but they did not apparently attempt the formation of soda anorthite.

* Synthèse des Minéraux et des Roches, Paris, 1883, p. 145.

The possibility of the existence of this mineral seems to have been first pointed out by Lemberg,[*] though he did not succeed in preparing it, and he remarks on its probable instability under ordinary conditions.

Soda anorthite seems to have been actually formed by S. J. Thugutt[†] by heating artificial "nephelite hydrate" to a white heat, followed by rapid cooling. A crystalline melt was obtained which contained lath-shaped sections of an apparently triclinic mineral, which showed numerous polysynthetic twinning lamellæ, with extinction angles of about 36°. The photomicrographs in Thugutt's paper show clearly sections of this twinned plagioclase-like substance.

E. Esch[‡] describes a nephelite in the nephelinite from the Etinde volcano in German Kamerun. This nephelite shows extraordinary optic properties, and in all probability is triclinic, the crystals being intricately twinned so as to resemble an apparently simple nephelite crystal. The individuals are biaxial, with small optic axial angle, optically negative, and so twinned that basal sections are often divided into sextants, one of which may be normal to a negative acute bisectrix, while the opposite sextant is then about normal to the positive obtuse bisectrix. From this behavior, combined with large extinction angles, Esch considers the mineral to be triclinic.

It may also be noted, as germane to the present subject, that the corresponding potassium alumino-silicate, $K_2Al_2Si_2O_8$, has been produced artificially in several modifications which differ crystallographically from the natural mineral kaliophilite.[§] One of these, formed by Lemberg and examined by Lagorio, was in aragonite-like twins, resembling those of the Etinde nephelite. Another was isometric, while those formed by Weyberg were prismatic and possibly tetragonal.

In the Geophysical Laboratory, soda anorthite was first obtained in 1905 by Dr. Allen by fusing together the component oxides in proper proportions. The resulting glass was clear and brilliant[‖] but contained bubbles here and there, and although it softened gradually at high temperatures it was not as viscous as albite glass. The power of crystallization of this substance from the pure melt is not so great as that of many silicates, owing to its high viscosity. The glass was crystallized by heating it to 1080°, and was examined by

* Zeitschr. deutsch. geol. Ges., vol. xl, p. 641, 1888.
† Neues Jahrb., Beil. Bd. ix, p. 561, 1894.
‡ Sitzb. Berl. Akad., vol. xviii, p. 400, 1891.
§ Cf. Z. Weyberg, Centralblatt Min. etc., p. 395, 1908.
‖ For a determination of the refractive indices of this glass, the writers are indebted to Mr. E. S. Larsen, of the Geophysical Laboratory. His values were obtained by the minimum deviation method with a polished prism of the glass. The results were: $n_{Na} = 1\cdot5181$, $n_{Li} = 1\cdot5148$, $n_{Tl} = 1\cdot5208$.

Wright at the time. It varied in granularity and, except for occasional patches of more crystalline material, was too fine for optic determinative work. No separate crystals were obtained and no goniometric measurements could therefore be made. Since 1905 repeated experiments have been made with the crystallization of this substance from the melt, and also by heating the glass at different temperatures, but the results of the optic examinations have been practically the same in each case, and the different experiments need not be considered in detail here.

Fig. 1.

Fig. 1. Polysynthetic albite-like twinning on artificial soda anorthite. Nicols crossed.   Magnification 85 diameters.

The most characteristic feature of this form of $Na_2Al_2Si_2O_8$ is its polysynthetic twinning, which in many instances closely resembles that of the plagioclases (fig. 1). On other sections the cross grating twinning of microcline is developed, and if encountered in a rock section might easily be mistaken for this (figs. 2 and 3). The extinction angles on such polysynthetically twinned individuals ranged up to 44° on symmetrically extinguishing sections, the angles between the (c) ellipsoidal axes of adjacent lamellæ being 88°. As in the plagioclase

lamellæ, the extinction angles in the zone of symmetry varied with the position of the sections, and the symmetrical extinction angles most commonly observed ranged between 35° and 40°, the ellipsoidal axis c being next the twinning junction line in each case.

In many of the sections showing apparently albite twinning lamellæ, a second set of polysynthetic lamellæ often appeared, making usually angles of 57° to 63° with the first, and so distributed in the lamellæ of the first set as to be symmetrical to

Fig. 2.

Fig. 2. Polysynthetic microcline-like twinning on soda anorthite. Nicols crossed. Mag. 75 diameters.

its planes of twinning. Thus, if the lamellæ of the first set (albite lamellæ) are placed in a north-south direction, then in lamella No. 1 of this set the lamellæ of the second set trend N. 60° E. approximately, while in the adjacent lamellæ No. 2 of the first set the lamellæ of the second set trend N. 60° W., the N.–S. direction acting as a plane of symmetry. The positions of extinction of the interposed lamellæ in any given twinning band of the first set agree closely with the extinction positions of the immediately adjoining second lamellæ of the first set.

The general tendency of this involved twinning is to produce a hexagonal network of interpenetrating lamellæ, but ordinarily one set predominates and the other sets appear only dimly outlined in the background.

As a result of this complicated twinning, single individual grains suitable for optical work were rarely observed, and were then too small for accurate measurements. Optic axial angle determinations were influenced particularly by this condition, and although much time was spent in searching for suitable

Fig. 3.
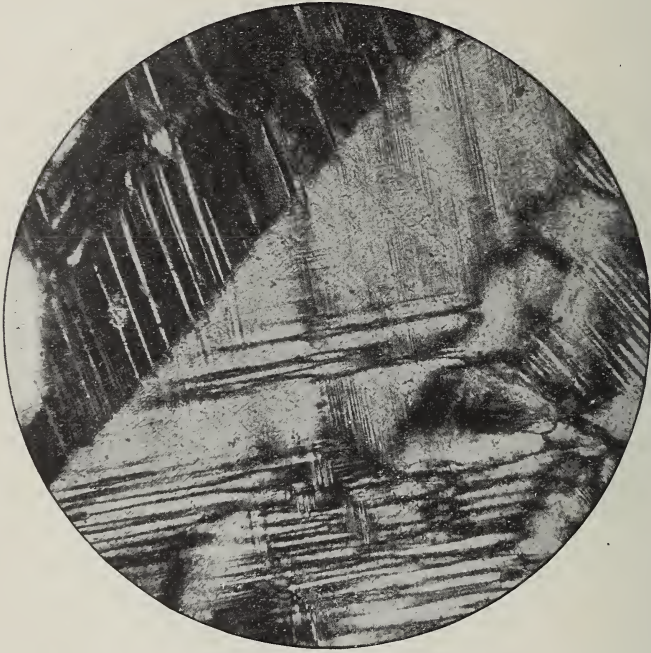
Fig. 3. Polysynthetic twinning on artificial soda anorthite. Nicols crossed. Magnification 75 diameters.

sections, the angular values obtained varied considerably. The most probable value for 2V is about $36°\pm5°$. The optic character is negative. The refractive indices were determined by the immersion method : $a = 1\cdot516\pm\cdot003$, $\gamma = 1\cdot520\pm\cdot003$. The birefringence is weak and was measured on several sections, the highest value for $a\text{-}\gamma$ being $0\cdot0042$.

The specific gravity of soda anorthite was determined by the pycnometer method of Day and Allen, and the value $2\cdot571$ at $25°$ was obtained.

Experiments on the melting temperature of soda anorthite have been made, and also on the relation between soda anorthite and nephelite, whether they are monotropic or enantiotropic, but the results are not yet decisive, and mention of them will be deferred until more definite information is at hand.

In one of the preparations crystallized at about 1100°, single grains free from twinning were observed, which proved to be uniaxial and optically negative, and similar to nephelite in other properties, except that the refractive indices were very slightly lower. Artificial nephelite has been produced by several workers.*

The effect of an impurity, or of the presence of other substances, on the stability of soda anorthite has not yet been determined. It is, however, of interest to note that, while soda anorthite crystallizes invariably out of the pure $Na_2Al_2Si_2O_8$ melt, crystals obtained by melting down natural nephelite from Magnet Cove, Arkansas, and then allowing it to crystallize, were uniaxial and optically negative, and agreed in optic properties with the original nephelite. Natural nephelite is not the pure sodium salt, contains but notable but varying amounts of potassium as ever-present and essential constituent, and from its melt not a trace of the triclinic form was observed to crystallize out.

It is to be hoped that eventually well-developed crystals of soda anorthite will be obtained suitable for precise optic and goniometric work, because then its relation to the plagioclase feldspars, whether isomorphous or not, can be positively determined. The fact of its notable solid solution in the Linosa plagioclase, the similarity in twinning phenomena, refractive indices, birefringence, specific gravity, triclinic symmetry relations, and also in the chemical formulas, are strong arguments in favor of close crystallographic resemblance and probable isomorphous relations between soda anorthite and the plagioclase feldspars.

In the preceding pages the name soda anorthite has been applied to the triclinic phase of $Na_2Al_2Si_2O_8$, this having been used previously by Lemberg and Thugutt. While this name has some justification by analogy, and might serve as a provisional designation, yet it is open to serious objections. In the first place it is not in harmony with the usual nomenclature of the feldspars, soda orthoclase, for instance, signifying

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* Fouqué and Michél Levy, C. R., lxxxvii. p. 961, 1878; xc, p. 698, 1880; and Bull. Soc. Min. Fr., ii, p. 116, 1879; and iii, p. 118, 1880; Hautefeuille, Ann. de l'École Monn. Supér., ix, 1880 : Bourgeois, Ann. Phys. Chim., 1883, p. 19 : Doelter, Zeitschr. Kryst., ix, p. 321, 1884; C. and G. Friedel, Bull. Soc. Min. Fr., xiii, p. 129, 1890.

not a purely sodic monoclinic feldspar, but an orthoclase in which sodium partially replaces potassium.   Also if, as is probable, the presence of this $Na_2Al_2Si_2O_8$ molecule is verified in other feldspars, the use of the term soda anorthite will be apt to lead to awkwardness and ambiguity.   The compound name, furthermore, does not lend itself to the formation of an appropriate symbol, as Ab, An, and Or, for use in feldspar formulas ; and finally the new triclinic feldspar, which has been actually formed in a pure state, and which we have shown to be capable of existence in nature in mixed crystals, is of such practical and theoretical importance as to deserve a special and distinctive designation.   For these reasons we propose to substitute for the earlier and essentially descriptive term soda anorthite, applied to the triclinic form of $Na_2Al_2Si_2O_8$, the name *Carnegieite* (symbol Cg), in honor of the founder of the Institution under whose auspices the mineral was collected and the present investigations were undertaken.

Locust, New Jersey, and
  Geophysical Laboratory of the
    Carnegie Institution of Washington, D. C., October, 1909.

Art. VI.—*Some Rare and Imperfectly Known Brachiopods from the Mississippian;* by Darling K. Greger.

The four species of Brachiopoda which are figured here have caused not a little confusion to collectors of Mississippian fossils, the writer having frequently observed them severally labeled as the *Rhynchonella ringens* of Swallow, in local collections. That the shell described by Prof. Swallow under the name above referred to may be definitely known, and that a distinctive appellation may be had for the forms long confused with it, is the object of the present paper.

Camarophoria ringens (Swallow). Figs. 7, 8.

Rhynchonella ringens Swallow, 1860, Trans. Acad. Sci. St. L., Vol. II, page 653.

Original description.—" Shell large, thick, triangular, plicated, truncated and flattened in front. Ventral valve flattened, triangular; the anterior and the posterior lateral margins abruptly turned up to meet the dorsal valve; the anterior lateral margins curved down in the opposite direction; beak acuminate; sinus wide and shallow, containing about eight plications. Dorsal valve more convex; anterior and posterior lateral margins abruptly turned down to meet the opposite valve; strongly arched towards the anterior lateral margins. The juncture of the valves is sharply and deeply serrated. Surface marked with about fourteen large plications on each valve. Length, 1·90; breadth, 1·48; thickness, 0·99."

The plications all have their origin at or near the beak and increase in size as they approach the front, the number occupying the sinus and fold being quite variable; their number is never increased either by implantation or bifurcation over the body of the shell.

The specimen we figure is from the Boyce collection and bears a label written by the late Prof. Swallow; and while it is not so large as the type, we have no reason to doubt its being the species to which his description applies, since we have collected from the Burlington cherts of Callaway county numerous single valves that equal the dimensions given by the author. Locality and horizon of the figured specimen, and a number of others in our collection—East of New Bloomfield, Callaway county, Mo., in residual cherts of the Burlington limestone.

That the shell figured by Dr. Girty[*] from the Madison

[*] Monograph U. S. G. S., vol. xxxii, pt. 2, 1899, p. 537, pl. lxix, figs. 1ᵃ, 1ᵇ, 1ᵉ.

limestone is not conspecific with *Camarophoria ringens* is obvious if one follows the description with care, but whether Dr. Girty's shell should be referred to our *Paraphorhynchus*

Figs. 1–12.

gibbosum, or to the species described by Dr. White[*] under the name *Rhynchonella caput-testudinis*, we are not in a position to state, nor are we willing to risk the placing of either in the genus *Paraphorhynchus*, since practically nothing is known of their internal structure. However, Dr. White's

[*] Proc. Boston Soc. Nat. Hist., 1862, vol. ix, p. 23.

description of the exterior of his shell would suggest a species of *Paraphorhynchus;* he says " * * * surface marked by from sixteen to eighteen distinct somewhat rounded plications on each valve, which mostly reach the beak with some distinctness, but are occasionally increased both by implantation and bifurcation; they are traversed by fine radiating lines and crossed by fine concentric lines of growth."

Camarophoria arctirostrata (Swallow).   Figs. 11, 12.

Rhynchonella arctirostrata Swallow, 1863, Trans. Acad. Sci. St. L., Vol. II, page 34.

This species was described by Prof. Swallow from material collected at Boonville, Mo., from the Keokuk limestone. The original description reads as follows: " Shell triangular or cuneate, valves nearly equal, costate, striate. Ventral valve most convex towards the beak, which is long, pointed, and strongly incurved. Dorsal valve most convex in front; beak small, pointed, and strongly incurved. Both valves flattened in the middle, and bent abruptly near the margins, forming perpendicular subrectangular faces on the sides and one more or less convex and rounded on the front. Each valve marked with from fourteen to sixteen rounded, radiating, plications, which extend to the beak—two or three implanted—and are ornamented by fine longitudinal striæ, and by obsolete concentric folds. The angle at the beak very variable."

Our figures are from specimens collected at the type locality and labeled by Prof. Swallow, being a part of the Boyce collection. Average measurements are as follows: length, 15^{mm}; breadth, 15^{mm}; thickness, 12^{mm}.

The general outline of this species at once recalls *Camarophoria subcuneata* Hall, which fact was noticed by Prof. Swallow, but the peculiar, interrupted, hair-like lines on the plications at once removes the possibility of its belonging to Hall's species. Prof. Swallow's statement that the ribs are ornamented by longitudinal striæ is correct only in a sense, since the striæ are not only interrupted but are also inclined to curve down to the interradial grooves. Sinus and fold obsolete or wanting in this species.

Paraphorhynchus gibbosum sp. nov.   Figs. 1–6.

Rhynchonella sp. Keyes, 1894, Mo. Geol. Surv., Vol. V, pl. xli, figs. 8 a–b.

Shell elongate-ovate, very gibbous, greatest width at or anterior to the median line, fold and sinus obsolete or wanting in most examples. Valves ornamented with a few coarse ribs, irregular in number and position, increased by implantation

and bifurcation, entire surface covered with fine longitudinal striæ, valve margins sharply serrate. Pedicle valve inflated, flattened in the middle, gently curved upwards in the anterior and posterior regions with the posterio-lateral margins inflected, beak somewhat prominent and pointed. Brachial valve decidedly more gibbous than the former, beak less prominent and obscured by that of the opposite valve, posterio-lateral margins inflected or flattened, corresponding with the opposite valve.

This is one of the very rare brachiopods of the Burlington limestone and well preserved specimens are seldom met with; it is only in specimens retaining the exterior uninjured that the delicate longitudinal striæ are to be observed.

Our collection contains specimens from Louisiana, Mo., and Hannibal, Mo., the last being the locality from which Dr. Keyes obtained his specimens. Figures 1, 3, and 4 are of the largest so far observed, measuring: length, 39^{mm}; breadth, 25^{mm}; thickness, 28^{mm}.

Paraphorhynchus ovatum sp. nov.   Figs. 9–10.

Shell elongate-ovate, greatest width anterior to the median line, vertically compressed, the transverse diameter always greater than the vertical, fold and sinus obscure, producing only a slight sinuosity in the marginal line. Surface ornamented with eighteen to twenty low rounded ribs, which have their origin near the beak, growing constantly larger as they approach the front; the surface is further ornamented by fine longitudinal striæ, three or four in the space of one millimeter.

Pedicle valve but slightly inflated, sloping gently from the center to the anterior and anterio-lateral margins and somewhat more abruptly to the posterior end; posterio-lateral margins inflected, beak not prominent, incurved. Brachial valve with less depth than the former, subequally sloping and inflected in the posterio-lateral region; beak small and blunt. Average dimensions of the specimens in our collection: 35^{mm} long, 27^{mm} broad and 16^{mm} in thickness, the greatest thickness being in the umbonal region.

Horizon and locality—Chouteau limestone, Kiesenger Bluff, Warsaw, Benton County, Mo.

EXPLANATION OF FIGURES.

Paraphorhynchus gibbosum sp. nov.

Fig. 1.   Brachial view of specimen from Hannibal, Mo.
Fig. 2.   Profile view of specimen from Hannibal, Mo.
Fig. 3.   Brachial view of large specimen from Louisiana, Mo.
Fig. 4.   Profile view of specimen from Louisiana, Mo.
Fig. 5.   Brachial view of young specimen from Hannibal, Mo.
Fig. 6.   Brachial view of specimen from Hannibal, Mo.

Camarophoria ringens (Swallow).

Fig. 7.   Posterior view of specimen from New Bloomfield, Mo.
Fig. 8.   Anterior view of same.

Paraphorhynchus ovatum sp. nov.

Fig. 9.   Brachial view of specimen from Warsaw, Mo.
Fig. 10.   Profile view of specimen from Warsaw, Mo.

Camarophoria arctirostrata (Swallow).

Fig. 11.   Brachial view of specimen from type locality, Boonville, Mo.
Fig. 12.   Pedicle view of somewhat smaller specimen from same locality.

Figures ¾ natural size.

Fulton, Missouri.

Art. VII.—*Descriptions of Tertiary Plants, III;* by
T. D. A. Cockerell.

A Sorbus from Florissant, considered to be a Hybrid.

Sorbus diversifolia (Lx.), fig. 1.

Myrica diversifolia Lx., Cret. and Tert. Flora (1883), p. 148, pl.
     xxv, f. 6 (not *Cratægus diversifolia* Steud.; not *Pyrus diver-*
     sifolia Bong.).

Cratægus acerifolia Lx., Cret. and Tert. Flora, p. 198, pl. xxxvi,
     f. 10 (not *C. acerifolia* Moench).

Cratægus lesquereuxi Ckll., Bull. Torr. Bot. Club, 33 (1906), p.
     311 (not *Sorbus lesquereuxii* Nath.).

Onoclea reducta Ckll., Bull. Am. Mus. Nat. Hist., 24 (1908), p. 76
     and 108, pl. vi, f. 4.

The extraordinarily variable plant to which the above names
have been applied is quite common in the Miocene shales of
Florissant, at Station 14.   A good leaf was also found by my
wife at Station 20.   In Knowlton's Catalogue (Bull. U. S.
Geol. Surv. No. 152) *Myrica diversifolia* is referred as a
synonym to *Cratægus flavescens* Newberry (*newberryi* Ckll.);
but in his Fossil Flora of the John Day Basin, p. 66, Dr.
Knowlton recognizes that while the John Day specimen
referred to *Myrica diversifolia* by Lesquereux is undoubtedly
C. flavescens, the Florissant specimens are doubtfully identical.
There occurs at Florissant (Station 14, *W. P. Cockerell*), a
species of *Cratægus* which I have provisionally referred to
C. newberryi, although the leaf is less deeply lobed, and it is
not unlikely that the plant is distinct.   This, however, has
nothing to do with the true *Myrica diversifolia*, which is
evidently identical with *Cratægus lesquereuxi*.   A comparison
of numerous specimens had convinced me that this well-named
"*diversifolia*" was a *Pyrus* in the broad sense, and probably
a *Sorbus;* but I possessed no material exactly comparable,
although I distinctly remembered having seen a similar living
plant.   During the past summer I was permitted to gather
leaves in Kew Gardens, and there at length I found what I had
been looking for, labelled *Pyrus pinnatifida* var. *fastigiata*,
and *Pyrus neuillyensis*.   These trees are hybrids between the
Aucuparia and *Aria* sections of *Sorbus*.   *P. pinnatifida*
Ehrh. is properly called *Sorbus hybrida* Linné.   It has the
apical half of the leaf like *Sorbus intermedia* Pers. (*Pyrus*
intermedia Ehrh.), while the basal half is variably cut into
leaflets in the manner of the *Aucuparia* group.   This occurs
in Europe as a natural hybrid (*intermedia* × *aucuparia*).

There is a variety known as *decurrens* Koehne, in which only three to five of the upper leaflets are connate in a terminal lobe, which, like the separate leaflets, is decurrent at the base. Another variety is *S. hybrida* var. *neuillyensis* (Dippel), (*Pyrus neuillyensis* Hort.), of garden origin, having about four pairs of separate leaflets, those of about the apical third connate, but the leaflets not at all decurrent at the base.

A related hybrid is *Sorbus thuringiaca* (Ilse) = *Pyrus thuringiaca* Ilse, with shorter leaves, as might be expected from the parentage, *S. aucuparia* × *aria*. In the fossils, the characters of these hybrids are reproduced with astonishing exactitude. The more common form is similar to *S. hybrida*,

Fig. 1.   Fig. 2.

Fig. 1.—*Sorbus diversifolia.*   Fig. 2.—*Sorbus nupta.*

but narrower, and as in var. *decurrens*, the divisions are strongly decurrent at the bases, so much so that the leaflets are not wholly separated. In a form which I collected at Station 14 (fig. 1), the lobing extends far toward the apex of the leaf. The form of the petiole, as well as the structure of the blade, is extremely similar in the fossil and recent leaves. Being thus wholly convinced that *Sorbus diversifolia* is a hybrid, I naturally sought for the parents. It was necessary to find in the shale species of the compound-leafed or *Aucuparia* type, and also the dentate, or slightly lobed *Aria* type. The first has already been published as *Sorbus megaphylla* Ckll., Bull. Am. Mus. Nat. Hist., 1908, p. 95, pl. ix, f. 29. The second, at first regarded as a mere variety of *S. diversifolia*, may be described as follows:

Sorbus nupta sp. nov., fig. 2.

Leaf-blade about 67^{mm} long, and nearly as broad, with short triangular lobes, the margin also sharply dentate. Structure and appearance of leaf exceedingly like that of the Italian *S. cratægifolia* (Targ.-Tozz.) Wenzig, except that the Italian plant has the base of the leaf strongly cordate, whereas in the fossil it is strongly though narrowly decurrent on the petiole, extending for a distance of at least 10^{mm}. The strong lateral veins are five or six pairs, as in *S. cratægifolia*. The sharp teeth are perhaps a little more in the manner of *S. latifolia* Syme (*rotundifolia* Auctt.). There is a strong resemblance to *S. intermedia* in the lobing and toothing, but the shape of the leaf is different.

Florissant, in the Miocene shales, Station 13 B (1908).

S. diversifolia is thus considered to be *S. megaphylla* × *nupta*. The only objection to this parentage appears to lie in the fact that *diversifolia* leaves are normally narrower than those of *hybrida*, whereas from the breadth of *S. nupta* one would expect them to be broader.

There is reason to believe that the decurrent base of the leaf is a primitive character; the earliest form of leaf in the *Pyrus* group may perhaps have been narrow-lanceolate, like the living *P. salicifolia* Pall. from the Caucasus, which I had an opportunity of examining in the Cambridge Botanical Garden. From this, *P. amygdaliformis* Vill. (S. Europe) affords a transition to the more ordinary types. The extreme limit of modification is seen in *Sorbus aucuparia* var. *laciniata* (*Pyrus aucuparia* var. *laciniata* Hort. Kew.), in which the leaflets themselves are deeply lobed.

SCIENTIFIC INTELLIGENCE.

I. CHEMISTRY AND PHYSICS.

1. *The Relative Volatility of the Bromides of Barium and Radium.*—STOCK and HEYNEMANN have determined the temperatures at which the bromides of calcium, strontium and barium begin to sublime in a quartz tube exhausted by the mercury pump as follows :

> Calcium bromide, about 720° C.
> Strontium bromide, " 770
> Barium bromide, " 820

These results showed that the temperature of sublimation rises with the atomtic weight of the metal in these cases, and it was inferred that barium bromide would sublime more readily than radium bromide. This was found to be the case by fractionally subliming several samples of barium bromide containing varying quantities of radium and determining the radium in the products by the electroscopic method. For instance, a sample gave 8·8 per cent of a sublimate containing 0·008 per cent of radium, while the residue, 88·2 per cent, contained 0·015 per cent of radium. In another case 17 per cent of sublimate contained 4·8 per cent of radium, while the 83 per cent of residue contained 6·6 per cent of radium. The authors are of the opinion that fractional sublimation may be of practical use in the preparation of pure radium salts—*Berichte*, xlii, 4088.   H. L. W.

2. *The Action of Light upon Hydrogen Chloride.*—The action of light in causing the combination of hydrogen and chlorine gases is very familiar, hence it is suprising to find from the experiments of COEHN and WASSILJEWA that ultra-violet light is capable of decomposing hydrochloric acid gas to some extent into hydrogen and chlorine gases. These investigators, having previously found a similar decomposition of SO_3 into SO_2 and O_2, passed pure HCl gas through a quartz tube, where it was exposed to the light of a quartz-mercury=vapor lamp. The gas was then led through a blackened glass tube into potassium iodide solution where the liberation of iodine indicated the formation of chlorine, and the unabsorbed gas, collected in a eudiometer, was shown to be hydrogen. The decomposition of the hydrogen chloride in this way amounted to 0·25 per cent. No decomposition was obtained when tubes of glass, instead of quartz, were used. Any suspicion that the liberation of chlorine here was due to the presence of atmospheric oxygen, which might give the reaction of the Deacon process, $4HCl + O_2 = 2H_2O + 2Cl_2$, was shown to be without foundation since hydrogen was shown to be present.—*Berichte*, xlii, 3183.   H. L. W.

3. *The Ratio between Uranium and Radium in Minerals.*—MLLE. GLEDITSCH has studied this question, which is important in

connection with the theory of the production of radium by uranium. Other investigators have concluded that this ratio is practically constant, but she has obtained the following results after making corrections for certain sources of error in her method:

	Radium : Uranium
French autunite,	$2 \cdot 85 \times 10^{-7}$
Joachimsthal pitchblende,	$3 \cdot 58 \times 10^{-7}$
Ceylon thorianite,	$4 \cdot 19 \times 10^{-7}$

While these results show magnitudes of the same order, they do not agree closely, and the author concludes that the determination of the mean life of radium based upon the existence of a constant ratio between the uranium and radium in minerals cannot be considered exact.

It may be observed in regard to this conclusion that the author does not appear to take into consideration the possible removal by solution of a part of the radium from the minerals. H. L. W.

4. *The Action of Radium Emanation upon the Elements of the Carbon Group.*—RAMSAY and USHER, using the emanation produced in about a week from $1 \cdot 2111$g. of metallic radium, have caused this to act upon solutions of silicon, titanium, zirconium, thorium, and lead compounds for periods of about four weeks, with the result that they believe that they have proven the production of carbon by this action. The following table shows the amounts of carbon found per cubic millimeter of emanation :

Solution of		Carbon, mg.
H_2SiF_6		$0 \cdot 518$
$Ti(SO_4)_2$		$0 \cdot 982$
$Zr(SO_4)_2$ {	I	$1 \cdot 071$
	II	$0 \cdot 873$
$Th(NO_3)_4$ {	I	$2 \cdot 93$
	II	$0 \cdot 968$
$Pb(ClO_3)_2$		$0 \cdot 102$

The carbon was found in the form of the dioxide, or as a mixture of this with the monoxide. The amount of CO_2 measured amounted in one case to more than $0 \cdot 5^{cc}$. The authors state that mercurous nitrate gave no trace of carbon dioxide or monoxide, and that similar experiments are being performed with the compounds of other elements.

It is probable that the statement in regard to this production of carbon from other elements will be received with much incredulity, because Sir William Ramsay's previous assertion of the production of lithium from copper in a similar manner was not confirmed.—*Berichte*, xlii, 2930. H. L. W.

5. *Quantitative Chemical Analysis ;* by CLOWES and COLEMAN. 8vo, pp. 564. Philadelphia, 1909 (P. Blakiston's Son & Co.).— This English book, which is also issued in America, has passed through eight editions, with continual improvement and enlargement, since its first appearance in 1891. It gives an introduction

to the subject by describing the general processes and giving an extensive series of simple gravimetric determinations (here called estimations according to the British custom) suitable for the practice of beginners. The more important methods of volumetric analysis are then taken up. The general quantitative analysis covers a wide range of subjects, largely technical in character; the analysis of ores, metals, alloys, fuels, fertilizers and other products. It takes up also fire assaying, sanitary water analysis, the analysis of milk, butter, alcoholic beverages, sugar, tea, tanning materials, soap, oils, fats and waxes, and technical gas analysis. One section of the book is devoted to ultimate organic analysis and molecular weight determinations. Although some of the topics are necessarily treated rather briefly and incompletely, the book is an excellent one for giving the student practice in nearly all of the usual work of the analytical chemist. The methods are generally well selected and clearly described, but there are naturally some variations between the British practice here given and what may be called the best American practice in analysis. The book has found extensive use as a text-book, and the new edition will doubtless be still more popular.   H. L. W.

6. *Positive Electricity*— Sir J. J. Thomson asks: — (1) Does a definite unit of positive electricity exist? (2) If so, what is the size of the unit ? This paper introduces a discussion upon these questions at the Winnipeg meeting of the British Association and therefore contains matter previously printed. There are, however, some new experiments upon the effect of magnetic fields on positive and negative rays, which led the author to elaborate theories in regard to neutral doublets. He concludes that even at the start from the cathode the "canal strahlen" include a large number of neutral doublets, if indeed they do not wholly consist of them. Much space is given to discussion of the neutral doublets, both in canal strahlen and retrograde rays, which proceed from the cathode toward the anode. It is supposed that these doublets are of the same character from whatever kind of gas they originate. Thomson refers to a former paper in which he showed that if a vessel was exhausted until the pressure was so low that the discharge would not pass, and small quantities of hydrogen, helium, air, oxygen, carbonic acid or argon were introduced so as to raise the pressure sufficiently to produce a discharge, the velocities of the particles were the same for all the gases. The paper closes with description of a method of measuring the effective magnetic field in the magnetic deflection of canal strahlen.—*Phil. Mag.*, Dec. 1909, pp. 821–845.   J. T.

7. *Doppler Effect in Positive Rays in Hydrogen.*—T. Royds has studied this effect, both in front and behind the cathode. He believes that the canal rays mostly start from the negative glow, and believes that the commencement of the cathode glow corresponds to the minimum Doppler effect when the cathode is viewed from

the anode side. After twenty hours exposure with a cathode fall of 2800 volts, he obtained a marked Doppler effect corresponding to the positive rays approaching the cathode. This minimum velocity is not constant for different wave lengths, but is approximately inversely proportional to the square root of the wave length.—*Phil. Mag.*, Dec. 1909, pp. 895–900.   J. T.

8. *Magnetic Rotation of Plane of Polarisation in the Ultrared.*—Many investigations have been undertaken to put Faraday's experiment on a sound theoretical basis. Voigt has placed all such investigations in two classes, and the author of this paper, Ulfilas Meyer, discusses Drude's theories, which are largely based upon the electron theory. He finds that with crystals of fluorspar, sylvin and rock salt, the amount of the turning of the plane of polarization diminishes with increasing wave length. At 8.85μ it is less than a minute for a thickness of the crystal of 1^{cm} and a field strength of 10,000 Gauss units. The influence of ions on this turning is very small in comparison to that of the ions. This conclusion is reached from the ground of Drude's view of the electron theory, according to which ultra-red absorbtion arises from vibrating ions, while ultra-violet is excited by resonance of rotating electrons.—*Ann. der Physik*, No. 132, 1909, pp. 607–630.
                                                            J. T.

9. *Instantaneous X-ray photography.*—FRIEDRICH DESSAUER states the desirability of shortening the time of exposure to X-rays, and describes a powerful apparatus which he has devised for this purpose. It consists of a very large induction coil, fed by a powerful current which on arising to a proper value is quickly broken by a peculiarly constructed fuse. This fuse is a calibrated piece of wire which is surrounded by a moist covering consisting of a mixture of earths. When the wire heats, the water vapor is formed quickly under pressure and the fuse explodes with violence, breaking the current. The author recommends his method to physicians and has obtained Röntgen cinematographs of the movement of the heart.—*Physikalische Zeitschrift*, Nov. 10, 1909, pp. 859–860.   J. T.

10. *Light and Sound ;* by WM. S. FRANKLIN and BARRY MACNUTT. Pp. viii, 344. New York, 1909 (The Macmillan Co.).—This volume is a part of a series of elementary texts ; practically a revision of Nichols and Franklin's Elements of Physics, which it is doubtless designed to replace. The present volume is the third of the new set : Mechanics having appeared in 1907, Electricity and Magnetism in 1908 and Heat being in course of preparation. Improvement is noted in the relegation to an appendix of the more detailed discussion of lens systems, of radiation and the addition of 86 problems as exercises on the several chapters. An excellent discussion of wave motion in general is illustrated by particular waves in water. A total of 143 pages have been added. Much of the additional matter pertains to practical applications, on the importance of which to elementary students the authors express their opinion in the

following words :—" A so called knowledge of elementary
science which does not relate to some actual physical condition
or thing is superlatively contemptible." D. A. K.

11. *Direct and Alternating Current Testing ;* by FREDERICK
BEDELL ; assisted by CLARENCE A. PIERCE. Pp. x, 265. New
York, 1909 (D. Van Nostrand Co.).—To call this book a labora-
tory manual of tests on direct and alternating currents, would
not be doing it justice. The consideration given to the under-
lying principles of the experiments, as well as to the significance
of the results, places it both in the category of reference and of
text books. It is not offered as an exhaustive treatment of the
subject but is sufficiently comprehensive to give the student a
good working knowledge. It presupposes only the usual college
courses in physical and electrical measurements. The subjects of
the seven chapters are :– D.C. generators; D.C. motors; synchron-
ous alternators ; single phase currents ; transformers ; polyphase
currents ; phase changers, potential regulators, etc. Other chap-
ters on A.C. motors and converters are promised in a later
edition. D. A. K.

12. *Elements of Physics ;* by HENRY CREW. Revised by
FRANKLIN T. JONES. Pp. xiv, 435. New York 1909 (The
Macmillan Co.).—This high school text is a revision of Crew's
original Elements of Physics and embodies much of his more
recent General Physics. The insides of the covers contain the
English and Metric systems of weights and measures, with tables
of their equivalents. In the appendix are given 370 questions
reproduced from examination papers of various high schools
throughout the country. Definitions and leading statements are
emphasised by bold-faced type, and numerous problems are
embodied in the text. It is to be hoped that in the next edition
the authors may eliminate such slips as "knots per hr.," "attraction
of gravity, g," "in physics rate always means 'divided by time'",
and revise the somewhat misleading discussion of harmonic
motion. D. A. K.

II. GEOLOGY

1. *Radio-activity and Geology. An account of the influence
of radio-active energy on terrestrial history ;* by J. JOLY. Pp.
287. London, 1909 (Archibald Constable & Co., Ltd.).—This
book is an outgrowth of the author's presidential address to Sec-
tion C of the British Association and brings into one volume the
present information regarding radio-activity in its bearings on
geology. Geologists will consequently find it a most welcome
volume since but few have the time or opportunity to follow in
the physical journals the rapidly accumulating results of recent
investigations.

The first larger subject treated is that of radium in the earth's
surface materials. Many measurements have now been made on

igneous and sedimentary rocks. The amount of radium varies, however, within wide limits, the abyssal radiolarian ooze and red clay being especially high. As radium loses half its mass in 1760 years while its ultimate parent uranium takes five billion years for the same loss, it is seen that the radium in the rocks is really a measure of the contained uranium. Strutt, extending the work of Rutherford, has shown that the radio-active materials in the crust exist in sufficient abundance so that a crustal layer less than 100 miles in thickness would continually supply the quantity of heat which the earth loses to space (45 miles in the original estimate). Joly argues, therefore, that the uranium must be concentrated in the outer crust of the earth. Consequently where this concentrated zone is depressed by the accumulating sediments of a geosyncline, the loss by conduction being lessened, the temperature must rise. Local excesses as in the Simplon tunnel are also thought to play an important part in determining local temperature gradients. Joly further argues that the instability of the earth's crust and the ocean floor are also due chiefly to uranium and radium becoming more deeply buried.

Another chapter of great geological interest is that on uranium and the age of the earth. Considering helium and lead as the ultimate disintegration products of uranium, measurements of their amounts in uranium minerals, while varying among themselves and pointing to the need of further research, agree in giving much larger values to geological time than estimates based upon denudation and sedimentation.

Throughout the volume, the author, while arguing for the large influence of radio-activity, shows a spirit of fairness and caution. But there is room for so many possibilities in the underearth, which he does not discuss, that a large degree of skepticism may be maintained toward many of his conclusions. Of the geological importance of radio-activity there can be no doubt and it seems adequate to more than account for the temperature gradient, so that instead of a cooling earth we may come to face the possibility of a heating earth. But the deep-seated distributions of energy, pressure and mass traceable to earth origin, whatever that may be, seem able to play the chief part in terrestrial dynamics without invoking the radio-activity of the outer crust as a controlling cause. The contributions of various writers, but more notably Chamberlin, show the weakness of the outer zone to generate compressive movements, which seem, on the contrary, to be initiated by shrinkage of the centrosphere, periodically producing collapse of a thick outer shell of the earth. The great vertical movements, on the other hand, as shown by investigations on isostacy, seem to be in their origin largely independent of denudation and sedimentation, but dependent upon differential volume changes in the outer hundred miles. The isostatic adjustments are further without doubt modified by surface unloading and loading. These considerations are not adequately discussed by Joly.

To make the foregoing criticisms specific by citing an illustrative point: it is inferred by Joly that uranium is concentrated in the outer hundred miles of the crust because if it extended indefinitely downward in the same amount, the energy liberated would be more than sufficient to maintain the temperature gradient. This inference, however, has no supporting evidence and leads in turn to some assumption as to the manner in which uranium could be so concentrated and yet remain in its extremely diffused state. On this inference of the subsurface concentration is nevertheless based an explanation of the making of mountains and of continental and oceanic movements. As other allowable inferences which would meet the same condition of a subsurface excess in radio-activity, it may be suggested that in the deep body of the earth the pressures and temperatures, greater than any attainable in the laboratory, may partially or completely inhibit the radio-active degradation of uranium, or offsetting heat-absorbing reactions in other materials may take place, or igneous activity may serve as a safety valve to reduce the excess of internal energy transmuted from subatomic to atomic form. These are all speculations which have not been disproved. None of them may be true, but they indicate the danger of arriving at conclusions supported on a complicated superstructure of reasoning when the stability of the foundation premises is open to serious question. In considering the problems connected with internal terrestrial activities the field of the unknown is so large that the method of multiple working hypotheses should be more largely employed than is done in this volume. Nevertheless much is brought out which is stimulating and suggestive.   J. B.

2. *The Geology and Ore Deposits of Goldfield, Nevada;* by F. L. RANSOME. U. S. G. S., Prof. Paper No. 66, pp. 253, 35 plates, 34 text fig. Washington, 1909.—The Goldfield district consists essentially of a low, domical uplift of Tertiary lavas and lake sediments resting upon a foundation of ancient granite and metamorphic rocks. The erosion of this flat dome has exposed the pre-Tertiary rocks at a number of places in the central part of the district, and these outcrops are surrounded by wide concentric zones of successively younger formations. Some of the later lavas were erupted after the dome had been elevated and truncated. The pre-Tertiary rocks consist to-day of quartz rocks intruded by masses of a granitic rock like that to which the name alaskite has been given. The Tertiary lavas include dolerite, rhyolite, basalt, andesite and latite. Most of these are found in different flows of different periods and lying between them are various fragmental rocks.

The sulphide ores of the Goldfield district are of complex mineralogical character, native gold and pyrite being accompanied by minerals containing copper, silver, antimony, arsenic, bismuth, tellurium, and other elements. In some ores the gold occurs free in fine particles, which, as a rule, are aggregated together to form yellow bands or blotches. The associated minerals are pyrite,

marcasite, bismuthinite, perhaps famatinite, and a new cupric sulphantimonite, which has been named goldfieldite. (See below.)

The most notable features of these ore bodies are their remarkable richness and their equally remarkable irregularity. The ores are associated with craggy outcrops of silicified volcanic rock. Associated with the silicification other processes of locally intense alteration, especially the formation of alunite, have also been active. The deposits have formed along irregular and branching zones of fissuring. The surface ores were oxidized and furnished a large part of the gold during the first years of exploitation.

GOLDFIELDITE occurs as a gray material in a dark telluric crust found at the Mohawk mine. The material was crushed and picked over under a lens. The gray portion appeared homogeneous, with the exception of a few minute specks of gold. Color, dark lead-gray, with a high metallic luster. Brittle. Conchoidal fracture. Hardness $= 3 - 3 \cdot 5$. No crystal faces noted. Analysis by Palmer on small amount of material gave :

Cu	S	Te	Sb	As	Bi	Au	Ag	Gangue
33·49	21·54	17·00	19·26	0·68	6·91	0·51	0·18	2·00 = 101·57

The mineral is considered to be a cupric sulphantimonite, in which part of the antimony is replaced by arsenic and bismuth and part of the sulphur by tellurium. Formula derived is $5CuS.(Sb,Bi,As)_2(S,Te)_3$.

It would seem, in view of the facts presented concerning this substance, that the giving to the material a name and rank as a new species is hardly warranted. The material was intimately mingled with other minerals and had to be crushed and picked over by hand, so that the purity of the material analyzed must be somewhat questioned. It showed no crystal forms. The analysis was made on a small amount of material, and shows a high summation, and the formula derived is only approximately justified by the analysis. It would seem desirable that more positive proof should be given before we can assume the existence of such an unusual compound as a *cupric* sulphantimonite.

W. E. F.

3. *United States Geological Survey ; Issue of Geologic Folios in pocket form.*—The Geological Survey has recently inaugurated the publication of an edition of the Folios of the Geologic Atlas of the United States in octavo form convenient for field use. The maps are folded and enclosed in a pocket so that the whole, including the accompanying text, forms a pamphlet of about 6 x 9 inches. The folio form will also be continued, as it is most satisfactory for office and library use, but the new pocket edition will be welcomed by those at work in the field. The Folio now received is No. 167 of the series, and describes the Trenton, New Jersey-Pennsylvania Quadrangle ; it is stated that the five folios, No. 164–168, have been printed and are ready for distribution in this new form. It is also to be noted that henceforth the separate maps, unfolded, showing the areal geology of the

Quadrangle, will be, when desired, furnished separately at the nominal cost of five cents each.

4. *Geological Survey of West Australia.*—The following publications have recently been received:

Annual Progress Report for the year 1908. Pp. 19, 3 maps.

Bulletin No. 32, containing: Greenbushes Tinfield, by A. Gibb Maitland, A. Montgomery, W. D. Campbell, and Mr. E. S. Simpson. Pp. 75, 2 maps, 2 plates, and 7 photos. Mount Malcolm Copper Mine, by Harry P. Woodward. Pp. 8, 1 plate. Fraser's Gold Mine, Southern Cross, by Harry P. Woodward. Pp. 6, 1 map, 1 plate.

Bulletin No. 35, containing Geological Report upon the Gold and Copper Deposits of the Phillips River Goldfield, by Harry P. Woodward. Pp. 104, 2 maps, 8 plates, 7 photos.

Phosphate deposits have been discovered near Christmas Island, where a layer of phosphatic travertine 153,600 square yards in area and with a thickness of two feet has been investigated. The travertine is believed to owe its origin to capillary attraction, drawing up ground water from the lime contained in the underlying sands. In an investigation of the Green Bushes Tinfield (Bulletin 32) examination was necessarily made of the laterite of this region, which has a wide distribution and varies in composition from solid and pure limonite to aluminous rocks almost destitute of iron and often so tough that explosives have little effect. The distribution and character of the laterite in the Green Bushes region "clearly indicates periodic and zonal changes in the climatic conditions." In connection with the petrographic description of the crystalline rocks of the Phillips River (Bulletin 35) analyses were made of the following types: soda-granite, spodumene, albite, and eclogite.   H. E. G.

5. *Contribuzioni allo Studio Petrographico della Colonia Eritrea ;* by E. Manasse. 4°, pp. 168, 8 plates and map. Siena, 1909.—This work is based upon the collection of rocks made by Profs. G. Dainelli and O. Marinelli during their geological researches in the Italian colony of Erythrea, East Africa, in 1905–1906. After a brief sketch of the geology of the area visited, the main body of the work is devoted to a detailed report of the results of a thorough petrographical study of the specimens. The author first describes, rather briefly, a series of schists of various kinds, including some porphyroid, mica schists, amphibolites, gneisses, etc. Then the igneous rocks are treated, and these were found to consist of granites, some of which, as shown by the analyses, are of alkalic character with predominant soda ; diorites of several types ; a hornblendite which is a local facies of diorite, and two specimens of teschenite. There are also dike rocks, granite and diorite prophyries, aplites, paisanite, bostonite, tinguaite, malchites and among the lamprophyres, kersantites and camptonites. The effusive rocks or lavas are also not wanting and include quartz porphyry, rhyolite and rhyolitic tuffs, obsidians and pumices. Dacite and a great variety of

basalts close the list. In the sedimentary rocks are found sandstones, argillites, limestones, travertine, etc. The work closes with a chapter dealing with various generalizations on the results obtained. It is illustrated by a large number of excellent photogravures made from microphotographs of the thin sections studied. Its value is also much enhanced by a large number of excellent chemical analyses of the various rocks, which are the result of much patient labor in the laboratory.

The work is an excellent contribution to our knowledge of East African petrology, and it is interesting to observe that the nature of the rocks is in harmony with the general alkalic character of the East African petrological province, as shown by a number of investigators during the last few years.   L. V. P.

6. *Carboniferous Air-breathing Vertebrates of the United States National Museum ;* by ROY L. MOODIE. Proc. U. S. Nat. Mus., vol. 37, pp. 11–28, with pls. 4–10.—This paper, the fifth of Dr. Moodie's contributions to our knowledge of the early Amphibia, is a result of the study of a small collection in the National Museum ; but one which is of great interest in that it contains the only known examples of scaled Amphibia from North America, as well as the only known specimen of a Carboniferous reptile from the Allegheny series. This reptile, *Isodectes punctulatus* Cope, Doctor Moodie thinks, shows certain aquatic as well as terrestrial adaptations ; the former being the broad-surfaced foot, such as MacGregor has described in *Mesosaurus brasiliensis.* The affinities of Isodectes are close to the Microsauria among the Amphibia ; to what group of reptiles it is related is not known.

Of the Microsauria, Moodie describes some 17 species and 15 genera, of which 3 of the former and 1 of the latter are new. The material comes in part from Linton, Ohio, and Cannelton, Pennsylvania.   R. S. L.

7. *Cenozoic Mammal horizons of Western North America,* by HENRY FAIRFIELD OSBORN; *with Faunal Lists of the Tertiary of the West,* by WILLIAM DILLER MATTHEW. Bull. U. S. Geol. Survey No. 361, 1909, pp. 1–138, with 15 text figs. and 3 plates.— For the student of faunal paleontology as well as the stratigraphical geologist this paper is of the utmost importance, containing as it does a bibliography, a general discussion of the geologic and climatic history of the Tertiary, a careful description of the successive faunal phases, and most comprehensive faunal lists of the Tertiary mammals.

The principal facts established are the two great natural divisions of geologic deposition and of habitat, the mountains and the plains ; the progressive aridity of the climate during the Cenozoic with its consequent soil denudation and deforestation, and the destruction of most of the larger forms of life during the lower Pleistocene glacial epoch. The contrast of the mountain and plains regions are no less striking than their resemblances. In the mountain region, with some exceptions, the drainage systems are the same to-day as in the Tertiary, while on the plains

the rivers are comparatively modern. In the mountains from the Basal Eocene to the John Day the rocks are not worked over, as erosion was retarded by the heavy cappings of lava in the John Day basin of Oregon, in the Bridger basin by a dense Pleistocene (?) conglomerate and in the Washakie by a fine conglomerate.

In the plains region, by contrast, the very extensive Oligocene strata were in part worked over to form the Miocene and these in turn to form the Pliocene; all three contributed to the Pleistocene, and all four are now contributing to the alluvium of the Great Plains.

The successive faunal phases are :—

1, Archaic Mesozoic mammals with partly South American, partly European affinities. Basal Eocene.

2, The first modernization, invasion of the archaic by the modern fauna—whence is not surely known, but Osborn favors a North American-Asiatic or Holarctic origin; the severance of the South American land connection—Initial elimination of the archaic fauna in competition with the modern. Wasatch.

3, Absence of fresh Eurasiatic migration, descendants of archaic and modern mammals slowly evolving and competing, with the gradual elimination of the archaic. Establishment of the North American Artiodactyla. Wind River to close of Mocene.

4, Second modernization—First knowledge of the plains' fauna —Absence of all archaic mammalia except the Hyænodontidæ— Reëstablishment of faunal resemblances with western Europe. Oligocene and Lower Miocene.

5, Fresh migrations from Europe. First proboscidians and true Felinæ. Middle Miocene to Lower Pliocene.

6, Land connection with South America. Intermigration of North and South American mammals. Middle and Upper Pliocene.

7 Increasing cold, moisture and forestation. Third modernization by Eurasiatic invasion—Gradual extinction of larger Ungulata. Pleistocene.

Conclusion :—North America promises to give us a nearly complete and unbroken history of the Tertiary in certain regions, which are, after all, comparatively restricted. Middle and Upper Eocene are approaching solution; Lower and Basal Eocene still require additional surveys. The chief remaining gap is now in the Pliocene stratigraphy, materials being at hand for an establishment of the Pleistocene sequence. R. S. L.

8. *New Fossil Mammals from the Fayûm Oligocene, Egypt;* by HENRY FAIRFIELD OSBORN. Bull. Amer. Mus. Nat. Hist., vol. xxiv, 1908, pp. 265–272, with 6 text figures.

New Carnivorous Mammals from the Fayûm Oligocene, Egypt; by H. F. OSBORN. Ibid., vol. xxvi, 1909, pp. 415–424 and 9 text figures.—In these two papers Professor Osborn describes part of the remarkable wealth of material collected in the Fayûm by the expedition from the American Museum sent out during the winter of 1906–1907. The first paper contains descrip-

tions of two new genera of uncertain ordinal position as well as two new genera of rodents, including in all an equal number of species. In the second paper a number of creodont genera and species are described, all referable to the Hyænodontidæ, the last surviving family of the order.   R. S. L.

9. *New or little known Titanotheres from the Eocene and the Oligocene;* by HENRY FAIRFIELD OSBORN, Bull. Amer. Mus. Nat. Hist., vol. xxiv, 1908, pp. 599–617 with 21 figures in the text.

"In the preparation of the U. S. Geological Survey monograph 'The Titanotheres' the collections of Eocene and Oligocene materials in the larger museums of the country have been reviewed with care. Like the Oligocene titanotheres previously reviewed, the Eocene titanotheres prove to be in a high degree polyphyletic." From the Wind River formation are two genera and three species; from the Lower Bridger one genus and three species; from the Upper Bridger and Lower Washakie three genera and five species; from the Upper Washakie and Lower Uinta two genera and four species; from the Upper Uinta two genera and three species, and finally from the White River Oligocene two new genera, each with a single species, are described.

Dolichorinus hyognathus, of which the more familiar name, *Telmatotherium cornutum,* is a synonym, is restored in the skeleton and gives a good idea of the appearance of one of these ancestral titanotheres.   R. S. L.

III. MISCELLANEOUS SCIENTIFIC INTELLIGENCE.

1. *The Autobiography of Nathaniel Southgate Shaler,* with a supplementary Memoir by his wife. Pp. 481, with 16 illustrations. Boston and New York, 1909 (The Houghton Mifflin Company).—The six or seven thousand students who heard Shaler's lectures at Harvard during his forty years service were always deeply impressed with his personality, his wide experience of men and the world, and his vivid presentation of the principles of geology, enlivened by ever-flowing narrative of pertinent incidents, all the more entertaining from being phrased in picturesque language. The personality of the man is strikingly presented in this volume, of which the first half, descriptive of his youth up to the beginning of the Civil War, comes from Shaler's own pencil—for it was his habit to prepare manuscript with pencil rather than with pen—while the second half, descriptive of his more mature years, is written by his wife. The picture that we gain of the way in which science was studied at Harvard under Agassiz is particularly interesting; a way that was well fitted for youths of the strong individuality that Shaler possessed. Several chapters on excursions along the coast of Maine and farther down east, with Hyatt, Stimpson, Verrill and others, are of special interest as

illustrating the delightfully primitive conditions of scientific exploration in the early sixties; they show the richness of happenings even on a near-by coast, if one only has the knack of meeting them as Shaler always had.

The memoir by Mrs. Shaler exhibits the extraordinary variety of relations into which Shaler entered after his return to Harvard at the close of the war. It includes accounts of his several journeys abroad, where he made personal acquaintance with the leading geologists of the time; of his work on the Kentucky State Geological Survey and on the Coast Survey; of his occasional westward journeys chiefly in connection with mining interests; of his wide excursions in literary fields, reflected again in the list of publications at the end of the volume; and above all of the innumerable activities at Harvard which made him, as William James put it, "the myriad-minded and multiple-personalitied embodiment of all academic and extra-academic *Kenntnisse* and *Gemüthsbewegungen*." The real worth of this book lies in the deep impression that it gives of the value of personality as compared to mere learning.   W. M. D.

2. *Third Report of the Wellcome Research Laboratories at the Gordon Memorial College, Khartoum;* ANDREW BALFOUR, Director. Published for the Department of Education, Sudan Government, Khartoum. Pp. 477, with 28 colored plates, 413 reproductions of drawings and photographs, and 19 maps and plans. London, 1908 (Baillière, Tindall & Cox); New York (Toga Publishing Co., 45 Lafayette St.).—This handsome volume shows the latest work of the enthusiastic investigators at this now famous tropical laboratory. As in the earlier reports, noticed in this Journal, the work covers a wide field of investigation, although such biological topics as concern the health of the natives are given a prominent position.

The blood parasites of man, domestic animals, rats, birds, reptiles, and fishes of the region have been subjected to extensive investigations by the director of the laboratory, and by Dr. Wenyon, both of whom contribute several beautifully illustrated reports, which form important contributions to the knowledge of these important parasites. The sanitary conditions existing in Khartoum are discussed, and further observations on sleeping sickness, kala-azar, and other diseases reported. Poisonous snakes and other reptiles have been studied by specialists, the parasitic worms investigated, and the insects of economic importance discussed and illustrated by colored plates.

The later chapters deal with well illustrated articles on the healing art as practiced by the dervishes, the physical characters of certain negroid tribes, and notes on ethnographical specimens, while the reports of chemical investigations at the laboratory conclude the work. The floating laboratory on the Jur river has proved a marked success.

The admirable courage shown by those who have made these investigations, under the most trying climatic conditions, has been

further tested by a recent fire which destroyed many of the important preparations and documents at the laboratory. w. r. c.

3. *Illustrations of African Blood-sucking Flies other than Mosquitoes and Tsetse-flies;* by ERNEST EDWARD AUSTIN. Pp. xv, 221, with 13 colored plates. London, 1909 (British Museum of Natural History).—Since the discovery that many of the most fatal diseases of man and animals are disseminated by means of the bites of blood-sucking flies, the British Museum has published a number of handsomely illustrated monographs on various groups of these insects. Belonging to this series is the present volume, which gives general and non-technical descriptions and excellent colored figures of 103 African species, all of which have blood-sucking habits, although it is not yet known which of them may serve in spreading diseases. w. r. c.

4. *The Cambridge Natural History;* edited by HARMER and SHIPLEY. Vol. IV. Crustacea and Arachnida. Pp. xviii, 566, with 286 figures. London 1909 (Macmillan & Co.).—The series of ten volumes of excellent treatises by specialists in the different groups of the animal kingdom is now complete, and forms perhaps the most convenient and generally useful work of reference on the subject that has appeared in the English language in recent years.

The present volume is quite up to the high standard of the others of the series, and treats of the Crustacea, and the widely divergent forms, as king crabs, spiders, scorpions, ticks, mites, water-bears, pycnogonids, and other animals, both fossil and living, which are now generally grouped together as Arachnida. The contributors for this volume are Geoffrey Smith, Henry Woods, A. E. Shipley, Cecil Warburton and D'Arcy W. Thompson. The general excellence of the text is shared by the numerous illustrations. w. r. c.

5. *The Human Body and Health: An Intermediate Text-Book of Essential Physiology, Applied Hygiene, and Practical Sanitation for Schools;* by ALVIN DAVISON. Pp. 223, with 150 illustrations. New York, 1909 (American Book Company).—The aim of this little book is to give the pupil in the public school a general knowledge of the principles of personal and public hygiene. Such of the essentials of the anatomy and physiology of the human body as it is necessary to introduce are clearly described and illustrated. w. r. c.

6. *International Congress of Radiology and Electricity.*—It is announced that an International Congress of Radiology and Electricity will be held in Brussels in 1910 under the patronage of the Belgian government and of the French Physical Society. A provisional program has been issued ; the address of the General Secretary is 1 Rue de la Prévôté, Brussels.

THE

AMERICAN

JOURNAL OF SCIENCE.

FOURTH SERIES

BRIEF
ANNOUNCEMENTS.

Recent pressure of business has hindered me from compiling a detailed list of new minerals arrived. I wish to mention, however, a new lot of the metallic Awaruite from Smith River, California, ranging in sizes from $\frac{1}{4}$ inch to 1 inch. These interesting metallic pebbles are of scientific value on account of the nickel being associated with the iron in the metallic state. Considering the great amount of attrition which they received from stream action, I find them very well preserved and deserving a place in every collector's cabinet. These range in price from 25 cents to $2,00.

Although the finest of the recent Iceland Zeolites and Franklin Furnace minerals have been sold off rapidly, I still have choice examples of these splendid specimens at reasonable prices.

Having received some excellent shipments representing chiefly Hungary, Saxony and other celebrated German localities, of which specimens I was unable to prepare a list in time for this issue, I shall be pleased to furnish further data on request. I noted in these shipments several specimens of the rare Argyrodite and other silver minerals too numerous to mention.

I recently received additional minerals from Colorado and can now supply any reasonable demand in Tellurides, native Tellurium, Amethystin-Quartz, Calciovolborthite and Carnotites. Prices on request.

I have also considerably increased my stock of the celebrated California Tourmalines so that I now feel that no dealer has ever had the quality and quantity of these specimens that I have, while the prices of same have been somewhat lowered, considering their value, as compared with former prices.

Have also made a recent addition to my stock of the Reconstructed Rubies, Sapphires and Pink Topaz, which places me in the best position for supplying the demands of my customers.

It would be advisable for those interested in the above to have their names on my mailing list, and I shall be pleased to send on approval for inspection and selection anything that may interest my patrons.

Information as to special lists and prices of individual specimens cheerfully given.

A. H. PETEREIT,

81—83 Fulton Street, New York City.

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ART. VIII.—*The Nitrogen Thermometer from Zinc to Palla-*
dium; by ARTHUR L. DAY and ROBERT B. SOSMAN; with
an Investigation of the Metals, by EUGENE T. ALLEN.

CONTENTS:

1. *Introduction and Plan.*

THE measurements of absolute temperature here offered
were undertaken in direct continuation of those published
from the Geophysical Laboratory two years ago,[*] with the
purpose of extending the gas scale to 1600°, or as near it as
might prove practicable. Except in explanations of new or
particularly important features, descriptive details have accord-
ingly been omitted here and must be sought in the first paper.
Substantially the same methods and apparatus have been
employed throughout.

One conclusion in particular which was brought out at that
time is entitled to even greater emphasis, namely, that the
existing uncertainties in the absolute temperature scale at
1000° and above are the result of experimental limitations and
not of any failure of the principles involved. The experi-
mental conditions were scrutinized with great care throughout
the first investigation, and not only were the known correction
factors all redetermined, but their total magnitude was reduced
nearly 75 per cent. This success, after so long and painstak-

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[*] Arthur L. Day and J. K. Clement, this Journal (4), xxvi, 405–463, 1908.

ing a study of the correction factors, led the authors to believe
that the upper end of the existing gas scale (melting point of
pure copper), which has been vacillating in a somewhat irregu-
lar way in various hands for three-quarters of a century, had
been finally confined to the limits ± 0·5°, or within 1°.
Although this ideal had been affectionately cherished for a
good many years, its triumph has been shortlived. The present
investigation has discovered a source of error which appears to
have passsed unnoticed before, which operates to raise the
temperature scale at the copper point about 1·4°. This kind
of history has repeated itself with remarkable persistence all
through the record of high temperature research, and may, of
course, do so again, but the limits of uncertainty are continu-
ally becoming narrower, and it appears to the authors unlikely
that further investigation will again reveal errors aggregat-
ing 1°.

On the other hand, the detailed study of temperature distri-
bution about the bulb (page 102) in which the present error
was discovered, cannot but convince an experienced observer
that the limit of refinement in an electrically heated air bath
has been practically attained, and that higher accuracy in gas
thermometry must be sought in a liquid bath which can be
stirred.

Since the publication of the Reichsanstalt scale[*] in 1900, it
has remained the standard for all temperature measurements
between 400° and 1100°. Its limit of accuracy as an absolute
scale was estimated to be about 3° at 1000°.

The work of Day and Clement was mainly directed to the
following essential features of the problem of absolute meas-
urement with a constant volume gas thermometer: (1) An
absolutely gas-tight bulb of definite volume; (2) uniform dis-
tribution of temperature over the bulb surface during the
measurements; (3) the reduction of the error due to the
unheated capillary tube connecting the bulb with the mano-
meter; (4) a more accurate determination of the expansion
coefficient of the bulb itself.

The results accomplished by them in these directions may
be outlined seriatim as follows: (1) The bulb chosen (90 parts
platinum, 10 parts iridium) is quite rugged enough for meas-
urements as high as 1500°, and no difficulty was experi-
enced in maintaining a nitrogen atmosphere in it without loss
by diffusion or leakage. At high temperatures the material
becomes considerably softer, but with the help of a gas-tight
furnace in which nitrogen could be maintained at the same
pressure outside the bulb as within, neither diffusion through
the bulb walls nor mechanical strain was encountered. Varia-
tions in the zero point of the thermometer, which have been

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[*] L. Holborn and A. L. Day, Ann. d. Phys. (4), ii, 505, 1900; this Journal,
(4), x, 171, 1900.

very persistent and inaccessible errors throughout the history of gas thermometry, have therefore now become practically negligible. This gas-tight furnace possessed the further advantage that the initial pressure of the gas, and consequently the sensitiveness of the instrument, could be varied within considerable limits. A sensitiveness as great as 1^{mm} of the manometer scale per degree was regularly employed. The iridium alloy has the disadvantage that platinum thermoelements, which are necessary for recording variations in the temperature over the surface of the bulb, and for transferring the gas thermometer temperatures to standard melting points, become contaminated in the presence of iridium at all temperatures above 900° C.; the higher the temperature and the longer the time of exposure, the greater the degree of contamination.

(2) It was sought to obtain a uniform temperature over the surface of the bulb by winding the (pure platinum) furnace coil on the inside of a refractory magnesia tube which contained sufficient iron oxide and other impurities to be a fairly good conductor of heat. The winding was somewhat closer at the ends than in the middle. This was further supplemented by secondary coils of smaller wire extending a few centimeters into the tube from each end. The current in the three coils could be independently regulated with the help of thermoelements attached to the bulb and giving its temperature at the middle and upon each shoulder (positions 2, 4, and 6, fig. 1). When these temperatures had been adjusted so that the differences between them were smaller than 0·5°, it was assumed that the temperature over the whole surface of the bulb was constant within those limits. (For the oversight in this assumption, see pages 99 and 102.)

(3) The platinum capillary and connections between the bulb and the manometer were much diminished in volume. Compared with the total volume of the bulb ($195 \cdot 7^{cc}$) this connecting volume amounted to ·0015 in their instrument, and reduced the total correction for the "unheated space" to less than 5° at 1100°, a correction factor not more than one-fourth as large as the best previous attainment in this direction. The uncertainty of the temperature distribution in the "unheated space" was perhaps 10 per cent, making the probable error from this source about 0·50°.

(4) A special bar 25^{cm} in length, made up from the same alloy as the bulb, was provided with a scale and its length measured in a special form of comparator at temperature intervals of 50° up to 1000°. The expansion was found to be $10^6 \beta = 8 \cdot 84 + 0 \cdot 00131 t$, with an error of about 0·5 per cent. An irregularity was detected both in the expansion and subsequent contraction in the region below 300°, which appeared variable with the rate of cooling or heating, and in character resembled the hysteresis which appears in a bar which has been subjected

to stress. If the bar was cooled down very slowly, it returned nearly to its initial length; if cooled rapidly, it required several days to return to its original dimensions. This irregularity makes up most of the 0·5 per cent uncertainty mentioned above.

Plan.—Above 1100° considerable uncertainty has existed in the temperatures of various fixed points. The melting point of nickel, considered as 1484°,[*] has been frequently employed. The curve of the platinum-rhodium thermoelement, extrapolated beyond the copper-point, has been still more generally used, but like any extrapolation, may lead to quite erroneous results. The only gas thermometer comparison that has been made in this region is that of Holborn and Valentiner,[†] but by their own estimate the accuracy of the upper portion of their scale is not greater than ± 10°. The chief purpose of our work was, therefore, to establish the temperature of several fixed points between 1100° and 1600° and to find what curve is followed by the platinum-rhodium thermoelement in this region, with an accuracy comparable to that obtained in the lower portion.

The plan of the work is simple. It consists, first, in selecting certain fixed thermometric points, usually melting points of metals, and in determining their reproducibility; second, in making a measurement of the true temperature on the nitrogen scale at or close by one of these fixed points; third, in transferring this known temperature by means of a thermoelement over to the fixed point in question. This transference by the thermoelement is necessary because the thermometer bulb cannot be put directly into melting or solidifying substances at high temperatures. The relation of electromotive force to temperature for any particular kind of thermoelement does not enter into the problem when the temperatures measured are close to the fixed points; a linear correction is then abundantly accurate. The interpolation curve, for any element, between the fixed points established by the gas thermometer, is therefore a separate matter.

The questions which remain to be answered are, then : (1) How exact and uniform can the temperature of the gas in the bulb be made (independently of any effort to measure this temperature)? (2) How accurately can its pressure be measured in order to establish that temperature on the nitrogen scale? (3) How accurately can this temperature be transferred from the thermometer and compared with the fixed melting point? (4) How accurately can the fixed points be reproduced for purposes of calibration of secondary measuring devices?

As has been stated, our experience has convinced us that the most of the variations in the gas scale temperatures of the

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[*] Holborn and Wien, Wied. Ann., xlvii, 107, 1892 ; and lvi, 360, 1895.
[†] Ann. d. Phys. (4), xxii, 1, 1907.

fixed points commonly in use, as given by various observers, are due, not to differences in the properties of different gases used, nor to differences in pressure, nor to differences between the constant-volume and constant-pressure scales, all of which have been frequently discussed from the theoretical stand-point; but to systematic errors residing in the apparatus and the methods employed. A large portion of the present work has therefore been devoted to finding out experimentally the effect of variations in all those conditions which might affect the results systematically.

2. *Apparatus.*

In all essential particulars the gas thermometer apparatus is that developed by Day and Clement and already described by them in detail (loc. cit.). It consists of four principal parts: (1) bulb, (2) furnace, (3) furnace jacket, and (4) manometer.

(1) *The Bulb.*— A great deal depends upon the material of which the bulb is made. Primarily and obviously, the bulb must be able to hold the expanding gas without absorbing or losing any portion of it throughout the temperature range of the measurements.

A secondary requirement, the importance of which increases rapidly when high accuracy is sought, is that it shall be possi-ble to use several thermoelements in the furnace with the bulb without their readings being endangered by contamination from the bulb material. As long as this intermediary role of the thermoelement remains a necessary one and alloys of platinum continue to provide the only successful bulb material, the contamination* of the platinum wire of the element by the alloyed iridium or other platinum metal in the bulb will remain a serious consideration in all temperature measurement above 900°.

Although the platin-iridium bulb served well as a gas con-tainer, the contaminating effect of the iridium upon the ther-moelements made the life of the latter, for measurements of such extreme accuracy, very short. Accordingly, at the close of the first series of experiments, a change was made from the platin-iridium bulb to one of platin-rhodium (80 parts platinum, 20 parts rhodium) 160^{mm} long and 47^{mm} in diameter. Inas-much as one of the wires of the thermoelement itself contains 10 per cent of rhodium to which the platinum wire is always exposed (and which gradually contaminates it, too, although very slowly), it was thought that the substitution of a rhodium alloy in the bulb might serve to retain the necessary qualities of stiffness and regularity of expansion with a minimum of disadvantage in the matter of contamination. These expecta-

*For a detailed account of the behavior and treatment of contaminated thermoelements, see Walter P. White, Phys. Rev., xxiii, 449, 1906.

tions have been completely realized. Although the rhodium
alloy is less rigid at temperatures of 1000° and beyond than
the iridium alloy, and requires more careful adjustment for
equal pressure within and without, no sagging of the bulb
walls or deformation from the gas pressure has appeared up
to 1550°. Meanwhile, the contamination of the thermoele-
ments in the presence of the rhodium alloy is now reduced in
magnitude about 80 per cent for a given temperature and time
of exposure.

(2) *The Furnace.*—The common practice of recent observ-
ers (Callendar, Harker, Holborn and Day, Jacquerod and
Perrot, Day and Clement) has been to use a cylindrical bulb
in which the length was three or four times the diameter,
enclosed in a concentric furnace tube (air bath) heated by the
electrical resistance of a coil of wire wound upon or within
it. To this bulb the heat is applied radially over its cylindri-
cal surface, but no heat is supplied at the ends. The furnace
tube itself and the winding of the coils have been changed at
different times and in a variety of ways in order to vary the
distribution of the heat supply. The arrangement used in
most of our experiments consisted of one main coil of platinum
wire $1·2^{mm}$ in diameter, wound on the inside of a refractory
magnesia tube 36^{cm} long and 2^{cm} thick. As has been our
habit for some years, the windings near the ends of the coil
are somewhat closer together than those at the middle, but
this device is not of itself sufficient* to compensate for dif-
ferences of temperature along the bulb at all temperatures.
In a particular case a favorable arrangement will provide an
almost perfect temperature distribution at 500°, but will over-
compensate the ends at 1000° sufficiently to spoil the meas-
urements. The conductivity of the bulb metal is wholly
inadequate to help out this overcompensation by conveying
surplus heat from the ends to the middle of the bulb. On the
other hand, a change in the winding which will correct the
overcompensation at 1000° provides insufficient compensation
at 500°. The arrangement which has become usual with us
is therefore to wind the coil somewhat more closely at the ends
than in the middle, with the idea of providing partial com-
pensation for the inevitable heat losses at the ends of the fur-
nace in this way, and in addition, to insert supplementary coils
of smaller wire in the ends of the furnace tube in order to
provide a small, independently regulated heat supply which
can be superposed upon that of the main coil and give the
desired uniformity at any temperature likely to be employed.
A furnace tube arranged in this way, except for accidental
variations, caused, for example, by the flaking off of the fur-

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* Day and Clement, loc. cit., p. 411.

nace lining, affords uniform temperature distribution over a
length of 20^{cm} in the center of the tube for a range of tem-
perature from 300° to 1550°, and no one temperature is more
difficult to regulate than another. This arrangement contains
a limitation, however, of considerably greater magnitude than
was at first suspected. The ends of the bulb face the com-
paratively cold ends of the furnace tube and radiate a sufficient
quantity of heat toward these cold ends to reduce the tem-
perature of the end surfaces of the bulb some 6 or 8° below
the mean temperature of the cylindrical surface.

In so far as this may appear to be a rather obvious condition
to be overlooked, it may be remarked parenthetically that it
is a common practice of physicists to assume that the tempera-
ture is constant over a radial cross-section near the center of a
cylindrical furnace which is reasonably long in comparison
with its diameter. With this in mind, the probability is even
greater that a metallic conductor only 4^{cm} in diameter (the end
surface of the bulb) perpendicular to the axis in such a furnace
will have a uniform temperature between its center and peri-
phery. The fact is that neither of these assumptions is justi-
fied, even in furnaces as long as twenty times the diameter.
This was shown in a number of actual measurements made
under varied conditions, differences of several tenths of a
degree being found as low as 300°, and of several degrees at
1000° and higher.

This situation demonstrates the futility of depending upon
metallic conductivity (of platinum) to equalize a steep tem-
perature gradient, and again emphasizes the fact, if further
emphasis is necessary, that the air bath, or, more explicitly,
the temperature distribution within the heating chamber, is
the most uncertain factor remaining in gas thermometry.

On account of difficulties in manipulation and accidental
leakage into the thermoelement system, we preferred not to
introduce additional heating coils into the furnace tube, and
accordingly undertook to stop the loss of heat by inserting
thin, platinum - covered diaframs opposite the ends of the
bulb. The situation was still further safeguarded, in exchang-
ing the platin-iridium for the platin-rhodium bulb by adding
a reentrant tube at the lower end of the bulb, to enable us to
measure the actual temperature prevailing at its center as well
as over the surface. In this way, we thought to obtain a more
representative integral of the surface temperature and a com-
petent comparison of this integral with the temperature
actually prevailing at the center of the bulb.

(3) *The Furnace Jacket.*—The furnace jacket was water-
cooled and could be closed air-tight around the furnace and
bulb together, so that the pressure could be maintained the
same within and without the bulb to avoid deformation.

(4) *The Manometer.*—The bulb communicated, by a capillary tube leading out through the furnace jacket, with the manometer, which consisted of two glass tubes communicating through a steel reservoir. At the top of the shorter arm, where the capillary joined it, was a fixed reference point to which the mercury was brought for each measurement of the pressure. A detailed description of the manometer will be found in the previous paper.[*]

3. *Details, Errors and Corrections.*

The gas thermometer for high temperatures has now reached a stage of development where it becomes necessary to examine many small sources of error. These will be discussed in the succeeding paragraphs without attempting to classify separately the variable errors of observation, and the systematic errors which may arise from conditions of the measurements or from constant corrections.

To bring out the plan of investigation of these errors, it will be well to recall the derivation of the gas thermometer formula. The gas scale, as is well known, is defined by the relation

$$\frac{pv}{1 + at} = K \tag{1}$$

in which K and a are constants and t is a function of p and v, the pressure and volume of a fixed mass of the gas. K and a are determined by two further conventions:

When $p = p_0$ and $v = v_0$ (at melting point of ice), $t = 0$ (2)
When $p = p_{100}$ and $v = v_{100}$ (at boiling point of water), $t = 100$ (3)

It is then evident that

$$a = \frac{p_{100} \dfrac{v_{100}}{v_0} - p_0}{100\, p_0}$$

which defines a as the mean pressure coefficient of the gas between 0° and 100° (when v_{100} and v_0 are nearly equal); and

$$K = p_0 v_0\,.$$

The temperature, t, is therefore defined by the formula:

$$t = \frac{p\, \dfrac{v}{v_0} - p_0}{a\, p_0} \tag{4}$$

the scale depending upon the gas chosen, the value of p_0, and the ratio $\dfrac{v}{v_0}$. In the theoretical constant-volume thermometer,

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[*] Loc. cit., p. 415, and this article, p. 107.

this ratio $\dfrac{v}{v_0}$ is unity, but in the experimental constant-volume thermometer it always varies considerably from 1. We have preferred therefore to treat equation (4) as the fundamental equation, introducing in place of $\dfrac{v}{v_0}$, however, the proper function of the expansion coefficient of the bulb material.

Since apparatus designed for high-temperature work is not suited for the most accurate determination of a, a has been treated in this discussion as a separately determined constant.

In the experimental gas thermometer, there is always a small space in the tube connecting with the manometer which is at various temperatures other than t. The pressure (p' or p_0') actually measured is not therefore the p or p_0 of the formula. Imagine that this supplementary space is heated up to the uniform temperature t, without any change in its volume, and let the resulting corrected pressure be p (or p_0 as the case may be). Furthermore, let

$$V = \text{volume of bulb at } t°.$$
$$V_0 = \quad\text{``}\quad\text{``}\quad\text{``}\quad 0°.$$
$$v_1 = \quad\text{``}\quad\text{``}\quad\text{``unheated space'' which is at temperatures other than } t \text{ (or than } 0°).$$
$$t_1 = \text{temperature of this space.}$$
$$\beta = \text{linear expansion coefficient of the bulb material.}$$

Under these conditions, formula (4) becomes:

$$t = \frac{1}{p_0\,a}\left[\,p\cdot\frac{V + v_1}{V_0 + v_1} - p_0\,\right]$$

$$= \frac{1}{p_0\,a}\left[\,p\left(1 + \frac{3\beta t}{1 + \dfrac{v_1}{V_0}}\right) - p_0\,\right]^{*} \qquad (5)$$

In this formula $\dfrac{v_1}{V_0}$ is a very small correction term; while the important quantities to be measured are p_0, p, a and β. The ratio $\dfrac{v_1}{V_0}$ becomes of importance, however, in determining the corrected pressure p from the measured pressure p'. The derivation of this correction is as follows:

The mass of the gas in the unheated volume under the actual conditions of measurement is proportional to $\dfrac{p'v_1}{1 + a t_1}$;

$$*\quad \frac{V + v_1}{V_0 + v_1} = \frac{\dfrac{V}{V_0} + \dfrac{v_1}{V_0}}{1 + \dfrac{v_1}{V_0}} = \frac{1 + 3\beta t + \dfrac{v_1}{V_0}}{1 + \dfrac{v_1}{V_0}} = 1 + \frac{3\beta t}{1 + \dfrac{v_1}{V_0}}$$

the mass of the gas within the bulb is proportional to $\dfrac{p'\mathrm{V}}{1+at}$.

If we now suppose the unheated space raised to the uniform temperature t without change of volume, the pressure being thereby raised to p, the total mass is proportional to $\dfrac{p(\mathrm{V}+v_1)}{1+at}$.

Therefore,

$$\frac{p'v_1}{1+at_1} + \frac{p'\mathrm{V}}{1+at} = \frac{p(\mathrm{V}+v_1)}{1+at}$$

whence

$$p-p' = p'\left(\frac{v_1}{\mathrm{V}+v_1}\cdot\frac{at-at_1}{1+at_1}\right)$$

This correction is easily calculated and tabulated ; or, better, the factor in parenthesis (in the second member of the equation) is plotted against temperature. In practice, the volume v_1 is divided into three portions at temperatures t_1', t_1'', and t_1''' as explained on p. 109, and the corrections obtained from the curve for each of these portions are simply added together to obtain the total correction $p-p'$. With these corrected pressures, p_0 and p, the temperature t is calculated by formula (5) on page 101.

The discussion of errors and corrections will now be taken up under the general outline sketched on page 96.

A. Temperature of the Gas in the Bulb. (a) Uniformity.—Above the temperatures where a liquid or vapor bath can be used to secure uniformity, the differences of temperature between different parts of a furnace has always been a serious limitation to the accuracy of the gas thermometer. This variation, even in a furnace containing well-conducting materials, is much larger than has usually been assumed, and the three equalizing factors of conductivity, radiation, and convection by air-currents, are all credited with much greater influence in bringing about uniformity than they really possess. It sometimes happens that our faith in these factors is inversely proportional to our quantitative information.

To remove this source of uncertainty, Day and Clement introduced two auxiliary heating coils in the furnace, one at each end, and by varying the three independent currents, brought the temperature at the middle and at both ends, on the outside of the bulb, to equality.

In our first measurements with the new bulb, the end elements were placed on the axis of the bulb, in positions 1 and 9 (fig. 1), instead of on the outside surface. It became evident at once that the supporting tube in the bottom of the furnace, used in the work of Day and Clement, had a consid-

erable cooling influence on the central portion of the bottom, an effect which would tend to make their results low. This effect was largely obviated by using, in place of the heavy magnesite tube, a thin Marquardt porcelain tube in the top of which was placed a Marquardt crucible, cut out into a three-pronged support. The bottom of the crucible acted as a screen to prevent radiation from the bottom of the bulb, and the smaller thickness and thermal conductivity of the tube practically prevented the loss of heat from the bottom by conduction. Later, a second diafram was added, about 1^{cm} lower down, primarily

FIG. 1.　　　　　　　　　　　FIG. 1*a*.

SECTION.
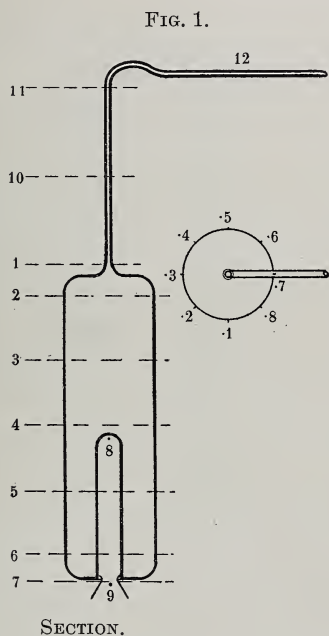
FIG. 1. Numbers indicate the positions of the thermoelements grouped about the bulb.
FIG. 1*a*. A photograph of the bulb made after the palladium-point determination showing all the elements and the diaframs in position.

for the purpose of centering the tube and bulb in the furnace, but without noticeable effect on the temperature distribution.
In addition to the three thermoelements mentioned, a fourth was located inside the reentrant, in position 8.* Several trials under varied conditions confirmed the fact that this element, when the other three were set equal, was 2° to 3° hotter than the one on the outside. A thorough exploration of the dis-

* See fig. 1, and note, p. 104.

tribution of temperature over the surface of the bulb was therefore undertaken.

Since the number of wires which could be led out through the packed joints was limited, the plan was adopted of using the bulb itself as a differential thermoelement, single platinum wires being tied to the bulb at points whose temperature was to be determined. Each of these wires formed, with the platinum of the standard element tied to the bulb at the middle, a differential element which would read zero if the wires were alike and if no difference of temperature existed between the two points on the bulb.

The relation of the wires was established by sealing each in turn to the platinum of the standard, and measuring their E.M.F. at various temperatures. The readings varied, according to the quality of the wire, from 0 to 40 microvolts. The method of evaluating differences of temperature, when such existed, is discussed on page 118.

The distribution of temperature lengthwise of the bulb was first investigated, and auxiliary wires were placed at the levels 1 (base of stem), 2 (top shoulder), 6 (bottom shoulder), 7 (bottom, outside of funnel), in addition to thermoelements at 4 (middle outside), 8 (inside reentrant), and 9 (bottom, just inside of funnel).*

With this system of thermoelements, it was found that at 1082°, when 9 was brought to equality with 4 and 1, the bottom of the bulb was superheated 6 to 8° at position 6, and about 4° at 7, due entirely to the fact that the thermoelement at 9, not being in contact with the bulb, lost sufficient heat by conduction and radiation downward to keep its temperature below that of the metal surrounding it. The element at 8, on the other hand, received heat by conduction up the reentrant tube and by radiation from below, which made it read higher than the element at the same level outside. The element at position 9 was therefore discarded and each setting of temperature made with reference only to the elements which were attached directly to the bulb.

The temperature between the middle and the top shoulder was also examined in several experiments. The temperature at this position was found to be within 0·5° of the other two, with a tendency to be lower than these.

Further experiments showed that in addition to the possibility of vertical variation of temperature, there was a varia-

* The system of numbering the positions of elements on the bulb is shown in fig. 1. The figure before the decimal point indicates the horizontal level, the figure after the decimal indicates the orientation around the bulb. For instance, an element in position 3·5 would be about half way between the top and middle and on the side of the bulb away from the front of the apparatus.

tion around the circumference of the bulb. This amounted
in the worst case (at 1450°) to a variation of 1·3° from the
mean, four elements being used around the circumference to
make the test. This variation seemed to be due either to
unequal conductivity of the furnace material at different
points or to the falling off of small portions of the furnace
lining, leaving exposed places on the wire. Variations of
this character are probably an unavoidable result of using a
furnace where the heat supply is so near to the point where it
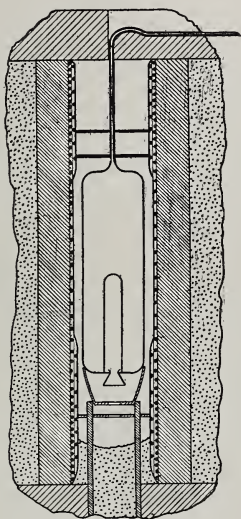
Fig. 2.   Fig. 3.
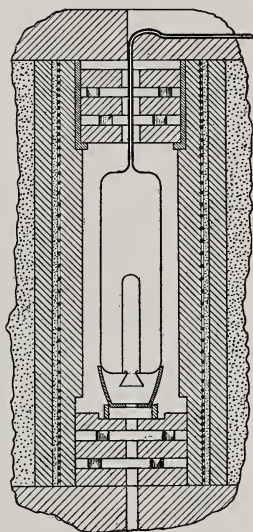
Fig. 2. Section of furnace and bulb showing the arrangement of coils and
diaframs about the bulb which gave the most uniform temperature distri-
bution in the measurement of both high and low temperatures. The sup-
plementary end coils were independently heated and regulated.

Fig. 3. A special arrangement of the heating coil and diaframs designed
to give a very uniform temperature distribution about the bulb. The coil
was heavily ballasted inward with a good heat conductor and outward with
a poor conductor. The heating coil was also divided into three sections
which could be independently regulated. This furnace was used at the
copper point only.

is measured, as is the case with the furnace which is wound
on the inside. This form of winding is necessary, however,
in order to reach the highest temperatures, so that absolute
uniformity of temperature around the bulb had to be sacrificed
to increased range of the instrument.

After this variation was discovered, measurements were
always made with four elements at equal distances around the

circumference of the bulb and the mean of their readings was taken.

In order to be perfectly certain that no systematic error was being introduced by using this one form of furnace (fig. 2.) throughout, it was replaced temporarily by a furnace of platinum wire wound on the *outside* of a similar tube. In this way a heavy mass of good heat-conducting material was introduced between the source of heat and the bulb, with the expectation that a more uniform temperature might thereby be obtained in the inside space. The two types of furnace are shown in figs. 2 and 3.

A measurement at the copper point with the outside-wound furnace gave as the melting point of copper 1082·6°, which differs only 0·4° from 1082·2°, the mean of the results obtained at the same pressure with the other furnace, and is identical with the final mean of all the results, thus proving that no systematic error was to be feared from the inside-wound type of furnace. The horizontal uniformity obtained in the outside-wound furnace was better than that in the inside-wound, but the furnace was more difficult to regulate and to hold at a given temperature.

(b) *Constancy of Conditions.*—Several causes interfered with the establishment of a constant temperature for observation. The three heating currents required constant observation and readjustment with the gradual extension of the heated zone toward the outside of the furnace. This comes to equilibrium for a particular temperature after about half an hour, after which the bulb was held steady 15–30 minutes longer before readings of the pressure were taken. The temperature thus established could be relied upon to remain constant to within 1 to 3 microvolts (0·1° to 0·3°) during the course of the pressure measurements.

Above 1100° a noticeable leakage of current from the heating coil into the bulb and thermoelements frequently appeared. This may have been due in part to conductivity across the narrow air space between bulb and coil, but was probably chiefly due to accidental contact between the protecting tube of one of the thermoelements and the furnace wall. To obviate any uncertainty from this cause, it was found necessary to use alternating current for all temperatures above 1100°. This was less easy to regulate than the direct current from storage batteries, but by careful regulation of the voltage of the motor generator supplying the alternating current, equally satisfactory results were obtained.

The constancy and exactness of the temperature at 0° were beyond question. On several occasions pressure measurements at 0° were made at intervals of one-half to one hour and no

measurable difference found. Similarly, repacking the bulb in a fresh supply of ice gave exactly the same value.

B. Definition of Temperature by Measurements of Pressure.—The procedure in measuring the pressure, p', was as follows : First the three mercury thermometers on the manometer were read to determine the temperature of the mercury column and scale ; then three to four settings of the barometer were made, alternating with measurements of the manometer. The mercury thermometers were read again at the close. During this interval the other observer made as many readings as possible of all the thermoelements.

Before the manometer was connected to the bulb, the point on the scale corresponding to the reference point of the manometer* was determined once for all before the manometer was connected to the bulb, by connecting the two arms and raising the mercury to the point, as in a regular pressure measurement. Subsequent manometer readings were subtracted from this fixed level, and the resulting difference corrected for the temperature and calibration corrections of the scale and then reduced to 0°. The barometer reading was similarly corrected. The algebraic sum of the two gave the pressure p', in terms of a centimeter of mercury at 0° and at the latitude and elevation of the laboratory. Since the absolute value of the pressure does not enter into the gas thermometer formula, corrections for altitude and latitude are superfluous.

Errors and Corrections in p'.—The level of the fixed reference point of the manometer varies with the temperature of the room because of the difference in expansion of the brass scale on the one hand and of the glass tube of the manometer which carries the fixed point on the other. This correction can be calculated from the expansion coefficients of the materials and amounts to 0.04^{mm} per 5°. Its direction and amount were checked experimentally by determining the fixed point at two temperatures differing by about 10°, the room being open on a cold day for the one case, and then closed and heated for the other. The difference found was 0.09^{mm}, and that calculated 0.08^{mm}.

The lengths of the divisions of the brass scale were corrected for change of temperature by a formula determined for this scale at the Normal-Aichungs-Kommission, the absolute length of the scale having been determined at 16°. In addition, calibration corrections, determined for each millimeter of the scale, were applied. The total scale correction was always less than 0.15^{mm}, hence the temperature measurement by the adjacent mercury thermometers was abundantly accurate for this purpose.

* p. 100.

The length of the mercury column was reduced to 0° by the expansion coefficient given in the Landolt-Börnstein-Meyerhoffer Tabellen. This correction varied from 0 to about $3\cdot00^{mm}$. As the mercury thermometers were calibrated and read to 0·1°, the uncertainty in this correction due to uncertainty in the room temperature may amount to $0\cdot05^{mm}$. For the calibration the mercury thermometers were compared with a Richter standard thermometer calibrated at the Reichsanstalt.

The barometer reading was corrected to 0° by the Landolt-Börnstein-Meyerhoffer table for barometer with brass scale. Two Fuess barometers were used. Both had been tested by the Bureau of Standards; one had an absolute correction of $0\cdot06^{mm}$, the other was exact. This was checked by direct comparison of the two. The variable error in the barometer is probably about the same as in the manometer reading ($0\cdot05^{mm}$). On a very windy day or during the approach of a storm, the barometer was too unsteady to permit satisfactory measurements to be made.

A further small correction to the barometer was necessary to allow for the weight of the air column between the cup of the barometer and the top of the mercury in the open manometer column. This correction was appreciable, amounting to $0\cdot16^{mm}$ in the extreme case.

To give some idea of the effect of these small corrections upon the final temperature measurement, it may be added that $1\cdot00^{mm}$ corresponds approximately to 1°.

To determine the corrected pressure, p, from the measured pressure, p' (see page 101), the volume of the unheated space, v_1, connecting the bulb with the manometer, must be known.[*]

TABLE I. — *Unheated Space.*

Space	Volume, c.c.		Uncertainty		Max. effect at Cu. pt. of errors
	Before Apr. '09	After Apr. '09	of vol.	of temp.	
Pt-Rh capillary, bulb to top furnace (v_1')	0·055	0·055	0·002	100°	0·04°
Pt-Rh capillary, top to outside furnace (v_1'')	0·086	0·086	0·003	50°	0·20°
Pt-Rh capillary to gold capillary	0·102	0·054			
Gold capillary	0·094	0·066			
Pt capillary and Ni valve	0·025	0·025	0·015	0·5°	0·20°
Space above meniscus	0·023	0·023			
Total	0·385	0·309			0·45°

[*] See discussion of this correction, Day and Clement, loc. cit., p. 410.

This was calculated from the dimensions of the capillary. The figures are given in Table I. This volume was reduced in April, 1909, by bringing the manometer closer to the furnace, since the water jacket of the furnace cut off the heat so completely that there was no risk in bringing the manometer as close as possible (35^{cm}). The volume v_1 was thereby reduced from $0 \cdot 39^{cc}$ to $0 \cdot 31^{cc}$, and the ratio $\dfrac{v_1}{V_0}$ from $0 \cdot 00187$ to $0 \cdot 00150$.

The volume, V, which enters into the correction term (see page 102) was determined by weighing the bulb empty, and filled with distilled water at a known temperature. A very accurate determination of this volume was not necessary, the important requirement being that the volume should not change during a run. A check on change of volume was obtained in the measurement of the value of p_0. The volume of the bulb at $0°$, up to the base of the capillary stem, was found to be :

On 13 June, 1908 (new) _ _ _ _ _ _ _ _ _ _ _ $205 \cdot 74^{cc}$
On 18 " " (after $1450°$) _ _ _ _ _ $205 \cdot 75^{cc}$
On 20 Apr., 1909 _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ $205 \cdot 82^{cc}$

The volume of the unheated space, v_1, was arbitrarily divided into three portions for the convenient determination of its average temperature, t_1. The first portion, v_1', extended from the base of the stem to the top of the upper brick of the furnace (see fig. 2); the second portion, v_1'', included the capillary stem as far as the outside of the furnace; the third portion, v_1''', extended to the surface of the mercury in the manometer and included all of that portion of the unheated space which remained at room temperature.

The temperatures of the portions v_1' and v_1'' were determined by placing a thermoelement at different points along the stem during several of the runs. As this temperature does not need to be known accurately, a few measurements gave a sufficient indication of the distribution of temperature in the portion of the "unheated space" within the furnace.

A liberal estimate of the degree of uncertainty in the values of v_1 and t_1 has been made and is included in Table I, together with the effect which such errors would have on the calculated temperature, t, at the copper point.

Errors and Corrections in p_0'.—The same instrumental corrections apply to p_0' as to p', but their proportional magnitude is, of course, larger. The values of the uncertainty in t due to these small errors will be found in Table IV.

Changes in the value of p_0 (the ice point) after heating to high temperatures have always been disturbing factors in gas thermometer measurements and have introduced uncertainties of a very intangible kind. This was especially true of the

porcelain bulbs formerly used, where both changes of volume and emission or absorption of gases by the walls occurred. The restoration of the platinum metals to favor as materials for the gas thermometer bulb has practically eliminated this uncertainty. During the present work small changes in the value of p_0 have frequently occurred after heating to a high temperature, which seem not to be due to any change in volume, for the determinations of the volume, V_0, given above (p. 109), show a total change after a year's work corresponding to less than 0.1^{mm} in p_0. In the early part of the work, the passage through the bulb wall of hydrogen or some other gas produced by the reducing action of wood fiber in an asbestos board insulator within the furnace, was suspected as being the cause of irregularity, particularly in view of the fact that Holborn and Valentiner had difficulties from this cause. Further, it was several times observed that heating the furnace and bulb to a higher temperature than they had reached before, caused a slight increase in the value of p_0,—whether due to some gas passing in from the outside, or coming out of the wall of the bulb, is not known. Air dried over calcium chloride was used outside of the bulb in the furnace enclosure throughout the work, and no indication was ever obtained of the passage of either oxygen or nitrogen through the wall of the bulb, since measurements at a given temperature (after the first heating to that temperature) gave the same value of p_0 within the error of measurement.

On one occasion an almost inappreciable leak in the manometer connection caused some uncertainty. All measurements affected by this error, when it was discovered, were rejected.

a.—Since the gas thermometer apparatus as arranged for high temperature measurements is not suited to a determination of the value of a (the pressure coefficient of the gas from 0 to 100°) with an accuracy comparable to that attained by Chappuis,[*] the value of a was treated as a constant. The figures used were:

$$\text{For } p_0 = 345 - 347^{mm}, \ a = 3665.8 \times 10^{-6}$$
$$\text{For } p_0 = 217 - 221^{mm}, \ a = 3664.0 \times 10^{-6}$$

A number of independent determinations of a for different pressures were made by Day and Clement[†] with the platiniridium bulb, but they show no appreciable difference from those by Chappuis within the experimental error of the apparatus. The probable error in Chappuis' results is not great enough to affect the high temperature values.

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[*] Trav. Mem. Bur. Int., vi and xii, 1888 and 1902.
[†] Day and Clement, loc. cit., p. 442.

Pure nitrogen was used throughout as the thermometric gas.*
The storage tank was refilled several times so that not all the
gas was from the same original supply; the filling of the bulb
was also changed several times. The bulb was first completely
evacuated and heated to a high temperature, after which the
connections and bulb were rinsed out several times with the
purified gas before the final filling.

Expansion Coefficient of the Bulb. (β).—The substitution
of a new alloy in place of the platin-iridium made necessary a
new determination of the expansion coefficient of the bulb
material. The method of its determination and the comparator
used for the purpose were fully described in the earlier article†
and do not require to be repeated here.

Three additional precautions were taken in carrying out the
measurements: The bar was increased in length to 0·5 meter,
and in diameter to 6^{mm}, in order to increase the sensitiveness of
the determination and the uniformity of temperature along the
bar respectively. In this case the bar was also made at the
same time and from the same alloy as the bulb itself, and was
therefore identical with it in composition.‡

In ruling the bar, the lines were spaced 0·2^{mm} apart instead
of 0·5^{mm}, as in the previous investigation. This enabled a
greater number of observations to be made within a narrow
region than heretofore, and has thus made it possible for us
to avoid the error from parallax described in the previous
paper.§

The third precaution involved a slight change in the com-
parator itself, and was made at the suggestion of Chappuis.
Our custom had been to verify the distance between the fixed
hairs of the microscopes before and after each heating by
measuring this distance in terms of a standard brass bar cali-
brated at the Bureau of Standards. The brass bar was then
replaced by the platin-iridium bar before the heating began,
and the length of the latter was measured in terms of the
initial distance between the fixed hairs, at intervals of 50° or

100° up to 1000°. This mode of procedure involved the assumption that the agreement of the measurements made before and after heating afforded adequate proof that no change had taken place *during* heating. The justification for this assumption lay in the fact that, (1) the furnace was completely water-jacketed to prevent any heat reaching the microscopes from the furnace ; (2) suitable insulating material introduced between the observer and the microscopes cut off any disturbing influence from the near approach of the observer's body; (3) the microscopes themselves, and the carriages upon which they were mounted, were connected by carefully selected invar bars

FIG. 4.
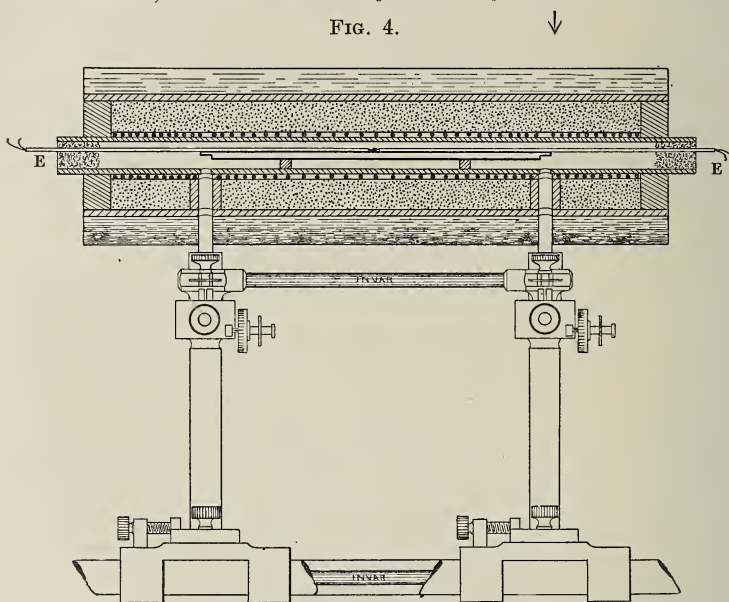
FIG. 4. Section through furnace showing bar, thermoelements (E, E) and microscopes in position. A section through the arrow is shown in fig. 5.

of negligible expansion coefficient, and, finally, (4) the faithful agreement of all the measurements before and after the many heatings left no reason for suspecting a variation.

Notwithstanding these conditions, it appeared to Chappuis that some positive proof should be offered that the distance between the cross-hairs remained unchanged while the heating was going on, inasmuch as all the measurements were made in terms of this distance. Accordingly, at his suggestion, it was arranged to retain a standard unheated bar in the field of the microscopes throughout the readings, so that the distance between the cross-hairs would be subject to check at any time

during the observations. The arrangement made for the purpose is very simple and effective, as can be seen from the neighboring diagrams (figs. 4 and 5). The last two series of measurements were made with this appliance, and the fixed distance was found to remain constant throughout the series to within 0·003ᵐᵐ, although on first setting up the apparatus a gradual adjustment of strain, amounting to 0·012ᵐᵐ, took place during the first two days.

The determination of β is subject to two errors; the first is uncertainty of temperature, the second occurs in the measure-

FIG. 5.
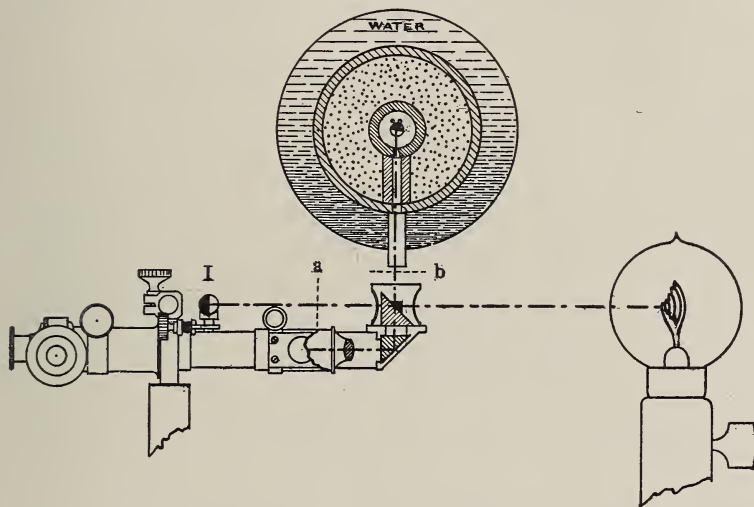
FIG. 5. A section through the furnace at one of the openings, showing the method of illumination of the heated bar and the standard cold bar (I) together with an arrangement for checking the distance apart of the cross hairs at each temperature. With a screen inserted at a only the hot bar is visible; with the screen at b only the cold bar.

ment of the change in length. It was impossible to wind the furnace (70ᶜᵐ long and 2ᶜᵐ inside diameter, with two side openings) so as to give a perfectly uniform temperature along the bar; but as the furnace winding and consequent distribution of temperature were varied considerably for each run, the uncertainty from this cause was eliminated in the average of all the observations. The error in the temperature measurement itself was probably not over 2°, which would give an error of less than 0·2 per cent at the highest temperature. Two thermoelements with a common junction were used, one entering from each end of the furnace. This not only gave a second temperature reading in confirmation of the first, but

a positive check upon the appearance of contamination in the thermoelements.*

With a half meter bar and a temperature interval extending from zero to 1400°, the total expansion amounts to about 7·8^{mm}. The micrometers reading the expansion were read with an accuracy of 0·002^{mm}.

There was some indication of a very small hysteresis in the expansion and contraction. Although the amount was not much greater than the experimental error, the measurements indicate that the bar was slightly shorter after heating than before, and that it gradually regained its original length.

The measurements at room temperature are given in Table II. The five measurements in this table which were made

TABLE II.—*Length of Platinum-Rhodium Bar.*

Date	Max. preceding temperature	Length at 0°	Date	Max. preceding temperature.	Length at 0°
1 July 1908	(New)	500·068	26 Sept. 1908	1150°	500·094
6 " "	900°	500·110*	1 Oct. "	25°	500·119
9 " "	28°	500·105	6 " "	1300°	500·034†
13 " "	900°	500·098*	27 " "	900°	500·108*
17 Sept. "	900°	500·108*	30 " "	1400°	500·096
19 " "	1200°	500·090	6 " 1909	28°	500·103
20 " "	23°	500·105	12 " "	22°	500·108*
22 " "	1200°	500·087	13 " "	1000°	500·109
24 " "	24°	500·096	15 " "	1400°	500·074†

* After interval of 4–7 days.

† Bent, after heating beyond last temperature at which measurements were made.

within a few hours after the bar had cooled from a high temperature, excluding the two where the bar was bent, average 500·095; while the ten measurements (excluding the first) which were made two days or more after heating, average 500·106. The difference is only 0·002 per cent of the total length, or 0·12 per cent of the total expansion to 1500°, or about 0·7 per cent of the expansion to 300°. This effect is, therefore, probably responsible for the observed irregularities between 0° and 300°, at which temperature most of the measurements were begun.†

C. *Transference of Temperature by the Thermoelement.*— The electromotive forces of the elements attached to the bulb were measured by a Wolff potentiometer. The standard of

* Day and Clement, loc. cit., p. 419.

† Kammerlingh-Onnes (Konink. Ak. Wet. Amsterdam, Proc., x, 342, 1907) has found the same effect after cooling platinum to very low temperatures.

electromotive force used was the true volt, in terms of which the E.M.F. of the Clark cell is 1·4328 at 15°, and of the saturated cadmium cell used, 1·01918 volts at 25°.

Several small corrections are necessary in order to obtain the true E.M.F. of the thermoelement. The calibration corrections of the potentiometer (Reichsanstalt calibration) were all negligible except that for the fixed resistance to which the standard cell was attached. This correction amounted to 1·3 microvolts in 10,000. The correction for the change of resistance with temperature of the potentiometer was also negligible. The E.M.F. of the standard cell varies with the temperature; hence the temperature of the cell was read at each measurement and a small correction applied. The readings were correct at 21·5°. For a variation of 5° from this temperature the correction was 2·2 microvolts in 10,000 microvolts. The resistance of the contacts of the potentiometer, and the small E.M.F.'s existing at contact points in the circuit of the thermoelement, introduced another small error which was determined by placing the thermoelement in ice and reading the E.M.F. This correction varied for the different elements from −1 to +4 microvolts.

As a check upon the absolute value, a Weston standard cadmium cell (calibration by the Bureau of Standards) whose E.M.F. was read directly on the potentiometer, was compared with the saturated cell each day. The agreement of the corrected values was usually within 0·5 microvolt. As in the case of the pressure measurement, the absolute value of the E.M.F. is not of importance, since it is used only for transference from the fixed points to the gas thermometer; the above corrections were applied, however, to reduce the readings to a common standard.

The effect of contamination of the thermoelement wires in furnace readings was much greater than the above mentioned errors.* Up to 1100° the contamination was not serious, but above that temperature the wires take up iridium together with some rhodium. It was hoped that the replacement of iridium in the bulb by rhodium, which is very much less volatile, would do away with this error, but there appeared still to be a very small percentage of iridium in the furnace wire, enough to affect the thermoelement wires appreciably, even though this furnace wire had been especially purified for this purpose.

Although the task became much longer and more laborious, it was thought wise to make an effort to avoid the error from contamination, even of this diminished magnitude, rather than to attempt to compromise with it by any scheme of approxi-

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* For a more thorough discussion of this effect, see Day and Clement, loc. cit., p. 419; and W. P. White, Phys. Rev., xxiii, 449, 1906.

mate evaluation. Accordingly, after every exposure of suffi-
cient length to endanger the thermoelectric readings, all the
thermoelements were removed from the furnace and their wires
tested for homogeneity. Where contamination was found,
the contaminated portion of the wire was at once cut off. This
is the only absolutely safe method of avoiding errors from this
cause, for it amounts to the use of new thermoelements exclu-
sively in all the determinations of temperature distribution
within the furnace as well as for establishing the absolute
temperature of the metal melting points.

A very simple method of testing the wires for contamina-
tion has been developed which consists in connecting the junc-
tion end of the wire to be tested, together with an uncontami-
nated wire, to the potentiometer and moving the free end of
the standard wire along the wire to be tested, while heating
the contact point of the two with a blast lamp.* The varia-
tion of the E.M.F. produced at this junction indicates the
degree of contamination of the wire; in the uncontaminated
portion this E.M.F. is small and constant within 3 mv. The
temperature obtained by the blast lamp flame is sufficiently
constant for the purpose and lies between 1460° and 1500°.

The wires could be relied upon to give a constant E.M.F.
within 2 mv. at 1000° over a length of at least 50^{cm}, so that
redeterminations of the fixed points were not necessary after
cutting off each small portion of contaminated wire. Each
test for contamination was continued over the 50^{cm} of wire
adjacent to the hot junction and so served as a test for the
homogeneity of the new wire which replaced the portion cut
off. In two cases a sudden change of E.M.F. along the unused
wire amounting to about 10 mv. showed the probable presence
of a junction point in the original sample from which the wire
was drawn. Such a junction point was of course not intro-
duced into the heated portion of the furnace.

In this connection, it should be pointed out that the relative
weight to be given to the element inside the bulb, as compared
with the outside elements, is greater at temperatures above
1100° than at temperatures below, for two reasons: (1) The
temperature at the middle of the bulb is not so much influenced
above 1100° by the temperature of the lower part of the fur-
nace, as it is below 1100°; (2) the outside elements are much
more subject to contamination than the inside element by
reason of the protection afforded by the intervening bulb walls
against contaminating material from the heating coils. This
is well shown by the data in Table VIII on the melting points
of diopside, nickel and cobalt. In the first measurements of
these temperatures, the elements were left on the bulb through

* W. P. White, loc. cit.

several runs, in consequence of which the temperatures derived by the outside elements steadily increase through the series (i. e., the readings of the outside elements on the bulb steadily decreased), whereas the temperatures derived from the inside element are fairly constant. Its contamination was found to be less in amount and distributed over a region of more constant temperature.

For insulating the thermoelement wires from the bulb and furnace, capillary tubes, both of Marquardt porcelain and of silica glass, were employed. The Marquardt tubes are open to the objection that they are very porous and offer little protection against contamination. The silica glass capillaries protected the wires very much better, but at $1100°$ and above they devitrified rapidly and at the end of a measurement at $1400°$ or over fell from the wires in small fragments, so that the wires had to be taken off and reinsulated after a single run.

For the convenience of others who may confront similar problems, it may be added that such extreme precautions as cutting off the elements at the first sign of contamination are excessive for most purposes. The region of highest temperature, and therefore of most rapid contamination in a good furnace, is also a region of constant temperature. Contamination would therefore produce little effect upon the reading of the thermoelement until it had crept out into the colder parts of the furnace, which it will do slowly during long exposures. The distribution of the contamination in an aggravated case is shown in the accompanying table, which is arranged in such a way that not only the magnitude of the contamination but also its distribution with respect to the bulb is roughly shown. The electromotive forces are determined, as has been explained, by bringing successive points of the contaminated

		Before Heating. Microvolts	After Heating. Microvolts
	40^{cm}	-4	-4
	35	-6	-8
Outside of furnace	30	-8	-7
	25	-9	-6
Bend of stem	20	-6	-10
	15	-5	-3
	12	-5	$+2$
	10	-5	$+9$
Shoulder of bulb	8	-5	$+83$
	6	-5	$+83$
	4	-6	$+41$
	2	-6	$+55$
Middle of bulb	0	-8	- - - -

wire into contact with an uncontaminated one in a blast flame (temperature, 1460–1500°), the cold junction being maintained constant at 0°. The absolute magnitude of the numbers in the column "before heating" represents the electromotive force between two uncontaminated platinum wires of (nominally) equal purity. Its constant value is a measure of the homogeneity of the new wire. Its departure from this constant value " after heating " is a measure of the contamination it has received. Slight irregularities are the result of variations in the blast flame temperature. Such observations merely serve to furnish information about the distribution and approximate amount of contamination received by the element, but do not of themselves provide the data to correct its reading in a particular furnace.

Integration of Temperatures over the Bulb.—By the method which has been already described (p. 104) the differences of temperature between the ends of the bulb and the middle were determined differentially by means of platinum wires attached to the bulb itself. Temperatures about the circumference were measured by separate thermoelements, as it was not practicable to measure these differences differentially because of the necessity of passing a platinum binding wire around the bulb to hold the four elements in position. A check on the accuracy of this differential method was obtained by using in one case a thermoelement at the top shoulder of the bulb and thus measuring the temperature at this point both directly and differentially by means of the platinum wire of this element. The two temperatures agreed within 0·8° when the deviation from the middle was 6°; when the temperatures at the middle and top were nearly equal, the two methods agreed to 0·1°.

Table III contains values of $\dfrac{\Delta E}{\Delta t}$, the rate of change of E.M.F. with temperature at various temperatures from 400° to 1500°, both for the 10 per cent rhodium alloy and for the 20 per cent

TABLE III.— *Values of* $\dfrac{\Delta E}{\Delta t}$ *for the alloys 90 Pt. 10 Rh. and*

80 Pt. 20 Rh.

Temp.	90 Pt. 10 Rh.	80 Pt. 20 Rh.
400°	9·4	11·5
600°	10·1	12·8
800°	10·8	14·2
1000°	11·4	15·6
1200°	11·8	16·9
1400°	12·2	17·5
1500°	12·4	17·8

alloy of which the bulb was made. The data for the 20 per cent alloy (which need be only approximate) were obtained by two methods : (1) An element was made up by combining a platinum wire with the 20 per cent rhodium bar used for the expansion coefficient determination, and its readings compared directly with those of a 10 per cent rhodium element in the melting point furnace. (2) A platinum wire was connected from the stem of the gas thermometer bulb outside of the gas thermometer furnace to the ice box, and the E.M.F. determined against the standard platinum wire attached to the middle of the bulb. In both cases, the E.M.F. of the junction of platinum with the rhodium alloy at room temperature was applied as a correction.

In order to obtain the true E.M.F. corresponding to the temperature as measured by the pressure of the gas in the bulb, it is necessary to integrate the various readings over the surface of the bulb. The following arbitrary weights were given to the different positions of elements on the surface :

Top axis	(position 1)	5
Top shoulder	(" 2)	20
Middle	(" 4)	55
Bottom shoulder	(" 6)	15
Bottom axis	(" 7)	5

The elements on the axis at both top and bottom, although sometimes deviating rather widely from the others, have comparatively small weight, as they affect only a small portion of the total volume. The element at the lower shoulder of the bulb is given less weight than that at the top because of the smaller volume of the lower half, due to the presence of the reëntrant tube.

It was easy to show experimentally that it matters very little what these relative weights assigned to the different readings may be, since the total correction was usually small. In a number of cases, two different settings of the temperature distribution were made at each temperature, one in which the elements at the top and bottom shoulders of the bulb were made equal to the middle, and one in which the elements at top and bottom on the axis of the cylinder were made equal to the middle. The pressures corresponding to these two settings, reduced to the same reading of the standard element, are shown for several typical cases in the table below.

Date	Temp.	Pressure when 1, 4, and 7 were equal	Pressure when 2, 4, and 6 were equal
22 Jan. 1909	1082°	1038·82^{mm}	1038·64^{mm}
2 July 1909	1395°	1285·43	1285·17
17 Sept. 1909	1489°	1331·40	1330·63

It is evident that even without any correction for the different distribution in the two cases, the readings agreed within $0\cdot2$–$0\cdot8^{mm}$, or about $0\cdot2$–$0\cdot9°$, so that the variation between any two arbitrary sets of weights which might be given to the different readings must lie well within this limit.

The Transfer to the Fixed Points.—After the thermoelements are removed from the bulb, their E.M.F. at the fixed points must be determined by immersing them in melting or freezing metals or salts. The instrumental corrections to the readings so obtained were the same as in the case of the gas thermometer readings. The error due to contamination was also present above 1100°, just as in the gas thermometer furnace, and was a very disturbing factor in determining the melting points of nickel, cobalt and palladium. Its source, however, was not usually iridium vapor from the furnace or rhodium from the wire of the element, but was either vapor of the melting metal itself, or (when a hydrogen atmosphere was used) the products of reduction of silica. In the presence of hydrogen, silica rapidly deteriorates platinum wire by reduction and alloying, as has been shown in this laboratory by Shepherd,[*] and elsewhere by several observers. The contamination can be partly prevented by the use of a glazed porcelain tube surrounding the thermoelement, instead of an unglazed magnesia tube; but an additional uncertainty is thereby introduced through the contamination of the melting metal by the melted glaze on the porcelain. For this reason nickel and cobalt did not prove to be as satisfactory fixed points as had been hoped, since it was necessary to melt them in an atmosphere of hydrogen. Palladium, however, can be melted in the open air and serious contamination by silicon thus be avoided, although the palladium itself gradually contaminates the wire.

Above 1100° it is better to make direct comparisons of all the elements with one or two whose fixed points have been determined, rather than to contaminate them all by a direct determination. For making these comparisons, the plan first used was to bring a crucible of molten silver to a constant temperature and insert the elements (protected by a glazed Marquardt porcelain tube) successively into the silver bath. There is an uncertainty, however, in these measurements of 2 to 3 mv., caused by small differences of temperature within the tube and to the slight cooling produced by introducing cold wires into the furnace. A better method is to join together the two platinum wires and the two alloy wires of the elements to be compared, and determine the small E.M.F.'s of each pair at several temperatures, from which the difference between the

[*] This Journal (4), xxviii, 300, 1909.

elements at those temperatures can be obtained by algebraic addition. This method offers a great advantage in that the temperature need be only approximately constant and approximately known, since the differences in most cases amount to only a few microvolts. By this method the comparison can be very quickly made at 1500° in the blast-lamp flame, which, with a little care, can be made to give a temperature constant to 20°.

D. Fixed Points.—Considerable attention was given in the previous paper to the standard melting points which serve to establish the gas thermometer scale for general use. In particular, a study was made of the purity of the zinc, silver, gold, and copper used, and of the magnitude of the errors likely to arise with the ordinary metals obtainable in the market.* During the present work, attention has been more particularly directed to the technic of melting point determination itself.†

All the metal melting points here described, except that of palladium, were made in an upright cylindrical furnace through which passed a glazed porcelain tube which could be tightly closed above and below and therefore permitted the atmosphere about the melting metal to be perfectly controlled. An effort was first made to accomplish this by placing the entire furnace inside a gas-tight bomb in which the atmosphere could be similarly varied, but the persistent retention of gases by the various clay insulating materials used about the furnace made this method slow, cumbersome, and very uncertain in its results. The only success which these bomb furnaces attained was to permit melting points to be measured in an approximate vacuum (about 1ᵐᵐ pressure). But it has since been found so much simpler to operate with a neutral or reducing atmosphere in the closed tube passing through the heated zone, that the vacuum furnace has not been used for this work.

The chief disadvantage in the use of a tube of this kind is its effect upon the temperature gradient along the furnace axis. More heat is diverted toward the ends of the furnace and the central constant temperature zone becomes shorter. It offers no difficulty except that greater care must be taken in locating the crucible within the constant temperature region.

The qualities desired in fixed thermometric points for establishing and reproducing a scale are:

(1) Exact reproducibility of the temperature in repeated determinations with the same charge of material and with a different charge independently obtained. This means that the metal or salt must be either perfectly pure or obtainable with a constant amount and kind of impurity.

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* E. T. Allen, in paper of Day and Clement, loc. cit., p. 454.
† See also W. P. White, Melting Point Determination and Melting Point Methods, this Journal (4), xxviii, 453 and 474, 1909.

(2) Independence of particular experimental arrangements. The melting point of a metal, for instance, must be sharp and definite enough so that with different kinds of furnaces and different rates of heating, the same temperature will be obtained.

(3) Convenience and safety of manipulation. A melting point which can only be obtained by the use of elaborate experimental arrangements is undesirable, even though it be reproducible and sharp. Furthermore, the substance must not injure the instrument to be calibrated.

(1) *Reproducibility.*—No extensive experiments have been made in the present work to test a large number of samples of different origin. It appeared sufficient to assure ourselves that all of the metals here used are obtainable in such degree of purity, or with such a constant amount of impurity, that the variations in their melting points are well within the limits of error in the scale itself. Waidner and Burgess[*] have recently made comparisons of various samples of pure zinc, antimony, and copper, and have found no differences exceeding $0.3°$.[†] Our experience has been the same. All of the metals in the present investigation are readily obtainable from the ordinary sources of supply. They have been carefully analyzed in this laboratory by Dr. E. T. Allen, and the results are given in section 6.

(2) *Independence of Experimental Conditions.*—A number of experiments were made to test the effect of different experimental arrangements on the points. Two different furnaces were tried, one 65^{mm} inside diameter and 150^{mm} long, the other 55^{mm} inside diameter and 230^{mm} long. The region of constant temperature in the second furnace was longer than in the first and accordingly there was a larger range in which the crucible could be moved about without affecting the temperature. This furnace was used for all work after March 6, 1909. The ultimate test was always the agreement between the melting and freezing points. Any serious disagreement of these two shows that some influence is entering from without.

The results of the study were briefly as follows: (1) The best dimensions for a charge of metal are about 25^{mm} diameter by 45^{mm} deep. (2) The thermoelement tube should be about 5^{mm} above the bottom of the crucible. (3) There is a region within the furnace in which the melting and freezing points agree and are independent of the rate of heating or (within limits) of the depth of immersion of the thermoelement; it is necessary to find this position of the crucible by trial. With this position once determined, the temperature of the zinc, antimony, silver, gold, and copper points can be relied upon

[*] Phys. Rev., xxviii, 467, 1909. Bull. Bur. Stds., vi, 149–230, 1909.
[†] In the case of antimony, this statement applies only to Kahlbaum's metal.

within 0·2°. With large charges and facilities for stirring the metal, Waidner and Burgess have found the zinc point to be reproducible in a given furnace, with a given sample, within less than 0·1°.

White* showed that the temperatures of the two silicate points used for the present scale are reproducible within 1·0° independently of the dimensions of the furnace or the rate of heating. For a mineral melting point, the charge should be small (about 3 grams), the heat should approach the thermal junction from the side and not from the ends, and a position in the furnace should be found in which the melting point, determined by a bare thermoelement, does not vary with the rate of heating.

The possibility has been several times suggested that the temperature of the thermoelement inside of the tube might possibly be lower by a small constant amount than the temperature of the metal outside of the tube, and that this error might not be brought to light by such experiments as have been described. Several melting and freezing points of copper were, therefore, determined by enclosing the entire thermoelement wire in a thin capillary of silica glass which was slipped over the wire, bent double, and melted down upon the wire at the junction by heating in the oxyhydrogen flame. This was dipped directly into the molten copper to within 5^{mm} of the bottom, so that there was practically no possibility that the temperature of the junction could be lowered by radiation or conduction upward. The melting point on element D obtained in this way was 10,473 microvolts as compared with 10,473 microvolts in the closed glazed tube. There appears to be no error from this cause.

Convenience and Safety of Manipulation.—Zinc and gold are the most convenient of manipulation, as they require no special atmosphere and the temperatures are easily reached. Antimony, silver, and copper require an atmosphere of carbon monoxide and are somewhat less convenient. More care needs to be taken with copper than with silver and antimony because of the considerable effect of a very small amount of oxide. Antimony, silver, gold, and copper were all melted in carbon monoxide, made by dropping formic acid into warm sulphuric acid, and purified by passage through sodium hydroxide, lead nitrate, and sulphuric acid. The lead nitrate was introduced to make certain that no trace of hydrogen sulphide, which might be formed if the acid became too dilute or too warm, could pass into the metal.

The two silicates (diopside and anorthite) and palladium were melted in air. The silicate points are very convenient to

* Diopside and its Relations to Calcium and Magnesium Metasilicates, this Journal (4), xxvii, p. 5, 1909.

arrange and manipulate, provided the furnace is well insulated so that the temperature can be reached without difficulty. Palladium strains the platinum resistance furnace near to its limit of endurance on account of the high temperature, but has the great convenience of not requiring a reducing atmosphere. Special pains need to be taken, however, in this case, to protect the thermoelement from contamination.

Nickel and cobalt were melted in an atmosphere of hydrogen which was made by electrolysis in a large glass and earthenware generator, and purified by passage through potassium pyrogallate and sulphuric acid. Just before the thermoelement was introduced, the hydrogen was displaced by pure nitrogen drawn from a steel tank in which it was stored under pressure. The supply contained a trace of hydrogen and was, therefore, purified by passing over hot copper oxide and through calcium chloride and sulphuric acid. The extreme lightness of this gas compared with the outside air (especially when it is heated to 1450°) makes necessary special precautions in order to keep out any trace of air. Furthermore, hydrogen always caused contamination in the thermoelement, which was not prevented even when the hydrogen was replaced for a short time during the melting by pure nitrogen. Nickel and cobalt are, therefore, not recommended for frequent use in the calibration of thermoelements, if the two points, diopside and palladium (or diopside and anorthite), give a sufficient calibration for the purpose in hand.

The apparatus used for the melting points of nickel and cobalt is shown in section in fig. 6. The top of the large porcelain tube (Marquardt, glazed outside only) was closed by a sliding cup of brass in which the thermoelement tube and two others for introducing hydrogen were fastened by heating the cup and pouring in molten solder. The porcelain tube extended far enough out of the furnace to keep the brass cup cool. A groove near the base of the cup carried a piece of asbestos cord which made a gas-tight joint with the porcelain tube and permitted the whole to be raised and lowered without moving the crucible or opening the top of the tube. Two diaframs of Marquardt porcelain above the crucible also prevented any considerable radiation upward to the brass cup.

In zinc, antimony, silver, gold, and copper, the thermoelement was protected by a glazed Marquardt tube of 5^{mm} inside and 8^{mm} outside diameter. In the case of antimony, the tube was further protected by a thin tube of graphite which fitted into the cover of the crucible. With diopside and anorthite, some contamination from iridium in the furnace may take place, but can be largely prevented by surrounding the tube with pure platinum. A glazed Marquardt tube cannot be used in

this case, for the glaze flows readily at these temperatures and may make its way into the charge. With nickel and cobalt, glazed Marquardt tubes and also pure magnesia tubes of the same size were used, but neither protects the element from contamination. In palladium only the pure magnesia tubes were used.

Zinc, antimony, silver, gold, and copper were melted in graphite crucibles 27^{mm} in diameter and 80^{mm} deep inside, and 37^{mm} in diameter and 100^{mm} high outside. The charge of metal was from 45^{mm} to 55^{mm} deep. Diopside and anorthite were melted in small platinum crucibles 10^{mm} in diameter and 18^{mm} deep, as described and illustrated in the paper already referred to.* Nickel was melted in an unglazed Marquardt porcelain crucible, lined with a paste consisting of about 90 per cent Al_2O_3 and 10 per cent MgO; and also in a Berlin "pure magnesia" crucible. The charge was about 25^{mm} in diameter and 30^{mm} deep. Cobalt could not be melted in the alumina lined crucible, as the metal penetrated through the lining and attacked the porcelain. It was, therefore, melted in a "pure magnesia" crucible made by the Königliche Porzellan Manufaktur. The material of these crucibles probably contains a small percentage of silica. Palladium was melted in a crucible made in this laboratory from a specially pure magnesia made by Baker and Adamson. The magnesia was first shrunk by heating to a temperature higher than that at which the crucible was to be used, and was then made into a paste with water and a little magnesium chloride, spun into form, and baked.

Particular details regarding each of the substances used will now be taken up in the order of their temperatures.†

Fig. 6.

Fig. 6. The furnace in which the standard metal melting points were made, showing the position of the metal with respect to the coil, the thermoelement (T) and the arrangement (H) for maintaining a hydrogen or nitrogen atmosphere.

* W. P. White, this Journal (4), xxviii, 477, 1909.
† See, also, E. T. Allen, in paper of Day and Clement, loc. cit., p. 454.

Zinc.—Two samples of " C. P. sticks" were used, both from Eimer and Amend. No appreciable difference could be observed between their melting points. Both melting and freezing points were sharp and measurable to a fraction of a microvolt. Successive readings did not differ by more than one microvolt. The charge was about 200 grams. The analysis has been published.[*]

Antimony.—Two samples of metal were used, both from Kahlbaum, and no appreciable difference was found between their melting points. An analysis of the first sample is given in section 6. The charge weighed about 150 grams. The melting point is sharp and does not differ from the freezing point by more than one microvolt, provided the undercooling which always precedes solidification does not exceed 15°. If the metal is undercooled too far to give an accurate freezing point, the fact is easily recognized by observing that the thermoelement does not return to a sustained constant temperature, but merely rises to a maximum, then falls again. The amount of undercooling is greater the higher the metal has been heated above its melting point after the melting is complete.

Silver.—The charge weighed about 260 grams. Only one supply was used, a specially purified sample obtained from the Philadelphia Mint, of which an analysis is given in the previous paper.[*] The melting and freezing points were sharp and agreed within one microvolt.

Gold.—A new charge of gold was used, weighing 350 grams. This was obtained from Dr. Eckfeldt of the Philadelphia Mint. No analysis was deemed necessary.[*]

Copper.—The copper was obtained in the form known as "copper drops cooled in hydrogen" (Eimer and Amend). Only one supply was used. The melting and freezing points were not quite as sharp as was the case with silver, but always agreed within 1 microvolt. The temperature is very susceptible to a trace of oxide, which not only lowers the temperature appreciably but makes it more uncertain, so that if a little oxidation has taken place it is recognizable at once. Waidner and Burgess[†] found that the best commercial electrolytic copper showed an average difference of 0·2° in the melting point from the purified copper drops. Charge, about 210 grams.

Diopside.—Two samples of diopside were used, one from the preparation of Allen and White[‡] and the other made up in 1909 by G. A. Rankin. No appreciable difference was found

[*] E. T. Allen, in paper of Day and Clement, p. 454.
[†] Loc. cit., p. 469 (Phys. Rev.) ; p. 174 (Bull.).
[‡] This Journal (4), xxvii, 1, 1909.

between the melting points. No freezing point can be obtained as the mineral undercools considerably. The charge used was 3 grams.

Nickel.—A sample of specially purified electrolytic nickel was obtained from Kahlbaum. The analysis showed less than 0·2 per cent total impurities. Care must be taken in the case of nickel that no oxide forms, as a fairly sharp break can be observed about 10° below the melting point, which may represent the eutectic of nickel and nickel oxide. This break disappeared when the nitrogen was replaced for a few minutes by hydrogen. This lower point may easily be mistaken for the melting point of the metal, and this mistake seems to have occurred in several of the published determinations of the melting point of nickel. Nickel absorbs hydrogen and possibly also nitrogen, and after cooling frequently showed excrescences and signs of "spitting" such as occur with silver in air.

Cobalt.—Kahlbaum's purest cobalt was used, containing less than 0·05 per cent total impurity. It was in the form of fine black powder, which was compressed into blocks for convenience in handling. The results obtained were not quite as satisfactory as with nickel on account of the higher temperature and more rapid contamination of the thermoelement. The absorption of gases seemed to be less than was the case with nickel.

Samples of Eimer and Amend's "98 to 99 per cent pure" nickel and cobalt were also tried. The difference between the two samples of nickel was not greater than the uncertainty in the melting point caused by contamination of the thermoelement. The "98–99 per cent pure" cobalt melted about 3·5° lower than the pure sample. Since the impurities in nickel are usually chiefly iron and cobalt, and those of cobalt are chiefly iron and nickel, and since the melting points of all three are close together, the melting points of the slightly impure metals can not be expected to lie far from those of the pure metals.

Anorthite.—Only one preparation of anorthite was used, made by G. A. Rankin 1909. The charge was about 3 grams. The melting point is not quite as sharp as that of diopside. Only the melting point can be obtained, as the mineral undercools considerably; it may even cool to glass without crystallization, in which case of course no melting point will be obtained on the following heating.

Palladium.—About 350 grams of pure palladium, in the form of sheet, was loaned to us by Dr. Heraeus. It melts and freezes quite sharply, making an excellent substance for a fixed thermometric point. The greatest uncertainty is caused by the vaporization of the metal and consequent contamination of the thermoelement wire. The charge used weighed 128–210 grams

In addition to the fixed points which have just been described, two other metal melting points, cadmium and aluminum, were incidentally determined. Only one measurement of the cadmium point was made on the gas thermometer, and this chiefly for the purpose of checking the extrapolation below the zinc point. The conditions of melting were the same as for zinc. The sample was obtained from Eimer and Amend, and its analysis has been given in a paper by Day and Allen.[*] The charge weighed 215 grams.

A sample of pure aluminum obtained from the Aluminum Company of America was melted in a graphite crucible of the usual size in an atmosphere of carbon monoxide. On account of the sensitiveness of aluminum to silicon contamination, the tube carrying the thermoelement was also provided with a thin protecting cover of graphite so that the metal came in contact only with pure graphite. The freezing point was sharp and constant. The melting point was less sharp but lay within 0·5° of the freezing point.

The effect on the final temperature of all the errors and corrections which have been discussed in this section, is shown in summarized form in Table IV.

The figures of Table IV serve to emphasize the statements already made, that the greatest present uncertainty in the high temperature gas scale arises from the lack of uniformity in an air bath, which not only leads to uncertainty as to what is the true temperature of the gas in the bulb, but also to errors in the transference by the thermoelement. The next largest uncertainty, due to the limitations of the materials used for fixed points, is not directly chargeable to the gas thermometer. In this connection, considerably more work needs to be done on the high thermometric points, comparable in thoroughness to the work in low temperature thermometry of Richards, Dickinson, and others, on the sodium sulphate transition point.

4. *Experimental Data and Calculated Results.*

A. Expansion Coefficient.—In Table V are given the experimental data on the expansion coefficients of the alloy 80 per cent platinum, 20 per cent rhodium. In the first column is given the date of the series, in the second and third columns the readings of the thermoelements at the middle of the bar, corrected for zero error and the temperature of the cadmium cell. The 12 other readings taken with each element at each temperature at different points along the bar cannot be given here, but the fourth and fifth columns contain the readings of the thermoelement corrected to represent the integrated tem-

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[*] Arthur L. Day and E. T. Allen, Phys. Rev., xix, 180, 1904.

TABLE IV.—*Estimated Errors and their Effect on the Value of t.*

Quantity affected	Source of error	Amount of error		Effect on t	
		at 400°	at 1500°	at 400°	at 1500°
(A) Temperature of gas	Temperature differences over bulb surface	2 mv.	5 mv.	± 0·2°	± 0·4°
	Variability	0	1 mv.	0	± 0·1°
(B) p_0	Reference point	0·02 mm.	0·02 mm.	± 0·04°	± 0·15°
"	Manometer setting	0·02 mm.	0·02 mm.	± 0·04°	± 0·15°
"	Scale corrections	0·01 mm.	0·01 mm.	± 0·02°	± 0·07°
"	Temperature of mercury	0·05 mm.	0·05 mm.	± 0·10°	± 0·38°
"	Barometer setting	0·03 mm.	0·03 mm.	± 0·06°	± 0·23°
"	Temperature of barometer	0·05 mm.	0·05 mm.	± 0·10°	± 0·38°
"	Variations in p_0	0	0–·05 mm.	0	0 to ±0·3
p	Reference point	0·02 mm.	0·02 mm.	± 0·02°	0
"	Manometer setting	0·02 mm.	0·02 mm.	± 0·02°	0
"	Scale corrections	0·02 mm.	0·02 mm.	± 0·02°	0
"	Temperature mercury	0·07 mm.	0·20 mm.	± 0·07°	± 0·05°
"	Barometer setting	0·03 mm.	0·03 mm.	± 0·03°	± 0·01°
"	Barometer temperature	0·05 mm.	0·05 mm.	± 0·05°	± 0·01°
"	Unheated $\{v_1$ space $\}t_1$	0·020 cc. 0·5–50°	0·020 cc. 0·5°–100°	± 0·07° ± 0·01°	± 0·5° ± 0·1°
β	Temperature	1·0°	2·0°	± 0·02°	± 0·11°
"	Expansion	0·005 mm.	0·008 mm.	± 0·02°	± 0·09
"	Hysteresis in expansion	0·01 mm.	0·01 mm.	± 0·04°	± 0·10°
(C) E.M.F.	Instrumental correction	1 mv.	2 mv.	± 0·1°	± 0·2°
"	Contamination	0	0–12 mv.	0	0 to +1·0°
"	Integration over bulb	3 mv.	12 mv.	± 0·3°	± 1·0°
(D) Fixed points	Instrumental corrections	1 mv.	2 mv.	± 0·1°	± 0·2°
"	Contamination	0	0–10 mv.	0	0 to −1·0°
"	Variation in given charge	Specific 1 – 10 mv.		Specific 0·1 – 1·0°	
"	Variation between different charges	Specific 1 – 20 mv.		Specific 0·1 – 2·0°	

A. L. Day and R. B. Sosman—

perature along the bar. For convenience, the integration was made in terms of microvolts instead of degrees. The sixth and seventh columns contain the temperatures corresponding

TABLE V.—*Observations of Expansion Coefficient, β.*

Date	Thermoelements				Temperature			Expansion from 0°	
	W	Z	W cor.	Z cor.	by W	by Z	Mean	mm on 500 mm	$10^6\beta$
1908									
Sept. 21	2261	2251	2312	2298	301·4°	301·4°	301·4°	1·404	9·32
	3197	3187	3273	3258	404·6	405·4	405·0	1·912	9·44
	4169	4153	4257	4237	506·0	507·1	506·6	2·434	9·61
	5157	5140	5237	5212	603·9	605·1	604·5	2·950	9·76
	6197	6178	6286	6262	705·4	707·2	706·3	3·500	9·91
	7264	7238	7362	7333	806·2	807·8	807·0	4·064	10·07
	8361	8335	8457	8420	905·9	906·7	906·3	4·640	10·24
	9509	9470	9599	9552	1006·9	1006·8	1006·8	5·241	10·41
	10662	10611	10733	10675	1104·5	1103·4	1104·0	5·828	10·56
	11963	11896	12018	11921	1215·3	1210·2	1212·8	6·469	10·67
Sept. 25	1817	1801	1848	1831	248·7	248·4	248·6	1·154	9·28
	2756	2735	2791	2768	353·4	352·9	353·2	1·666	9·43
	3699	3674	3726	3702	451·8	452·0	451·9	2·158	9·55
	4686	4655	4691	4662	549·7	550·3	550·0	2·668	9·70
	5711	5679	5691	5660	648·2	649·2	648·7	3·191	9·84
	6820	6788	6772	6742	751·2	752·6	751·9	3·757	9·99
	7847	7813	7754	7720	842·2	843·2	842·7	4·262	10·11
	8980	8945	8845	8809	940·8	941·4	941·1	4·827	10·26
	10140	10102	9939	9901	1036·4	1037·0	1036·8	5·403	10·42
	11368	11327	11109	11063	1136·9	1136·4	1136·7	6·012	10·58
Oct. 3	2291	2272	2302	2283	300·3	299·8	300·1	1·384	9·22
	3228	3205	3250	3228	402·2	402·2	402·2	1·899	9·44
	4208	4181	4243	4215	504·6	504·9	504·8	2·432	9·63
	5205	5175	5247	5216	604·8	605·5	605·2	2·964	9·79
	6238	6206	6281	6249	704·9	705·9	705·4	3·511	9·95
	7297	7263	7342	7309	804·4	805·5	805·0	4·069	10·11
	8401	8365	8446	8408	904·9	905·6	905·3	4·644	10·26
	9536	9497	9576	9534	1004·9	1005·2	1005·1	5·231	10·41
	10675	10647	10710	10670	1102·6	1103·0	1102·8	5·830	10·57
	11884	11857	11926	11875	1207·5	1206·2	1206·8	6·466	10·71
Oct. 29	8419	8377	8366	8324	897·4	898·0	897·7	4·618	10·29
	9551	9507	9436	9392	992·6	992·8	992·7	5·169	10·41
	10706	10663	10539	10496	1088·0	1088·2	1088·1	5·752	10·57
	11884	11849	11786	11751	1195·6	1195·7	1195·7	6·401	10·70
	13137	13104	13134	13101	1309·9	1309·8	1309·9	7·154	10·92
1909	W	D	W cor.	D cor.	by W	by D			
Oct. 13	2304	2301	2235	2232	293·0	293·0	293·0	1·352	9·23
	6222	6217	6180	6175	695·2	695·9	695·6	3·452	9·92
	9501	9494	9493	9486	997·6	998·1	997·9	5·190	10·40
Oct. 14	9540	9536	9542	9544	1001·9	1003·1	1002·5	5·200	10·37
	10666	10663	10690	10691	1101·9	1102·5	1102·2	5·811	10·54
	11839	11836	11783	11783	1195·4	1195·7	1195·6	6·410	10·72
	12998	12993	13121	13120	1308·9	1308·6	1308·8	7·156	10·93
	14183	14170	14390	14372	1413·4	1411·6	1412·5	7·832	11·09

to the readings in columns 4 and 5, and the eighth column, the mean of these two temperatures. The micrometer readings are not given, but in column 9 will be found the expansions reduced to millimeters for that portion of the bar lying between the 0 and 50^{cm} marks on the ends. Each of these represents the mean of eight settings at each end of the bar. In the last column are given the values of the mean expansion coefficient from 0°, calculated by dividing the expansion by the length at 0 and by the temperature.

For convenience of comparison, the values of β at the nearest round temperatures were interpolated linearly between the observations in each series, and the results are given in Table VI. Values interpolated between these values are given in parentheses.

TABLE VI.— *Values of $10^6 \beta$ at Round Temperatures for the alloy 80 Pt, 20 Rh.*

Temp.	21 Sept. 1908	25 Sept. 1908	3 Oct. 1908	29 Oct. 1908	13 Oct. 1909	14 Oct. 1909	Mean
250		9·28					
300	9·31	(9·36)	9·22		9·24		9·28
350	(9·37)	9·43	(9·33)		(9·33)		9·36
400	9·43	(9·49)	9·44		(9·41)		9·44
450	(9·52)	9·55	(9·53)		(9·50)		9·52
500	9·60	(9·62)	9·62		(9·58)		9·61
550	(9·67)	9·70	(9·71)		(9·67)		9·69
600	9·75	(9·77)	9·79		(9·76)		9·77
650	(9·83)	9·84	(9·86)		(9·84)		9·84
700	9·90	(9·92)	9·94		9·93		9·92
750	(9·98)	9·99	(10·02)		(10·01)		10·00
800	10·06	10·06	10·10		(10·09)		10·08
850	(10·14)	10·12	(10·17)		(10·16)		10·15
900	10·23	(10·20)	10·25	10·29	(10·24)		10·24
950	(10·31)	10·27	(10·32)	(10·36)	(10·32)		10·32
1000	10·40	(10·36)	10·40	10·42	10·40	10·37	10·39
1050	(10·47)	10·44	(10·48)	(10·50)		(10·45)	10·47
1100	10·55	(10·52)	10·57	10·59		10·54	10·55
1150	(10·60)	10·60	(10·64)	(10·65)		(10·63)	10·62
1200	10·65	(10·67)	10·71	10·71		10·73	10·69
1250				(10·81)		(10·82)	10·81
1300				10·90		10·92	10·91
1350				(10·99)		(10·99)	10·99
1400						11·07	11·07
1450							(11·15)
1500							(11·23)

The table shows that the percentage error at 300° is greater than that at 1200° and above, probably on account of the larger effect of the hysteresis in the expansion and contraction, already discussed on page 114. The agreement of the results is very satisfactory, particularly in view of the fact that each

series represents an entirely different curve of temperature variation along the bar. In some cases the temperatures at the ends were lower than at the middle, in others higher than at the middle, and in one series one end was higher and the other lower. The mean of all, therefore, probably eliminates any error which might arise from variation of temperature along the bar.

The results are represented within the limits of error by the straight line equation :

$$10^6\beta = 8\cdot79 + 0\cdot00161t.$$

This may be compared here with the expansion coefficients between 300° and 1000° determined by the authors for the 10 per cent iridium alloy,* and of Holborn and Day† for the 20 per cent iridium alloy and for pure platinum :

$$\begin{array}{lll} \text{80 Pt. 20 Ir.} & 10^6\beta = & 8\cdot20 + 0\cdot00142t \\ \text{90 Pt. 10 Ir.} & 10^6\beta = & 8\cdot84 + 0\cdot00131t \\ \text{Pt.} & 10^6\beta = & 8\cdot87 + 0\cdot00132t. \end{array}$$

B. Gas Thermometer Data and Fixed Points.—In Table VII are given the observed gas thermometer data.‡ In the first column is the date of the measurement. The measurements are numbered chronologically in the second column for convenience of reference. In the third column is the measured pressure, p' (or p_0') in millimeters of mercury at 0°, corrected as described on pages 107 and 108. The application of the correction for unheated space (see p. 108) gives the pressure p (or p_0) which is found in the fourth column. In the fifth column is the value of the temperature, t, calculated by formula (5) on page 101. In column 6 are given the readings of the standard thermoelements in microvolts, and in column 7 the positions of these elements on the bulb ; for the significance of these figures see fig. 1 and note on page 104. In the last column are given the other elements which were used on the bulb, together with their positions designated in the same way. The italicized letters represent single platinum wires instead of thermoelements.

A few measurements in which the value of p_0 changed by more than 0·1 per cent have been omitted ; their position is shown by the absence of their corresponding serial numbers.

* Published in paper of Day and Clement, loc. cit, pp. 425–441.
† This Journal (4), xi, 374, 1901.
‡ For the measurements in the table, seven furnaces were employed, using three supplies of platinum wire of about 400 grams each. One of these furnaces was wound on the outside, the other six on the inside of the tube. It was possible to rewind the wire at least once after the furnace had burned out. Failure always occurred several cms. away from the bulb in the end portions of the furnace, which, in order to secure uniformity of temperature over the bulb, had to be considerably superheated. Only one measurement was made at the palladium point, as this one rendered the furnace unfit for further use ; the conditions of this measurement, were, however, perfect.

Table VII—*Observed Gas-Thermometer Data.*

Date	No.	p' (or p_0')	p (or p_0)	t	Standard Elements	Position	Other elements and positions
1908				Gas Filling No. 1			
30 Nov.	1	217·65	217·63	0°	- - - -		
"	2	1037·77	1042·72	1079·87	W 10443 } X 10491 }	4 8	Z (1), S (9)
1 Dec.	3	217·45	217·43	0	- - - -		
2 Dec.	5	217·10	217·08	0	- - - -		
3 Dec.	6	948·81	952·84	960·59	W 9061 } X 9100 }	4 8	Z (1), S (9)
4 Dec.	7	217·12	217·10	0	- - - -		
16 Dec.	8	217·08	217·06	0	- - -		
17 Dec.	9	1038·50	1043·48	1083·61	W 10483 } X 10555 }	4 8	Z (1), S (9)
18 Dec.	10	217·18	217·16	0	- - - -		
19 Dec.	11	1038·57	1043·56	1083·77	W 10473 } X 10512 }	4 8	Z (1), S (9)
21 Dec.	12	217·06	217·04	0	- - - -		
23 Dec.	15	217·49	217·47	0	- - - -		
24 Dec.	16	1242·38	1249·71	1365·71	A 13866 } X - - - - }	4 8	Y (1), S (9)
28 Dec.	17	217·57	217·55	0	- - - -		
1909 22 Jan.	18	1039·78	1044·74	1082·84	A 10502 } Y 10612 }	4 8	Z (9), B (1·3) W (2·3), S (6·7) X (7·3)
"	19	1038·82	1043·79	1081·87	A 10506 } Y 10584 }	4 8	Do.
"	20	1037·85	1042·83	1080·89	A 10498 } Y 10555 }	4 8	Do.
23 Jan.	21	217·36	217·34	0	- - - -		
25 Jan.	22	543·01	544·07	418·40	A 3414 } Y 3436 }	4·5 8	Do.
"	23	542·27	543·32	417·43	A 3408 } Y 3435 }	4·5 8	Do.
26 Jan.	24	703·78	705·81	629·80	A 5510 } Y 5550 }	4·5 8	Do.
"	25	702·64	704·67	628·34	A 5501 } Y 5529 }	4·5 8	Do.
"	26	949·56	953·63	960·22	A 9090 } Y 9159 }	4·5 8	Do.
"	27	948·15	952·23	958·41	A 9075 } Y 9119 }	4·5 8	Do.
"	28	1039·03	1044·05	1083·01	A 10515 } Y 10593 }	4·5 8	Do.
"	29	1037·92	1042·93	1081·56	A 10505 } Y 10556 }	4·5· 8	Do.
27 Jan.	30	217·33	217·31	0°	- - - -		
28 Jan.	31	542·87	543·92	418·30	A 3410 } Y 3436 }	4·5 8	Do.
"	32	542·07	543·11	417·25	A 3404 } Y 3425 }	4·5 8	Do.
"	33	704·06	706·07	630·21	A 5514 } Y 5553 }	4·5 8	Do.

TABLE VII—(*Continued*)

Date	No.	p' (or p_0')	p (or p_0)	t	Standard Elements		Posi-tion	Other elements and positions
28 Jan.	34	703·35	705·37	629·31	A	5510 ⎱	4·5	Z (9), *B* (1·3), *W*
					Y	5537 ⎰	8	(2·3),*S*(6·7)*X*(7·3)
"	35	948·96	953·05	959·46	A	9087 ⎱	4·5	Do.
					Y	9142 ⎰	8	
"	36	949·86	953·97	960·69	A	9098 ⎱	4·5	Do.
					Y	9163 ⎰	8	
"	37	1038·50	1043·57	1082·23	A	10511 ⎱	4·5	Do.
					Y	10576 ⎰	8	
"	38	1038·99	1044·06	1082·90	A	10512 ⎱	4·5	Do.
					Y	10585 ⎰	8	
"	39	1039·61	1044·68	1083·68	A	10509 ⎱	4·5	Do.
					Y	10617 ⎰·	8	
29 Jan.	40	217·37	217·35	0°	- - - -			
"	41	949·32	953·38	959·78	A	9086 ⎱	4·5	Do..
					Y	9156 ⎰	8	
"	42	948·58	952·66	958·81	A	9085 ⎱	4·5	Do.
					Y	9131 ⎰	8	
"	43	1039·29	1044·34	1083·15	A	10515 ⎱	4·5	Do.
					Y	10595 ⎰	8	
"	44	1038·49	1043·56	1082·09	A	10511 ⎱	4·5	Do.
					Y	10568 ⎰	8	
"	45	1039·63	1044·71	1083·58	A	10508 ⎱	4·5	Do.
					Y	10617 ⎰	8	
30 Jan.	46	217·39	217·37	0	- - - -			

GAS FILLING No. 2

Date	No.	p' (or p_0')	p (or p_0)	t	Standard Elements		Posi-tion	Other elements and positions
18 Feb.	47	346·74	346·70	0	- - - -			
22 Feb.	48	346·78	346·74	0				
					A	2487 ⎱	4·5	*W* (1·3), *B* (2·2),
23 Feb.	49	745·09	746·19	319·55	D	2483 ⎬	4·5	*X* (6·2), *S* (7·3),
					Z	2462 ⎰	8	Y (12)
					A	3414 ⎱	4·5	Do.
"	50	866·47	868·15	418·40	D	3406 ⎬	4·5	
					Z	3385 ⎰	8	
					A	4451 ⎱	4·5	Do.
"	51	995·97	998·38	524·71	D	4439 ⎬	4·5	
					Z	4413 ⎰	8	
					A	5510 ⎱	4·5	Do.
"	52	1122·39	1125·61	629·37	D	5495 ⎬	4·5	
					Z	5463 ⎰	8	
24 Feb.	53	346·67	346·63	0	- - - -			
26 Feb.	59	346·24	346·20	0	- - - -			
					A	10508 ⎱	4·5	*W* (3·3), *B* (2·2),
"	60	1657·03	1665·07	1083·17	D	10473 ⎬	4·5	*X* (6·2), *S* (7·2),
					Z	10422 ⎰	8	Y (12)
27 Feb.	61	346·45	346·41	0	- - -			
					A	7895 ⎱	4.5	*B* (3·2), *W* (2·3),
1 Mar.	62	1388·84	1394·13	853·76	D	7869 ⎬	4.5	*X* (6·2), *S* (7·2,)
					Z	7829 ⎰	8	Y (12)
					A	9086 ⎱	4·5	Do.
"	63	1513·67	1520·20	960·29	D	9055 ⎬	4·5	
					Z	9010 ⎰	8	
					A	10265 ⎱	4·5 ·	Do.
"	64	1632·03	1639·78	1062·15	D	10229 ⎬	4·5	
					Z	10178 ⎰	8	

TABLE VII—(*Continued*)

Date	No.	p'(or p_0')	p (or p_0)	t	Standard Elements	Position	Other elements and positions
1 Mar.	65	1655·77	1663·81	1082·84	A 10511 D 10474 Z 10420	4·5 4·5 8	*B* (3·2), *W* (2·3), *X* (6·2), *S* (7·2), Y (12)
2 Mar.	66	346·20	346·17	0	----		
3 Mar.	67	1386·28	1391·55	852·44	A 7885 D 7861 Z 7820	4·5 4·5 8	*W* (3·3), *B* (2·2) *X* (6·2), *S* (7·2) Z (8), Y (12)
"	68	1511·95	1518·48	959·81	A 9088 D 9059 Z 9013	4·5 4·5 8	Do.
"	69	1628·71	1636·46	1060·24	A 10257 D 10221 Z 10169	4·5 4·5 8	Do.
"	70	1654·46	1662·50	1082·73	A 10511 D 10478 Z 10444	4·5 4·5 8	Do.
5 Mar.	71	345·98	345·94	0	----		

GAS FILLING No. 3

Date	No.	p'(or p_0')	p (or p_0)	t	Standard Elements	Position	Other elements and positions
4 June	72	345·31	345·27	0	----		
"	73	861·67	862·94	417·07	A 3403 E 3419 F 3414 G 3416 Z 3370	4·1 4·3 4·5 4·7 8	Y (1), *a* (2·4), *b* (6·4)
"	74	1118·50	1120·83	629·11	A 5516 E 5535 F 5528 G 5529 Z 5461	4·1 4·3 4·5 4·7 8	Do.
5 June	75	345·31	345·27	0	----		
"	76	1510·50	1515·27	959·77	A 9090 E 9114 F 9099 G 9108 Z 9002	4·1 4·3 4·5 4·7 8	Do.
"	77	1628·08	1633·64	1060·53	A 10258 E 10285 F 10266 G 10279 Z 10161	4·1 4·3 4·5 4·7 8	Do.
"	78	1652·36	1658·10	1081·28	A 10503 E 10529 F 10510 G 10523 Z 10404	4·1 4·3 4·5 4·7 8	Do.
7 June	79	345·50	345·46	0	----		
10 June	80	345·52	345·48	0	----		
18 June	81	1512·96	1517·69	961·21	F 9129 E 9128 A 9080 G 9122 Z 9015	4·1 4·3 4·5 4·7 8	*a* (1), *b* (2·4), *c* (6·4), *e* (7·3)
"	82	1630·94	1636·53	1062·53	F 10299 E 10300 A 10252 G 10292 Z 10181	4·1 4·3 4·5 4·7 8	Do.

TABLE VII—(*Continued*)

Date	No.	p'(or p_0')	p (or p_0)	t	Standard Elements	Position	Other elements and positions
18 June	83	1653·61	1659·37	1082·14	F 10534 E 10534 A 10487 G 10526 Z 10403	4·1 4·3 4·5 4·7 8	a (1), b (2·4) c (6·4), e (7·3)
"	84	1654·51	1660·27	1082·91	F 10536 E 10534 A 10485 G 10525 Z 10426	4·1 4·3 4·5 4·7 8	Do.
19 June	85	345·51	345·47	0	----		
GAS FILLING No. 3a							
19 June	86	219·73	219·71	0	---		
"	87	710·34	711·83	627·61	F 5520 E 5520 A 5484 G 5516 Z 5437	4·1 4·3 4·5 4·7 8	a (1), e (2·3) c (6·3), f (7·3)
"	88	962·21	965·23	961·71	F 9139 E 9136 A 9089 G 9131 Z 9036	4·1 4·3 4·5 4·7 8	Do.
"	89	1051·74	1055·41	1082·75	F 10540 E 10538 A 10490 G 10531 Z 10428	4·1 4·3 4·5 4·7 8	Do.
21 June	90	219·74	219·72	0	----		
22 June	92	220·65	220·63	0	----		
24 June	93	220·62	220·59	0	----		
25 June	95	220·56	220·53	0	---		
2 July	96	1283·36	1288·82	1391·97	H 14251 E 14227 F 14222 G 14245 Z 14121	4·1 4·3 4·5 4·7 8	Do.
"	97	1285·43	1290·89	1394·89	H 14282 E 14247 F 14241 G 14274 Z 14156	4·1 4·3 4·5 4·7 8	Do.
3 July	98	221·02	220·99	0	----		
"	99	1281·97	1287·45	1393·34	H 14213 E 14214 F 14196 G 14216 Z 14099	4·1 4·3 4·5 4·7 8	Do.
"	100	1284·05	1289·54	1396·17	H 14264 E 14242 F 14235 G 14259 Z 14156	4·1 4·3 4·5 4·7 8	Do.
6 July	101	220·62	220·60	0	----		

Table VII—(*Continued*)

Date	No.	p'(or p_0')	p (or p_0)	t	Standard Elements	Position	Other elements and positions
			Gas Filling No. 4				
8 July	102	216·81	216·79	0	....		
"	103	1261·35	1266·80	1391·15	H 14235 ⎫ E 14216 ⎪ F 14209 ⎬ G 14222 ⎪ Z 14124 ⎭	4·1 4·3 4·5 4·7 8	a (1), e (2·3) c (6·3), f (7·3)
"	104	1263·13	1268·59	1393·55	H 14249 ⎫ E 14229 ⎪ F 14199 ⎬ G 14236 ⎪ Z 14155 ⎭	4·1 4·3 4·5 4·7 8	Do.
9 July	105	217·36	217·33	0	....		
"	106	1261·71	1267·15	1391·64	H 14251 ⎫ E 14236 ⎪ F 14233 ⎬ G 14241 ⎪ Z 14123 ⎭	4·1 4·3 4·5 4·7 8	Do.
"	107	1263·01	1268·46	1393·44	H 14240 ⎫ E 14236 ⎪ F 14225 ⎬ G 14233 ⎪ Z 14152 ⎭	4·1 4·3 4·5 4·7 0	Do.
10 July	108	217·35	217·33	0	....		
"	109	1306·60	1312·52	1455·37	H 15019 ⎫ E 15020 ⎪ F .... ⎬ G .... ⎪ Z 14903 ⎭	4·1 4·3 4·5 4·7 8	Do.
12 July	110	217·36	217·34	0	....		
"	111	1305·53	1311·35	1453·52	H 14978 ⎫ E 14980 ⎪ F .... ⎬ G ... ⎪ Z 14867 ⎭	4·1 4·3 4·5 4·7 8	Do.
"	112	1305·46	1311·28	1453·31	H 14980 ⎫ E 14960 ⎪ F 14947 ⎬ G .... ⎪ Z 14872 ⎭	4·1 4·3 4·5 4·7 8	Do.
13 July	113	217·40	217·38	0	....		
10 Sept.	114	217·38	217·36	0	....		
11 Sept.	115	1328·68	1334·79	1484·70	H .... ⎫ E 15389 ⎪ F 15374 ⎬ G .... ⎪ A 15357 ⎭	4·1 4·3 4·5 4·7 8	a (1), c (2·3) e (6·7), f (7·3)
"	116	1332·18	1338·32	1489·60	H ... ⎫ E 15411 ⎪ F 15417 ⎬ G 15418 ⎪ A 15421 ⎭	4·1 4·3 4·5 4·7 8	Do.
13 Sept.	117	217·62	217·60	0	....		

TABLE VII—(*Continued*)

Date	No.	p'(or p_0')	p (or p_0)	t	Standard Elements	Position	Other elements and positions
15 Sept.	118	1329·92	1336·03	1487·36	H ---- E 15391 F 15389 G 15399 A 15382	4·1 4·3 4·5 4·7 8	a (1), c (2·3) e (6·7) f (7·3)
16 Sept.	119	217·51	217·49	0			
17 Sept.	120	1329·68	1335·78	1486·95	H ---- E 15386 F 15376 G 15368 A 15379	4·1 4·3 4·5 4·7 8	Do.
"	121	1331·40	1337·51	1489·34	H ---- E 15397 F 15396 G 15389 A 15412	4·1 4·3 4·5 4·7 8	Do.
18 Sept.	122	217·52	217·50	0			
21 Sept.	123	1306·75	1312·72	1454·83	H ---- E 14991 F 14996 G 14957 A 14982	4·1 4·3 4·5 4·7 8	Do.
"	124	1307·28	1313·25	1455·60	H ---- E 14979 F 14984 G 14952 A 14996	4·1 4·3 4·5 4·7 8	Do.
22 Sept.	125	217·45	217·43	0			
27 Nov.*	126	1045·80	1049·49	1090·59	H 10618 E 10626 F 10622 G 10616 C 10567	4·1 4·3 4·5 4·7 8	a (1·5), J (2·4) c (6·2), e (7·2)
29 Nov.	127	217·28	217·26	0			
9 Dec.	128	1129·52	1133·91	1206·63	H 12002 E 12006 F 12003 G 12010 C 11914	4·1 4·3 4·5 4·7 8	Do.
"	129	1194·81	1199·74	1298·01	H 13106 E 13112 F 13107 G 13115 C 13007	4·1 4·3 4·5 4·7 8	Do.
"	130	1261·16	1266·68	1391·45	H 14246 E 14250 F 14248 G 14256 C 14146	4·1 4·3 4·5 4·7 8	Do.
10 Dec.	131	217·30	217·28	0			
20 Dec.	132	1125·92	1130·29	1201·50	H 11940 E 11946 F 11951 G 11949 C 11887	4·1 4·3 4·5 4·7 8	a (1), J (2·3), c (6·2), e (7·1)

* Outside-wound furnace. See page 106.

TABLE VII—(*Concluded*)

Date	No.	p' (or p_0')	p (or p_0)	t	Standard Elements	Position	Other elements and positions
20 Dec.	133	1302·40	1308·33	1450·03	H 14950 E 14958 F 14962 G 14955 C 14882	4·1 4·3 4·5 4·7 8	a (1), J (2·3) c (6·2), e (7·1)
"	134	1372·16	1378·78	1550·15	H 16156 E 16160 F 16170 G 16148 C 16075	4·1 4·3 4·5 4·7 8	Do.
21 Dec.	135	217·29	217·27	0	----		

The melting and freezing points of the metals and salts, measured with the various thermoelements used during the investigation, as well as the frequent comparisons of thermoelements with each other, are too numerous to be published here, especially as they are practically all summarized in Table VIII.

Table VIII contains the final temperature of each thermometric point studied. In the first column is the number of the experiment corresponding to that in Table VII. In the second column is the correction in degrees to be applied to each of the thermoelement readings on the *outside* of the bulb, integrated from the readings of the auxiliary elements as described on page 119; in the third column is given the corresponding correction in microvolts. In the fourth column are the readings of the standard elements on the *outside* of the bulb, corrected as above mentioned. In the fifth column are the readings of the same thermoelements at the fixed point in question, as obtained in the melting or freezing of metal or salt; these figures usually represent the mean of a considerable number of determinations.

In the sixth and seventh columns are the corresponding figures for the element *inside* of the bulb. In this case, however, no correction has been applied to the reading of the element, since, being located practically at the center of the bulb, it might be expected to represent the mean temperature of the entire volume of the bulb.

In the eighth and ninth columns are the temperatures of the fixed points derived from the preceding four columns. In the last column is given the weight assigned to each measurement. In assigning these weights the number of standard thermoelements used, the amount of variation in p_0, and other incidental variables were taken into consideration.

As has been pointed out on page 116, the relative weights to be assigned to the inside and outside elements are different at

different temperatures; (1) on account of the difference in contamination, and (2) on account of the fact that the inside element is subject to the influence of conduction and radiation from below.   The weights assigned were as follows:

Temperatures	Outside Element	Inside Element
400–1100°	3	1
1100–1300°	2	1
1300–1550°	1	1

The final weighted mean of the inside and outside elements is given at the head of each section of the table.

In the last section of the table are given various points which were determined to aid in interpolating between the fixed points by means of the thermoelement.

The only comment which need be made here on the data in Table VIII concerns the figures given under the heading "copper point." In this section of the table, the values derived at the two different initial pressures (217–221^{mm} and 346–347^{mm}) are quoted separately in order to bring out the fact that the difference between the temperatures obtained from these two pressures is less than the experimental error. In the other sections of the table the data obtained at the two pressures are not separately arranged. Above the copper point only the low pressure was used, as the high pressure would have exceeded the range of the manometer.

The significance of the comparison between the inside-and outside-wound furnaces, which appears in the first half of the section on the copper point, has been commented on elsewhere (see p. 106).

5. *Interpolation Between the Fixed Points.*

The preparation of formulae to represent the relation between the temperature defined by the gas thermometer and the electromotive force of a thermoelement has always been a cause of considerable dissatisfaction, both to the maker and the user. The chief reason for this is perhaps the fact that the formulae used have been applicable only to limited portions of the curve and have therefore given no suggestion of physical significance. In the Reichsanstalt publication* the data extended from 300° to 1100° and included several good fixed points (melting points of pure metals) between which no interpolation, however rough, could go far astray. Accordingly, in so far as interpolation was concerned, but little attention required to be given to the formulation of this relation. It was sufficient that a simple formula of the form

$$E = -a + bt + ct^2$$

could be made to represent the observations between 300° and 1100° within the limits of the errors of observation.

* Holborn and Day, 1900, loc. cit.

TABLE VIII—*Temperatures of the Fixed Points.*

Exp. No.	Integrated correction to outside elements Degr's	M.V.	Standard Elements Outside Corrected	Fixed Pt.	Inside Uncorrected	Fixed Pt.	Temperature By Outside Element	By Inside Element	Weight
			Zinc Point.	418·2°					
22	0·0°	0	A 3414	3411	Y 3436	3436	418·1°	418·4°	2
23	−0·3	−3	A 3405	3410·5	Y 3445	3435	418·0	418·4	2
31	0·0	0	A 3410	3410·5	Y 3436	3435	418·3	418·2	2
32	−0·2	−2	A 3402	3410	Y 3425	3434	418·0	418·1	2
50	−0·1	−0·5	A 3413	3411			418·2		
			D 3405·5	3406	Z 3384·5	3382	418·4		
							418·3	418·2	3
73	−0·2	−2	A 3401	3413·5			418·4		
			E 3417	3429			418·3		
			F 3412	3429			418·8		
			G 3414	3429	Z 3370	3382	418·6		
							418·5	418·3	4
					Weighted Mean,		418·2°	418·3°	
			Antimony Point.	629·2°					
24	−0·1	−1	A 5509	5503	Y 5550	5546	629·2°	629·4°	2
25	−0·5	−5	A 5496	5503	Y 5529	5545	629·0	629·9	2
33	−0·1	−1	A 5513	5503	Y 5553	5544	629·2	629·3	2
34	−0·5	−5	A 5505	5503	Y 5537	5543	629·1	629·9	2
52	−0·5	−5	A 5505	5503			629·6		
			D 5490	5492	Z 5463	5460	629·2		
							629·4	629·1	2
74	−0·2	−2	A 5514	5504			628·2		
			E 5533	5530			628·8		
			F 5526	5530			629·5		
			G 5527	5530	Z 5461	5461	629·4		
							629·0	629·1	4
87	−0·3	−3	F 5517	5530			628·9		
			E 5517	5530			628·9		
			A 5481	5504			629·9		
			G 5513	5530	Z 5437	5461	629·3		
							629·2	629·9	4
					Weighted Mean,		629·1°	629·5°	
			Silver Point.	960·0°					
6	+0·8	+9	W 9070	9057	X 9100	9071	959·4°	958·0°	1
26	−0·3	−3	A 9087	9083	Y 9159	9141	959·9	958·6	2
27	−0·8	−9	A 9066	9083	Y 9119	9141	959·9	960·4	2
35	−0·7	−8	A 9079	9082	Y 9142	9141	959·7	959·4	1
36	−0·1	−1	A 9097	9082	Y 9163	9141	959·4	958·7	1
41	−0·3	−3	A 9083	9081	Y 9156	9141	959·6	958·5	2
42	−0·8	−9	A 9076	9081	Y 9131	9141	959·3	959·7	2
63	−0·6	−7	A 9079	9084			960·7		
			D 9048	9058	Z 9010	9019	961·2		
							960·9	961·1	2

Table VIII—(Continued)

Exp. No.	Integrated correction to outside elements Degr's	M.V.	Standard Elements Outside Corrected	Fixed Pt.	Inside Uncorrected	Fixed Pt.	Temperature By Outside Element	By Inside Element	Weight
				Silver Point—(Cont.)					
68	−0·7	−8	A 9080	9085			960·3°		
			D 9051	9058	Z 9013	9019	960·4		
							960·4	960·3°	2
76	−0·2	−2	A 9088	9082			959·2		
			E 9112	9113			959·7		
			F 9097	9113			961·2		
			G 9106	9111	Z 9002	9018	·960·2		
							960·1	961·2	4
81	+0·3	+3	F 9132	9113			959·5		
			E 9131	9113			959·6		
			A 9083	9082			961·1		
			G 9125	9111	Z 9015	9018	960·0		
							960·0	961·5	4
88	+0·3	+3	F 9143	9113			959·0		
			E 9139	9113			959·4		
			A 9093	9082			960·7		
			G 9135	9112	Z 9026	9018	959·6		
							959·7	960·1	4
					Weighted Mean,		959·9°	960·2°	
				Gold Point. 1062·4°					
64	−0·3	−3	A 10262	10265			1062·4°		
			D 10226	10233	Z 10178	10193	1062·8		
							1062·6	1063·4°	2
69	−0·4	−4	A 10253	10266			1061·4		
			D 10217	10234	Z 10169	10193	1061·7		
							1061·6	1062·3	2
77	−0·3	−3	A 10255	10263			1061·2		
			E 10282	10295			1061·6		
			F 10263	10296			1063·4		
			G 10276	10294	Z 10161	10193	1062·1		
							1062·1	1063·3	4
82	+0·4	+4	F 10303	10296			1061·9		
			E 10304	10295			1061·8		
			A 10256	10263			1063·1		
			G 10296	10294	Z 10181	10193	1062·4		
							1062·3	1063·6	4
					Weighted Mean,		1062·2°	1063·2°	
			Copper Point. 1082·6° (Lower Pressure. $p_0=217-221^{mm}$)						
2	+1·2	+14	W10457	10478	X 10491	----	1081·7	----	1
9	+1·0	+12	W10495	10478	X 10555	----	1082·2	----	1
11	+1·2	+14	W10487	10478	X 10512	----	1083·1	----	1
18	+0·7	+ 8	A 10510	10502	Y 10612	10573	1082·2	---	2
19	−0·4	− 5	A 10501	10502	Y 10584	10573	1082·0	1081·0	3

Table VIII—(*Continued*)

Exp. No.	Integrated correction to outside elements Degr's	M.V.	Standard Elements Outside Corrected	Fixed Pt.	Inside Uncorrected	Fixed Pt.	Temperature By Outside Element	By Inside Element	Weight
			Copper Point (Lower Pressure)—Cont.						
20	−0·8	− 9	A 10488	10502	Y 10555	10573	1082·1°	1082·5°	3
28	−0·3	− 4	A 10512	10501	Y 10593	10573	1082·1	1081·4	3
29	−0·9	−10	A 10494	10501	Y 10556	10573	1082·2	1083·0	3
37	−0·6	− 7	A 10504	10501	Y 10576	10573	1082·0	1082·0	2
38	−0·3	− 4	A 10509	10500	Y 10585	10573	1082·2	1081·9	2
39	+0·7	+ 8	A 10517	10500	Y 10617	--	1082·3		2
43	−0·3	− 4	A 10512	10500	Y 10595	10573	1082·2	1081·3	3
44	−0·9	−10	A 10501	10499	Y 10568	10573	1082·0	1082·6	3
45	+0·6	+ 7	A 10515	10499	Y 10617	----	1082·3	----	2
89	+0·5	+ 6	F 10546	10534			1081·8		
			E 10544	10534			1081·9		
			A 10496	10503			1083·4		
			G 10538	10533	Z 10428	10432	1082·4		
							1082·4	1083·1	4
126*	+0·4	+ 5	E 10631	10534			1082·2		
			F 10627	10534			1082·6		
			G 10621	10533			1083·0		
			H 10623	10535	C 10567	10470	1083·0		
							1082·7	1082·5	4
					Weighted Mean		1082·2°	1082·2°	
			Copper Point—Cont. (Higher Pressure. $p_0 = 346\text{--}347^{mm}$)						
60	−0·7	− 8	A 10500	10502			1083·4°		
			D 10465	10470	Z 10422	10432	1083·6		
							1083·5	1084·1°	1
65	−0·8	− 9	A 10502	10503			1083·0		
			D 10465	10471	Z 10420	10432	1083·4		
							1083·2	1083·9	2
70	−0·3	− 4	A 10508	10504			1082·4		
			D 10475	10472	Z 10444	10432	1082·6		
							1082·5	1081·8	2
78	−0·1	− 1	A 10502	10503			1081·4		
			E 10528	10534			1081·8		
			F 10509	10534			1083·4		
			G 10522	10533	Z 10404	10432	1082·3		
							1082·2	1083·7	4
83	+0·1	+ 1	F 10535	10534			1082·1		
			E 10535	10534			1082·1		
			A 10488	10503			1083·5		
			G 10527	10533	Z 10403	10432	1082·7		
							1082·6	1084·6	4

* Made with outside-wound furnace.   See page 106.

TABLE VIII—(*Continued*)

Exp. No.	Integrated correction to outside elements		Standard Elements				Temperature		Weight
	Deg'rs	M.V.	Outside Corrected	Fixed Pt.	Inside Uncorrected	Fixed Pt.	By Outside Element	By Inside Element	

Copper Point—Cont. (Higher Pressure)

Exp. No.	Deg'rs	M.V.	Outside Corrected	Fixed Pt.	Inside Uncorrected	Fixed Pt.	By Outside Element	By Inside Element	Weight
84	+0·7	+ 8	F 10544	10534			1082·0°		
			E 10542	10534			1082·3		
			A 10493	10503			1083·8		4
			G 10533	10533	Z 10426	10432	1083·0		
							1082·8	1083·5	
					Weighted Mean,		1082·7°	1083·7°	
					Mean of 2 pressures,		1082·5°	1082·9°	

Diopside Point. 1391·2°

Exp. No.	Deg'rs	M.V.	Outside Corrected	Fixed Pt.	Inside Uncorrected	Fixed Pt.	By Outside Element	By Inside Element	Weight
96	0·0	0	E 14227	14228			1392·1°		
			F 14222	14229			1392·5		
			G 14245	14229			1390·7		
			H 14251	14231	Z 14121	14103	1390·4		
							1391·4	1390·5°	1
97	+1·0	+13	E 14260	14228			1392·4		
			F 14254	14229			1393·0		
			G 14287	14229			1390·4		
			H 14295	14231	Z 14156	14103	1389·9		
							1391·4	1390·5	1
99	−0·1	− 1	E 14213	14228			1394·5		
			F 14195	14229			1396·0		
			G 14215	14229			1394·4		
			H 14212	14231	Z 14099	14103	1394·8		
							1394·9	1393'7	1
100	+0·7	+ 9	E 14251	14228			1394·4		
			F 14244	14229			1395·0		
			G 14268	14229			1393·1		
			H 14273	14231	Z 14156	14103	1392·9		
							1393·8	1391·8	1
103	−0·4	− 5	E 14211	14228			1392·5		
			F 14204	14229			1393·1		
			G 14217	14229			1392·1		
			H 14230	14231	Z 14124	14103	1391·2		
							1392·2	1389·4	3
104	+1·0	+13	E 14242	14228			1392·5		
			F 14212	14229			1394·9		
			G 14249	14229			1392·0		
			H 14262	14231	Z 14155	14103	1391·1		
							1392·6	1389·3	3

Table VIII—(*Continued*)

Exp. No.	Integrated correction to outside elements Degr's	M.V.	Standard Elements Outside Corrected	Fixed Pt.	Inside Uncorrected	Fixed Pt.	Temperature By Outside Element	By Inside Element	Weight
			Diopside Point—(Cont.)						
106	−0·6	− 8	E 14228	14228			1391·7°		
			F 14225	14229			1392·0		
			G 14233	14229			1391·3		
			H 14243	14231	Z 14123	14103	1390·7	1390·0°	2
							1391·4		
107	+ 0·9	+12	E 14248	14228			1391·9		
			F 14237	14229			1392·8		
			G 14245	14229			1392·2		
			H 14252	14231	Z 14152	14103	1391·8	1389·4	2
							1392·2		
130	−0·6	− 7	E 14243	14228			1390·2		
			F 14241	14230			1390·6		
			G 14249	14230			1389·9		
			H 14239	14228	C 14146	14153	1390·6		
							1390·3	1392·0	3
					Weighted Mean,		1392·0°	1390·4°	
			Nickel Point. 1452·3°						
109	+ 0·7	+ 8	E 15028	14977			1451·2°		
			H 15027	14980	Z 14903	14850	1451·6		
							1451·4	1451·1°	1
111	0	0	E 14980	14977			1453·2		
			H 14978	14980	Z 14867	14850	1453·7		
							1453·5	1452·1	2
112	+ 0·9	+11	E 14971	14977			1453·8		
			F 14958	14978			1454·9		
			H 14991	14980	Z 14872	14850	1452·4		
							1453·7	1451·5	2
123	−0·6	− 7	E 14984	14977			1454·3		
			F 14989	14978	A 14982	14945	1453·9		
							1454·1	1451·8	2
124	+ 0·8	+10	E 14989	14977			1454·6		
			F 14994	14978	A 14996	14945	1454·3		
							1454·5	1451·5	1
133	−0·3	− 4	E 14954	14977			1451·9		
			F 14958	14976			1451·5		
			G 14955	14981			1452·2		
			H 14946	14977	C 14882	14898	1452·5		
							1452·0°	1451·3°	4
					Weighted Mean,		1453·0°	1451·6°	

Table VIII—(*Continued*)

Exp. No.	Integrated correction to outside elements Degr's	M.V.	Standard Elements Outside Corrected	Fixed Pt.	Inside Uncorrected	Fixed Pt.	Temperature By Inside Element	By Outside Element	Weight
					Cobalt Point. 1489·8°				
115	+0·1	+ 1	E 15390	15439			1488·7°		
			F 15375	15435	A 15357	15409	1489·6		
							1489·1	1488·9°	3
116	+1·4	+17	E 15428	15439			1490·5		
			F 15434	15435			1489·7		
			G 15435	15441	A 15421	15409	1490·1		
							1490·1	1488·6	3
118	−0·5	− 6	E 15385	15439			1491·7		
			F 15383	15435			1491·6		
			G 15393	15441	A 15382	15409	1491·3		
							1491·5	1489·6	2
120	−0·4	− 5	E 15381	15439			1491·7		
			F 15371	15435			1492·1		
			G 15363	15441	A 15379	15409	1493·3		
							1492·7	1489·4	1
121	+0·7	+ 9	E 15406	15439			1492·0		
			F 15405	15435			1491·8		
			G 15398	15441	A 15412	15409	1492·8		
							1492·2	1489·1	1
							1490·6°	1489·0°	
					Palladium Point. 1549·2°				
134	−0·7	− 9	E 16151	16143			1549·5°		
			F 16161	16138			1548·3		
			G 16139	16145			1550·6		
			H 16147	16145	C 16075	16058	1550·1		
							1549·6°	1548·8°	
					Anorthite Point. 1549·5°				
134	−0·7	− 9	E 16151	16148			1549·9°		
			F 16161	16141			1548·6		
			G 16139	16148			1550·9		
			H 16147	16145	C 16075	16060	1550·0		
							1549·9°	1549·0°	
					Interpolation Points.				
49	−0·1	− 1	A 2486	2492			320·2°		
			D 2482	2486	Z 2462	2465	320·0		
							320·1	319·9°	
					Mean for cadmium,		320·0°		
51	0·0	0	A 4451	4450			524·6		
			D 4439	4442	Z 4413	4417	525·0		
							524·8	525·1	
					Mean for A = 4450,		524·9°		

TABLE VIII—(*Concluded*)

Exp. No.	Integrated correction to outside elements		Standard Elements				Temperature		Weight
	Degr's	M.V.	Outside Corrected	Fixed Pt.	Inside Uncorrected	Fixed Pt.	By Inside Element	By Outside Element	
Interpolation Points—(Cont.).									
62	0·0	0	A 7895	7900			854·2°		
			D 7869	7881	Z 7829	7848	854·9		
							854·6	855·5°	
67	−0·2	−2	A 7883	7900			854·0		
			D 7859	7881	Z 7820	7848	854·5		
							854·3	855·0	
			Mean for A = 7900,				854·7°		
128	−0·2	− 2	E 12004	12000			1206·3		
			F 12001	12001			1206·7		
			G 12008	12001			1206·1		
			H 12000	12003	C 11914	11928	1206 9		
							1206·5	1207·8	
132	+0·1	+ 1	E 11947	12000			1206·0		
			F 11952	11097			1205 3		
			G 11950	12001			1205·8		
			H 11941	12003	C 11887	11928	1206·8		
							1206·0	1205·0	
			Mean for E = 12000,				1206·4°		
129	−0·6	− 5	E 13107	13100			1297·4		
			F 13102	13101			1297·9		
			G 13110	13101			1297·2		
			H 13101	13103	C 13007	13028	1298·1		
							1297·7	1299·3	
			Mean for E = 13100,				1298·5°		

If the investigator's responsibility could be made to end with the representation of his own observations, no serious difficulty would arise, but such a formula when published is placed in the hands of many who do not realize that no physical significance was attached to the formula by its author and that its extrapolation in either direction would be fraught with grave danger. A mere inspection of the equation is sufficient to show that the electromotive force does not become zero for zero temperature, thereby immediately proving that extrapolation downward does not correspond to the observed readings of the thermoelement. In the Reichsanstalt equation this constant term was in fact sufficiently large to lead to absurdities if the extrapolation was continued far below 300°.

Notwithstanding the warning contained in this situation, extrapolation upward of the thermoelectric curve has been

employed almost universally for the determination of temperatures above 1100°, not only for direct determinations of temperature with the thermoelement itself, but also for the calibration of optical pyrometric apparatus.   The absence of absolute determinations in this region has left this practice in undisturbed security until recently, when some doubt has been thrown upon the validity of irresponsible upward extrapolation by various observations.   (1) The increase in the accuracy now attainable with the optical pyrometer has given an independent thermal scale comparable with that of the thermoelement and overlapping the same region.   The two curves have not been found to correspond.   (2) Experimental determinations of the melting point of platinum by continuing observations of the thermoelement up to a point where a portion of its platinum wire melts, have been undertaken in the national laboratories of Germany, England and the United States, and have yielded a value measured upon the extrapolated thermoelectric curve of about 1710°.   The agreement in the different determinations was good and the result found general acceptance for a time.   More recently, Holborn and Valentiner have made successful measurements with the gas thermometer at the temperature of melting palladium, and although high accuracy was not attempted, it became clear that the palladium point obtained by extrapolating with the thermoelement was much too low and by inference the platinum point also, for the various optical methods give opportunity for a very good determination of the temperature difference between the melting points of the two metals.   The most recent estimates of the platinum melting point obtained in this way place it between 1750° and 1775°, indicating that the upward extrapolation with the thermoelement has given rise to an error of about 50° at the platinum point.

The data obtained in the present investigation throw much light upon this situation.   If we take the observations of our series over the range covered by the Reichsanstalt scale (300° to 1100°) and write an equation for these of the same type as that used at the Reichsanstalt, it will read,

$$E = -302 + 8 \cdot 2356t + \cdot 0016393t^2$$

and this equation will reproduce the temperatures of the standard melting points which fall in this region with a maximum error of 3 microvolts, an accuracy far within the errors of observation.   But if we extrapolate this curve in accordance with the general practice above described, and compare the resulting electromotive forces with our observations between 1100° and

1550°, a somewhat startling surprise awaits us. Although the curve below the copper point is a practically perfect reproduction of the observations, it diverges from the gas thermometer scale at the melting point of palladium by 245 microvolts, which represents a temperature error of nearly 20°. This comparison is made in the table below :

	Temperature	Observed Microvolts	Calculated Microvolts	Observed—Calculated Microvolts
Zinc	418·2°	3429	3429	0
Antimony ...	629·2	5530	5530	0
Silver	960·0	9113	9115	— 2
Gold	1062·4	10295	10298	— 3
Copper	1082·6	10534	10534	0
Extrapolation.				
	1207·1	12000	12027	—27
	1298·8	13100	13161	—61
Diopside	1391·2	14228	14338	—110
Nickel	1452·3	14945	15112	—167
Cobalt	1489·8	15439	15608	—169
Palladium ...	1549·2	16143	16388	—245

If, on the other hand, we follow Day and Clement, and represent t as a function of E, using the same data as before, the equation will take the form

$$t = 47·2 + ·11297E - 1·3946(10)^{-6}E^2$$

This curve passes through the fixed points below 1100° nearly as accurately as the previous one, and is also quite competent to interpolate temperatures throughout the range of the old standard scale. Extrapolating this in turn up to the palladium point and comparing it with our gas thermometer measurements in the higher region leads to temperatures about 40° too low.

	Observed	Calculated	Observed—Calculated
Zinc	418·2°	418·2°	0°
Antimony ...	629·2	629·3	— 0·1
Silver	960·0	960·9	— 0·9
Gold	1062·4	1062·4	0
Copper	1082·6	1082·5	+ 0·1
Extrapolation			
	1207·1	1202·0	+ 5·1
	1298·8	1287·8	+11·0
Diopside	1391·2	1372·0	+19·2
Nickel	1452·3	1424·0	+28·3
Cobalt	1489·8	1459·0	+30·8
Palladium ...	1549·2	1507·0	+42·2

The untrustworthiness of the present practice of extending thermoelement values obtained below 1100° into the region above that temperature is therefore abundantly demonstrated.*

We were unable to find a simple parabola with which to represent the whole series of observations between 300° and 1550° within the errors of observation. The simplest procedure is therefore to divide the long curve into two parts. This plan is carried out below in the form in which it will probably be found most useful. A parabola passing through zinc, antimony and copper reproduces the results over that temperature range within the errors of observation. A similar parabola through copper, diopside and palladium gives the upper temperatures as accurately as they were measured. These two equations offer a means of safe and convenient interpolation throughout the entire range of the gas thermometer measurements. In this series are included certain gas thermometer measurements given at the end of Table VIII which were made at temperatures between the fixed melting points, for the purpose of checking the interpolation formula, together with a single gas thermometer determination of the cadmium melting point. The temperature 854·1 appears here corrected by $-0·6°$, since the series, of which this measurement formed a part, showed a systematic difference of about this amount from the final average of antimony and silver, which lie on either side of this point.

Cadmium to Copper

$$E = -302 + 8·2356t + ·0016393t^2$$

	Temperature	Observed Microvolts	Calculated Microvolts	Observed— Calculated Microvolts
Cadmium	320·0°	2504	2501	+3
Zinc	418·2	3429	3429	0
	524·9	4470	4472	−2
Antimony	629·2	5530	5530	0
	854·1	7927	7928	−1
Silver	960·0	9113	9115	−2
Gold	1062·4	10295	10298	−3
Copper	1082·6	10534	10534	0

Copper to Palladium

$$E = -1941 + 11·1746t + ·00032161t^2$$

	Temperature	Observed Microvolts	Calculated Microvolts	Observed— Calculated Microvolts
Copper	1082·6	10534	10534	0
	1207·1	12000	12010	−10
	1298·8	13100	13112	−12
Diopside	1391·2	14228	14228	0
Nickel	1452·3	14977	14967	+10
Cobalt	1489·8	15439	15421	+18
Palladium	1549·2	16143	16143	0

* For an account of some of the dangers of careless interpolation, see Day and Clement, loc. cit., p. 453.

It is possible to write a cubic equation which will reproduce the entire series from zinc to palladium without error greater than the normal accuracy of the observations themselves. The equation offered makes no pretensions to a least square solution with balanced residuals, but is arranged so that the greatest uncertainties are found in that portion of the curve where the greatest experimental error lies. The coefficients were rounded off for convenience of computation.

Cadmium to Palladium

$$E = -169{\cdot} + 7{\cdot}57t + 0{\cdot}002648t^2 - 0{\cdot}0000004724t^3$$

	Temperature	Observed Microvolts	Calculated Microvolts	Observed — Calculated Microvolts
Cadmium	320·0°	2504	2509	−5
Zinc	418·2	3429	3425	+4
	524·9	4470	4466	+4
Antimony	629·2	5530	5525	+5
	854·1	7929	7934	−5
Silver	960·0	9113	9121	−8
Gold	1062·4	10295	10296	−1
Copper	1082·6	10534	10530	+4
	1206·4	12000	11988	+12
	1298·5	13100	13091	+9
Diopside	1391·2	14228	14215	+13
Nickel	1452·3	14977	14963	+14
Cobalt	1489·8	15439	15424	+15
Palladium	1549·2	16143	16157	−14

6. *Analysis of Metals.* (*By E. T. Allen.*)

The object of these analyses was primarily, of course, to decide whether the metals should be used or rejected for the temperature scale, and those selected were examined very carefully so that in the future, when more is known about the specific lowering which the various impurities produce on the melting point, corrections may be made if desirable.

The accuracy of the determinations is problematical. There is of course the possibility of increased solubility of difficultly soluble compounds in the comparatively concentrated solutions of the metals from which the impurities have to be precipitated, viz., 5 to 6 g. in 250^{cc} volume. Also, when it is necessary to separate the bulk of the metal by precipitation from the impurities, as it sometimes is, one cannot be sure that the impurity sought is not occluded by the precipitates. In most cases, the latter source of error is probably the more serious. Only methods worked out synthetically with materials laboriously prepared could decide these questions. Large quantities of metal, 25 to 100 g., were generally taken for analysis, and

since the impurities were weighed to the tenth of a milligram, the results are generally stated to the ten-thousandth of a per cent. This does not mean that the results are considered accurate to this figure. The variation in successive determinations comes in the thousandths, so that the fourth decimal place may have about as much value as the second in an ordinary analysis. Great pains have been taken to purify precipitates, often by many precipitations, so that in all cases the figures given may be regarded as minima. In all cases, too, I have endeavored to avoid missing anything, by repeating every process, rejecting no precipitate or solution until it was decided that nothing more was to be gotten from it. In any reasonable case of suspicion, blank determinations were made with the reagents.*

Heraeus' Palladium.

The palladium was naturally suspected to contain other metals of the platinum group. It is well known that the separation of these metals is a problem of unusual difficulty. The plan here was therefore to precipitate most of the palladium from solution as one of its characteristic compounds and, while the filtrate was reserved for impurities, to redissolve and again precipitate the metal as another characteristic compound. In this way it was hoped that those impurities which were retained by the first precipitate would not be occluded by the second. The sheet metal was first cut into shavings on a milling machine which was especially cleaned for the purpose. Then the shavings were boiled a short time with dilute hydrochloric acid to remove any iron from the surface, washed and dried. After an unsuccessful endeavor to dissolve the palladium in nitric acid (insoluble brown hydroxide (?) always formed), it was dissolved in aqua regia and rid of nitric acid by successive evaporations with excess of hydrochloric acid. It was then dissolved in dilute hydrochloric acid and diluted further to about 1 l. Ammonia was added in excess.† A precipitate came down and redissolved on warming—all but a little ferric hydroxide which was filtered off. The filtrate was then evaporated again to about 250^{cc}, diluted and precipitated with stirring, by dilute hydrochloric acid. The voluminous precipitate of $PdCl_2.2NH_3$ was now filtered and washed on a Büchner porcelain funnel, using suction. The filtrate we will call "solution A." The precipitate was then dried and

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* After considerable experience in the examination of these "pure" metals, the writer has reached the conclusion that a 10 g. portion, in the great majority of cases, will give as satisfactory results as a larger portion and with far less labor.

† E. F. Smith and H. F. Keller, Amer. Chem. Jour., xiv, 423, 1892.

ignited in a large porcelain crucible. The resulting metal was dissolved in aqua regia and freed of nitric acid. This solution was diluted and precipitated by potassium iodide, and the filtrate—" solution B "—removed as above.

From solutions A and B, separately, the platinum metals were first removed by long boiling with ammonium formate. The metal—1 to 2 g. in weight, mostly palladium—was filtered and the filtrate and washings were examined further for other heavy metals by the usual methods.

Separation of the Palladium from the Platinum Metals.— Considering now the ammonium formate precipitate, Erdmann and Makowka* have obtained satisfactory separations of palladium from platinum and iridium by treating the solution of the mixed chlorides with acetylene. Palladium comes down as acetylide and the other metals are unprecipitated. I found also that *rhodium* solutions even on heating were not precipitated by acetylene. As for osmium, the ease with which it oxidizes and the high volatility of its oxide makes its elimination, in the process of preparing the palladium, fairly certain. Ruthenium, the rarest element among the platinum metals, need hardly be looked for ; still it was sought for in the iridium found. The acetylene method was used, for lack of a safer one, though very tedious. In solutions at all concentrated, I find the palladium ceases to precipitate long before it is entirely removed from solution. Perhaps this is due to the accumulation of acid liberated in the process. At least, when the solution is separated from the acetylide, evaporated and diluted again, acetylene brings down another portion. After five or six operations, a residual solution was obtained on which acetylene had no further action. The acetylide was now carefully ignited with a little ammonium nitrate, the metal redissolved, and the whole process repeated. The residual solution was then added to the first and from it NH_4Cl brought down platinum. In the chlor-platinate no iridium was found. It was ignited and the metal was entirely soluble in a few drops of aqua regia. It was again precipitated with NH_4Cl and finally weighed as platinum— $Pt = 1.6$ mg. $= 0.007$ per cent. No rhodium was found in the filtrate. In the attempt to dissolve in aqua regia the several portions of metal formed by igniting the acetylide, tiny insoluble residues accumulated. These were fused with $KHSO_4$, which, as is well known, dissolves palladium and rhodium but not iridium or platinum if the temperature is kept low. The soluble portion was dissolved in water and precipitated with ammonium formate. It turned out to be palladium, since it was precipitated by potassium iodide and no trace of rhodium was found.

* Zeitschr. anal. Chemie, xlvi, 146, 147, 1907.

The portion insoluble in $KHSO_4$ was freed from silica (which came from the dish) by $HCl + HF$, ignited, and weighed. Ir + [Ru] = 1·9 mg. = 0·008 per cent. When fused with $K_2CO_3 + KNO_3$, some blue insoluble IrO_3 was formed, but the fusion showed no yellow color, and in view of the minute quantity of material, it was not thought worth while to search more carefully for ruthenium.

The final precipitate of palladium acetylide was changed to chloride, diluted, and saturated with SO_2 for gold, but none appeared.

Nothing else was found in the metal except a trace of copper. The iron found earlier had to be reprecipitated several times from chloride solution by ammonia to get rid of palladium. The precipitate was finally transformed into sulphate and determined volumetrically.—Fe = 2·6 mg. = ·010 per cent.

Analysis of Palladium.

Au	none
Ru	none
Rh	none
Pt	·007%
Ir	·008%
Cu	trace
Zn	doubtful trace
Fe	·010%
	·025%

Kahlbaum's Electrolytic Nickel.

Two 50 gram portions were dissolved separately in measured quantities of nitric acid and then carried to white fumes with excess of sulphuric acid. Both portions were then dissolved in water and filtered. There was a small dark residue which was washed thoroughly and extracted with aqua regia, leaving a little silica from the dish. The yellow chloride obtained was freed from nitric acid, saturated with SO_2 and left to stand. *No gold.* Changed to chloride again and tested with caustic soda and H_2O_2. *Still no gold.* Acidified and reprecipitated with NH_4Cl, a characteristic yellow precipitate was obtained. Confirmed by dissolving the chlor-platinate in hot water and precipitating by hydrogen. Pt = 2·3 mg. = 0·0023 per cent. The main solution was then precipitated by H_2S ($v = 2$ l.). The small black precipitate obtained was worked over for gold and platinum with the above.

Other heavy metals were tested for in the ordinary way. 0·2 mg. $PbSO_4$ = about 0·1 mg. Pb. Cu = 52·3 mg. = 0·0523 per cent.

Ammonium Sulphide Group.—The voluminous solution was now freed from hydrogen sulphide by evaporation, some

ammonium persulphate was added and a stream of air passed through the solution for some time. *No manganese.* $Fe_2O_3 = 6·1$ mg., after repeated precipitation. Fe = 4·2 mg. Repeated efforts were made to separate zinc with H_2S on the principle of the lower solubility of ZnS in dilute acids, but without satisfaction. First I tried to precipitate a small fraction of the nickel, hoping to get all the zinc with it. The volume of the solution was about 5 l. But unless so much acid was added that strong doubts were entertained of recovering any zinc that might be present, the fraction of the nickel precipitate was far too great. Again, all the nickel was precipitated and the precipitate was digested with cold 10 per cent solution of hydrochloric acid. Here one had to fear either the failure to remove the zinc or the removal of too much nickel to handle without so many precipitations that a small quantity of zinc would probably be lost. It is doubtful whether we have any method which will give very small amounts of zinc in metallic nickel.

The whole solution was now tested for cobalt as follows: It was freed from H_2S by evaporation, acidulated with HCl and precipitated by *a*-nitroso-*β*-naphthol in 50 per cent acetic acid. This was added in several portions. After long standing the precipitate was collected and washed. The voluminous precipitate was very cautiously burned in a capacious porcelain crucible. Much tar was formed. The residual oxide was dissolved in nitric acid and the cobalt separated from nickel by KNO_2 in the usual way. The potassium cobalto-nitrite was finally decomposed by sulphuric acid and precipitated electrolytically from ammoniacal solution. Co = 101·4 mg. + 4·9 mg. recovered from filtrate and weighed as sulphate. Total = 0·1063 per cent. Fe and Co were also determined in a separate 10 g. portion of metal. $Fe_2O_3 = 0·7$ mg. Fe = 0·49 mg. = 0·0049 per cent. Co = 10·3 mg. = 0·1030 per cent. A separate 10 g. portion was taken for sulphur. It was dissolved in nitric and evaporated on the water bath. This solution was diluted and precipitated with a slight excess of sodium carbonate. The filtrate was just acidulated, evaporated, and treated with barium chloride. No precipitate.

Analysis of Nickel.

Au	none	Bi	none
Pt	·0023%	Cd	"
As	none	Zn	none found
Sb	"	Co	·1063%
Sn	"	Mn	none
Pb	·0001%	Fe	·0042%
Cu	·0523%	S	none

·165%

Kahlbaum's Cobalt.

Two 25 g. portions of the metal in the form of powder were dissolved in 150^{cc} water $+ 35^{cc}$ concentrated H_2SO_4. The analysis was quite similar to that of the nickel. In the H_2S group were found : Cu $= 8.9$ mg. $= 0.0178$ per cent. $PbSO_4 = 12.9$ mg. Pb $= .0176$ per cent. In the $(NH_4)_2S$ group manganese was tested for as in the nickel. None was found. $Fe_2O_3 = 0.9$ mg. Fe $= .0006$ per cent. As the tests for Ni and Zn were unsatisfactory, another portion of 25 g. was dissolved in dilute sulphuric acid and precipitated by H_2S. The filtrate from the sulphides was filtered and freed from excess of H_2S by evaporation. Then it was diluted to 1 liter and divided into two portions. Both were neutralized by sodium carbonate. In the one, manganese was sought for by ammonium persulphate. In the other nickel was looked for. A little ammonia was added and then an alcoholic solution of dimethylglyoxime. A precipitate containing much cobalt was obtained. This was worked over for nickel but none was found. For sulphur the method used in the analysis of nickel was followed. $BaSO_4 = 14.4$ mg., blank $= 5.1$ mg., difference $= 9.3$ mg., S $= 0.013$ per cent.

Analysis of Cobalt.

Ag	none	Cu	.0178%
Au	"	Bi	none
Pt	"	Cd	"
As	"	Zn	"
Sb	"	Ni	"
Sn	"	Fe	.0006%
Pb	.0176%	Mn	none
		S	.013%
			.049%

Aluminum.

Owing to the difficulty of handling this metal, small portions (10 g.) only were taken for analysis. *Heavy metals*, except arsenic and antimony, were sought for in the hydrochloric acid solution by ordinary methods. Only a trace of copper was found.

Phosphorus, Arsenic, and Sulphur.—For these elements, a separate portion was dissolved in caustic alkali in a special apparatus entirely of glass. The vessel was first filled with purified hydrogen and then the alkali was introduced and the gases evolved were passed through silver nitrate solution. At the end, the gases remaining in the vessel were displaced by hydrogen. The precipitated silver was worked over for the different elements. *No As nor Sb.* A separate portion was used for sulphur. $BaSO_4 = 1.4$ mg. S $= .002$ per cent.

Silicon.—10 g. metal were dissolved in a mixture of nitric and sulphuric acids, using a platinum dish. With hydrochloric acid alone nearly all the silicon is lost as hydride. The brown amorphous residue was filtered, washed and fused with sodium carbonate. From the fusion silica was obtained in the usual way. $SiO_2 = 41.4$ mg. $Si = 0.194$ per cent. Repetitions gave 0.189 per cent and 0.190 per cent.

Carbon.—10 g. metal were dissolved in NaOH and filtered through glowed asbestos, washed first with water, then with dilute acid and finally with water and dried at 105°. The asbestos and residue were then transferred to a combustion tube and burned in air free from CO_2. The gases were passed through standard $Ba(OH)_2$. A considerable precipitate was obtained, while a blank gave no trace. The excess of $Ba(OH)_2$ was the ntitrated with standard acid using phenolphthalein as indicator. 5.05 mg. CO_2 found. $C = 0.014$ per cent. A duplicate in which the metal was dissolved in KOH gave 0.012 per cent.

Iron.—10 g. metal were dissolved in hydrochloric acid, and to the solution was added tartaric acid free from iron. From this solution the iron was precipitated by colorless ammonium sulphide. The precipitate was finally changed to sulphate and determined volumetrically. $Fe = 4.6$ mg. Blank determination gave 0.3 mg. $Fe = 0.043$ per cent.

Calcium, Sodium, and Potassium were sought for in the hydrochloric acid solution, by precipitating with ammonia, washing the large precipitate and testing the evaporated filtrate. *No Ca.* Some alkaline chloride was found, but a blank showed that it came from the ammonia, as there was only a difference of 1.6 mg. between the chloride of the blank and that in the determination. *No Na or K.*

Analysis of Aluminum.

As	none		C	0.013%
Sb	"		S	0.002%
P	"		Ca	none
Cu	0.003%		Na	"
Fe	0.043%		K	"
Si	0.190%			
				0.251%

Antimony.

25 g. metal were powdered in an agate mortar and treated with 35 per cent HNO_3 on the steam bath. As soon as the reaction was practically complete, the antimonic acid was extracted

with hot dilute nitric acid, transferred to a filter and washed with water. The filtrate and washings were then evaporated to dryness with hydrochloric acid, while the antimonic acid was digested repeatedly with yellow sodium sulphide till the soluble portion was dissolved. The residue, after a little washing, was dissolved in nitric acid, evaporated to dryness, freed from nitric by hydrochloric acid, and the chlorides united with the first extract. The whole was precipitated by hydrogen sulphide. The washed sulphides were then extracted with colorless ammonium sulphide. From this solution the sulphides were thrown down by acid, filtered and washed. Then they were dissolved in hot dilute caustic potash. The solution was boiled with perhydrol for complete oxidation, and arsenic sought for by Fischer's method, viz., reducing by ferrous ammonium sulphate and distilling in a current of hydrochloric acid gas. *No As.*

A separate portion of 5 g. was taken for tin. McCay's method was tried.* $SnO_2 = 1·3$ mg. $Sn = 1·0$ mg. $= ·02$ per cent.

A separate portion of 25 g. was used for sulphur. The metal was oxidized by nitric acid as before, and the soluble portion separated and evaporated. The residue was then heated with a small excess of sodium carbonate and filtered. The residue was also boiled out several times with sodium carbonate solution. The two solutions were then acidified with hydrochloric acid and treated with barium chloride. The portion soluble in nitric acid gave a slight precipitate, which was further purified, after the usual washing and drying, by fusion with sodium carbonate. The water extract containing the soluble sulphate was acidified and precipitated a second time. $BaSO_4 = $ trace.

Analysis of Antimony.

As	none	Cd	none
Sn	0·02 (?)	Ni	"
Ag	none	Co	"
Pb	trace (?)	Mn	"
Cu	0·004	Zn	"
Bi	none	Fe	0·007%
		S	trace (?)

·031%

In the following table, the results of these and previous† analyses of metals for the temperature scale are summarized :

* Private communication.
† Day and Clement, loc. cit., p. 454.

Summarized Analyses of Metals.*

Impurities stated in fractions of 1%	Metals							
	Palladium	Cobalt	Nickel	Copper	Silver	Aluminum	Antimony	Zinc
Pt	0·007	none	·0023	·0011†	·0001			
Ir	·008							
Rh	none							
Ru	"							
Au	"	none	none	none	·0005			
Se				"				
Te				"				
As		none	none	"	none	none	none	none
Sb		"	"	"	"	"		·002
Sn		"	"	"	"		·02 (?)	
Hg	·				"		none	
Ag		none	none	·0006			"	none
Pb	none	·0176	·0001	none	·0008			·051
Bi	"	none	none	"	none		none	none
Cu	trace	·0178	·0523		trace	·003	·004	none
Cd	none	none	none	none	none		none	·004
Ni	"	"		"	"	none	"	none
Co	"		·1063	"	"	"	"	"
Fe	·010	·0006	·0042	·0038	·0011	·043	·007	·006
Zn	trace ?	none ?	none ?	·0007	none		none	
Mn		none	none				"	
Si				none		·190		none
C					·0003	·013		
S		·013	none	·0020	·0004	·002		none
P						none		
Ca						"		
Na						"		
K						"		
Total	·025	·049	·165	·008	·003	·251	·031	·063

* A blank opposite any impurity means that it was not looked for.
† Means platinum metals.

7. Conclusion.

It is now something over five years since the Geophysical Laboratory took up the task of redetermining the absolute temperature scale from 300° to 1100° with the nitrogen thermometer, and of extending it, if it should prove practicable to do so, to 1600° C., for it is in this upper region that most of the mineral relations which it is the chief purpose of the laboratory to study are found. Two preliminary publications have been made during the investigation. One, a brief summary of preliminary work up to 1100°, was given before the National Academy of Sciences and the American Physical Society in April, 1907,* the second covered the same ground at con-

* Abstract, Phys. Rev. xxiv, 531, 1907.

siderable length in 1908.* The present paper extends the
observations to 1550°, and completes the work contemplated
under the original plan.

No attempt will be made to offer an inclusive summary of
the whole investigation. It is a record of experimental
measurements covering an unusually wide range of details
which do not admit of brief classification. The errors which
have heretofore been present in measurements with the nitro-
gen thermometer have been reduced by the present investiga-
tion to about one-fourth their former magnitude and the
certainty of their evaluation is at least proportionately increased.

The chief source of present uncertainty is the temperature
distribution over the surface of the bulb in an air bath. No
indication of a limit to the temperature attainable with the
nitrogen thermometer or to its ultimate accuracy was discovered
during the present investigation.

The magnitudes of the errors, and their effects on the tem-
perature, are summarized in Table IV, page 129. The deter-
minations of the expansion coefficient of the bulb material
(80 Pt. 20 Rh) are summarized on pp. 131–132.

The melting temperatures of the metals and salts which
have been used as fixed points to establish the new scale
are brought together in the table below, together with
the conditions under which the determinations were made.
The generally accepted Reichsanstalt scale is printed beside it
for convenient comparison. The analyses of the metals are
summarized on p. 159.

To this table has been added a new estimate of the melting
temperature of platinum, of which we could make no direct
determination. Its general acceptance and availability as a
fixed point of reference, and the wide disagreement between
the direct determinations heretofore made of it, form a suffi-
cient reason for its inclusion. The estimate is arrived at in this
way: There is a remarkably close agreement between inde-
pendent determinations of the *temperature interval* between
the melting points of palladium and platinum :

Nernst and von Wartenberg†	204°
Holborn and Valentiner (at the Reichsanstalt)‡	207°
Waidner and Burgess (at the Bureau of Standards)§	207°

If we therefore simply add 206° to our determination of the
palladium point, we obtain 1755° as the melting point of pure
platinum, with an absolute error of perhaps no more than
± 5°. The table follows:

* This Journal (4), xxvi, 405, 1908.
† W. Nernst and H. von Wartenberg, Ber. d. Deutsch. phys. Ges., iv, pp.
48, 146, 1906.
‡ L. Holborn and S. Valentiner, Ann. d. Phys. (4), xxii, 1, 1907.
§ C. W. Waidner and G. K. Burgess, Bull. Bur. Standards, iii, p. 163, 1907.

Substance	Point	Atmosphere	Crucible	Temperature	The Reich-sanstalt Scale
Zinc	Melting and freezing	Air	Graphite	418·2° ±0·3	419·0°
Antimony	Do.	Carbon monoxide	Do.	629·2 ±0·5	630·6
Silver	Do.	Do.	Do.	960·0 ±0·7	961·5
Gold	Do.	Do.	Do.	1062·4 ±0·8	1064·0
Copper	Do.	Do.	Do.	1082·6 ±0·8	1084·1
Diopside (pure)	Melting	Air	Platinum	1391·2 ±1·5	
Nickel	Melting and freezing	Hydrogen and Nitrogen	Magnesia and Magnesium Aluminate	1452·3 ±2·0	
Cobalt	Do.	Do.	Magnesia	1489·8 ±2·0	
Palladium	Do.	Air	Pure Magnesia	1549·2 ±2·0	1575·*
Anorthite (pure)	Melting	Do.	Platinum	1549·5 ±2·0	

In addition, the following temperatures were incidentally obtained :

Cadmium	Melting and freezing	Air	Graphite	320·0 ±0·3	321·7
Aluminum	Freezing	Carbon monoxide	Do.	658·0 ±0·6	657·
Platinum	Melting	Air		1755·	

Geophysical Laboratory,
　　Carnegie Institution of Washington,
　　　　Washington, D. C., December 24, 1909.

* Holborn and Valentiner, loc. cit.

Art. IX.—*A New Sclerometer ;* by A. L. Parsons (University of Toronto).

The physical properties of minerals and metals have for a long time been a subject for investigation, and among the first of these properties to be studied were hardness and tenacity, but although the tensile strength and crushing point of the various substances are easily measured, the determination of hardness or resistance which a substance offers to abrasion is not so well understood. The sclerometer which was devised by Seebeck and later improved by Grailich and Peckarek is the one which is best known, but it is little used because the length of time which is required for a single measurement prevents the common use of an instrument which should be of valuable assistance to the mineralogist and metallurgist.

A bibliography of works on sclerometry is given by Jaggar[*] which includes the most important papers and outlines the principles employed by various investigators in using their own instruments or those devised by others.

The new instrument differs from those of Seebeck, Grailich and Pekarek and others in that the force that is necessary to make a scratch is measured by means of a spring and not by weights.

Description of the Instrument.[†]

The instrument consists of four working parts on a base, as follows (see fig. 1) :—

1. *Steel spring* (F) with test-point holder (H) fastened to the column (S).

2. *Object holder* (O) with divided horizontal circle (C), horizontal screw (1) for moving the object to be tested from side to side, and two vertical screws (2 and 3) to give the object the desired inclination.

3. Carriage (7) with transport screw (4) and spring (5) to move the test object, while making the scratch, and a slide (6).

4. Micrometer screw (E) and scale (8) to measure the elevation, which is proportionate to the force necessary to make a scratch.

5. Base (G) to hold the working parts together.

1. The spring (F) consists of a strip of steel 120^{mm} long, from the column (S) to the test point, 4–8^{mm} wide and 0·75^{mm} thick. It is firmly fastened by a screw to the top of the

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[*] This Journal (4), iv, p. 399, 1897.
[†] Price of instrument, 80 marks from the mechanic, P. Stoe, Heidelberg, Germany, Jubilaeums Platz, 70.

column (S) and with this can be raised or lowered in the socket (B). The rod (St) behind the column prevents lateral movement of the spring in raising or lowering the same. On the free end of the spring is screwed the test point holder (H_1, H_2, or H_3) which carries the crystal point or metal point with which the test object is to be scratched.

The following three point-holders seem desirable and are provided with the instrument: H_1 with diamond point. This is preferably a tetrahedral cleavage fragment, as this form gives

Fig. 1.
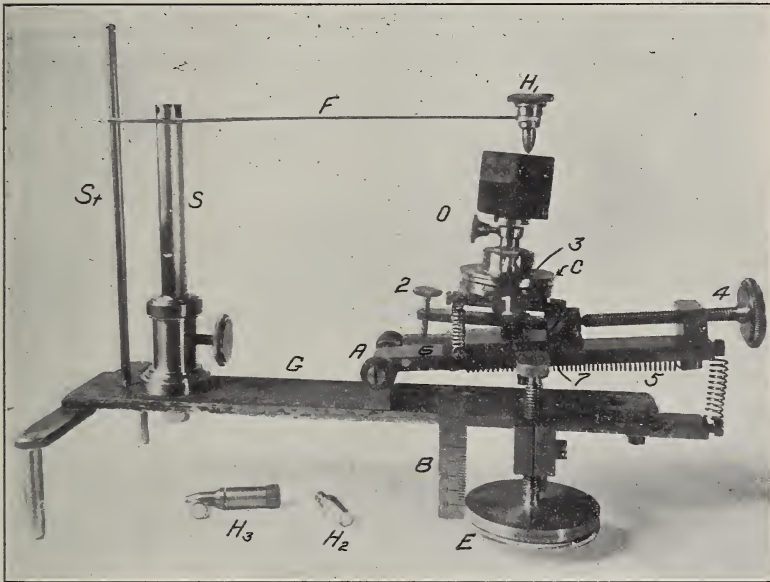
the sharpest cutting edge and is least liable to variations in hardness. H_2, a holder in which a needle of steel or other metal can be fastened. Generally a sewing needle is used, as there is little variation in hardness in needles from the same packet. For very soft substances a brass pin or a copper point may be employed. H_3, a holder with a cup-like depression in which a crystal or other substance may be fastened by means of wax "kit."* This may be either a substance of *known* hardness with which another is to be compared or one of *unknown* hardness which is to be tested by scratching the surface of a substance whose hardness is known.

* A piece of "kit" is provided with each instrument.

2. The object carrier (O) holds the crystal or other test object firmly in the position desired for making the tests. The crystal is fastened by wax "kit" to a small plate which is set in a socket at the top of the carrier.

The adjustment of the test object is as follows:

1. To bring the surface under the test point the transport screw (4) and the screw (1) are used. The screw (1) has also the purpose of moving the test object from side to side so that duplicate measurements may be made in parallel positions.

2. To give the face of the test object the desired inclination so that it forms with the slide (6) a wedge, it is tilted by means of the screw (2). The inclination will vary according to the hardness of the substance to be tested; very soft substances require only a slight inclination while harder materials require a greater one. This inclination of the surface to be tested is one of the most important features of the instrument, as it gives the measure of the pressure of the spring (F) when the crystal is moved by the transport screw (4).

3. To level the test object from side to side a screw (3) on the rear of the instrument is employed.

4. To test the hardness of the substance under investigation in different directions the graduated circle (C) is turned about its axis. This circle is divided into 36 parts so that each division gives 10°.

3. The transport screw (4) and accompanying spring (5) move the test object under the test point. The inclination of the surface to be tested to the plane of the slide (6) forms a wedge which by the movement of the screw (4) raises the spring (F) until a scratch is made.

4. The micrometer screw (E) raises or lowers the test object until it just touches the test point. Each division on the screw head measures an elevation of 0.01^{mm}.

5. The base (G) carries the different parts and needs no particular description.

Measurement.

The crystal or other test object is fastened to the top of the object holder (O) and inclined by means of the screw (2) so that the face to be investigated forms a wedge with the track (6). By the screw (3) it is made horizontal from side to side. By raising or lowering the column (S) the test point is brought to a position where it nearly touches the surface to be tested. By means of the micrometer screw the crystal is then raised until the test point just comes in contact with the face to be tested at the point *a*, fig 2.

Now by means of the transport screw (4) and the accompanying spring (5) the crystal is moved in the direction indicated by the arrow points so that as the surface acts as a wedge the test point (H) is raised and the spring (F) is bent from position F_1 to position F_2. By this movement a position is reached where the test point makes a scratch on the surface to be tested which is indicated in the figure as b. By the movement of the test object from position I to position II this point b has been brought to the position b' and the point b has also been raised the distance $a\ b' = d$. After the scratch has been made a reading is made on the micrometer screw E. The crystal is then lowered by means of the micrometer screw

Fig. 2.
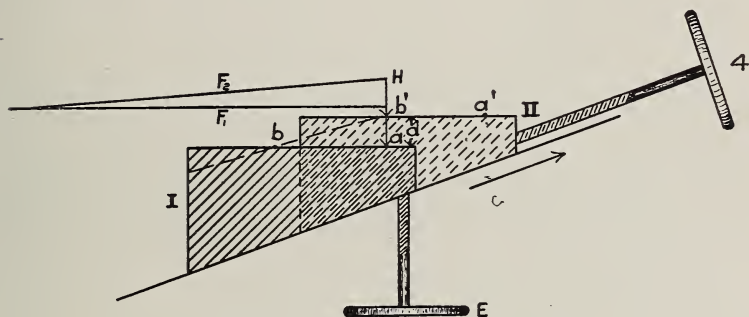
until the test point just touches the crystal or other substance at the point b', in other words at the beginning of the scratch, and a second reading is made on the micrometer screw which gives the distance ab' in divisions on the micrometer screw. This distance gives a measure of the bending of the spring or of the pressure necessary to make a scratch on the crystal, that is, it is a measure of the hardness.

In practice the lowering of the crystal by means of the micrometer screw gives a forward motion of the crystal in the direction of the arrow points in the figure and the beginning of the scratch must be brought under the test point by the transport screw (4). It is also found better in practice to lower the crystal or other test object so that the test point does not touch the surface, and then raise the test object again until the point just touches.

Calibration.

In this instrument the force that is necessary to make a scratch is measured by the strain on the spring (F) and the

reading is made in divisions on the micrometer screw (E).   In the instruments of Seebeck and others this same force is measured by the weights with which the test point is loaded. This measurement by weights has the advantage that the weights are constant, while the bending of the spring (F) is dependent upon the material and dimensions of the same, and with each instrument we get a different factor.   In order to reach comparable results it is necessary to reduce the divisions on the micrometer screw to measures of weight   This reduction of elevation to weight is called the *calibration of the instrument.**

The calibration of the instrument is made in this way.   A glass plate is fastened to the object carrier and a scratch is made with the diamond point.   The glass is now brought to the position where the test point just touches the beginning of the scratch.   This point is determined when the test point just meets its reflection in the glass.   The reading on the micrometer screw (E) is taken, the plate lowered by means of the micrometer screw and a weight placed on the test point holder (H) by which the spring is bent.   The plate of glass is now raised until the test point just touches the beginning of the scratch and a second reading is made on the micrometer screw (E).   Subtracting the second reading from the first gives the number of divisions on the micrometer screw that corresponds to a given weight.

By lowering the glass plate by means of the micrometer screws not only the plate but the track (6) and the object carrier (O) describe a small arc of a circle about A so that the beginning of the scratch must be brought under the point by means of the transport screw (4).†

The deflection of the spring for various weights is measured and a table can be made for all.

The results of the calibration are as follows:

	Weight	Reading	Deflection of needle in divisions of graduated circle	No. of divisions equivalent to 1 grm.	Mean No. of divisions equivalent to 1 grm.
	grm.				
First trial..	0	183·0	0		
	5	170·0	13	2·6	
	10	159·0	24	2·4	
	20	134·5	48·5	2·425	
	50	60·5	122·5	2·45	2·469

*Every instrument is furnished with a calibration table so as to give the weight that corresponds to one division on the micrometer screw.

† A very slight error is thus introduced but in practice this can be neglected, as the determinations of hardness are made in the same way and the errors are comparable.

	Weight grm.	Reading	Deflection of needle in divisions of graduated circle	No. of divisions equivalent to 1 grm.	Mean No. of divisions equivalent to 1 grm.
Second trial.	0	211·5	0		
	5	199·0	12·5	2·5	
	10	186·5	25·0	2·5	
	20	162·5	49·0	2·48	
	50	86·0	125·5	2·51	2·4975
Third trial.	0	135·0	0		
	5	123·0	12·0	2·4	
	10	110·0	25·0	2·5	
	20	85·0	50·0	2·5	
	50	7·0	128·0	2·56	2·49
Fourth trial.	0	193·5	0		
	5	180·5	13·0	2·6	
	10	168·5	25·0	2·5	
	20	143·5	50·0	2·5	
	50	67·0	126·5	2·53	2·5325
Mean of all					2·4975

The results agree closely so that the elevation may be considered proportional to the weight and in this instrument a load of 10 grams is equivalent to 25 divisions on the micrometer screw.

Results of Measurements.

Plane and polished surfaces of glass, iron, copper, and brass were taken as test objects. A few trials were made with crystal faces, but further study is necessary before it can be stated that the instrument is suitable for determining the hardness of unpolished surfaces.

Measurements with the diamond point (a tetrahedral cleavage fragment):

A. *Copper.* 10 measurements: Pressure = 1·2, 1·2, 1·8, 1·6, 1·6, 1·4, 1·6, 1·8, 2·0, 1·4 grm. Mean of first five measurements = 1·48 grm.; mean of second five measurements = 1·44 grm.; mean of all 1·46 grm.

B. *Brass.* 10 measurements: Pressure = 1·6, 2·0, 2·2, 2·2, 2·0, 2·2, 2·2, 2·2, 1·6, 1·7 grm. Mean of first five measurements = 2·00 grm.; mean of second five measurements = 1·98 grm.; mean of all 1·99 grm.

C. *Iron* (rolled). 10 measurements: Pressure = 2·2, 1·8, 2·0, 1·6, 2·2, 2·0, 2·2, 1·8, 2·0, 1·8 grm. Mean of first five measurements=1·96 grm.; mean of second five measurements = 1·96 grm.; mean of all 1·96 grm.

D. *Glass* (object glass for microscope). 10 measurements: Pressure = 3·8, 4·0, 4·2, 4·0, 4·0, 3·8, 4·2, 4·2, 4·2, 4·4 grm.

Mean of first five measurements = 4·0 grm.; mean of second five measurements = 4·16 grm.; mean of all 4·08 grm.

Measurements with steel point (sewing needle, number 5 sharp):

E. *Copper.* 10 measurements: Pressure = 5·0, 4·8, 4·0, 4·8, 4·0, 4·2, 3·8, 4·2, 4·2, 4·0 grm. Mean of first five measurements = 4·52 grm.; mean of second five measurements = 4·08 grm.; mean of all 4·3 grm.

F. *Brass.* 10 measurements: Pressure = 16·4, 12·0, 10·4, 10·4, 9·8, 14·0, 13·0, 10·8, 10·8, 10·4 grm. Mean of first five measurements = 11·8 grm.; mean of second five measurements = 11·8 grm.; mean of all 11·8 grm.

The ten measurements were made each time on the same piece of copper, brass, etc. with the same inclination of the surface and the same direction for the scratch. After each scratch the plate was moved a little to one side by means of the screw (1) so that the ten scratches were parallel and near each other.

The beginning of the scratch with the diamond point was always sharp and easily seen and is a very distinct point. With the steel needle, however, the beginning of the scratch on steel was somewhat uncertain. The scratch did not have a sharp beginning but was microscopic and gradually increased in depth with the increase of pressure.

In general a diamond point will probably give the best results for all substances except possibly for those which are extremely soft. Special study is being made to determine this point.

The nearly equal results obtained by scratching iron and brass with diamond were surprising and the two were tested against each other. The iron made a scratch on the brass very easily and the brass made a scratch on the iron but apparently with greater difficulty, but the point on the iron was, however, sharper than the point on the brass. It would appear that in the determination of hardness other properties such as tenacity, elasticity, flexibility, etc. must be taken into consideration, and it is hoped that this instrument may be of assistance in the study of the relations between these properties.

The results show a good determination when the mean of five measurements is taken.

The measurement is rapid and requires less than three minutes for a measurement when the test object is in position or for ten consecutive measurements less than a half hour.

The advantages of the instrument above mentioned are rapidity of observations, compactness, and cheapness. So far as observations have been made up to the present time, the instrument gives good results for polished faces of glass and metal, but further study is necessary to show its availability for minerals.

Heidelberg, Aug. 14, 1909.

Art. X.—*Dodecahedral Jointing due to Strain of Cooling;* by Fred. H. Lahee.

In the woods just south of Beacon St., and about a quarter of a mile west of Hammond St., Chestnut Hill, Mass., the Roxbury conglomerate is cut by a fine-grained, basaltic dike* which, in some parts, disintegrates into small (average diameter, ⅝ in.), polyhedral, often roughly dodecahedral, fragments. The dike has approximately plane-parallel sides, is four feet thick, strikes N. 20° E., and dips 78° E., its attitude being parallel to a prominent joint set of the country rock. That it entered a relatively cool rock is indicated by the fact that its texture, moderately fine in the middle, becomes very fine at the contact. It contains occasional large phenocrysts (xenocrysts) of apatite and biotite, both of which are well shaped, and of pink acid feldspar, which has outlines made irregular by the invasion of short tongues of the groundmass.

Near the country rock, on each side, in a zone from four to ten inches wide, hexagonal columnar jointing is poorly developed perpendicular to the contact surface. Inwards, the columns give place to the polyhedral blocks already mentioned as conspicuous in the disintegration of the rock.

Obviously the joints† which give rise to such many-sided fragments are of small extent. Furthermore, they (the joints) often vary in direction, or may die out entirely; but in spite of this irregularity, it is not difficult to find blocks bounded by twelve rhombohedral faces that intersect one another at angles nearly equal to the similar angles of a perfect dodecahedron. The surfaces of the blocks are relatively coarsely granular, without a well-developed feather fracture, a feature not uncommon on the more finely textured hexagonal columns. Where the phenocrysts are in the path of fracture, the break either passes round the obstacle, or takes advantage of the mineral cleavage. These statements clearly point to the inference that the dodecahedral jointing, like the hexagonal, is an effect of tension due to cooling.

Hexagonal columnar jointing has long been so interpreted. In the ideal case, according to the principles of least action, the columns begin their development as a series of three-way fractures (each fissure at an angle of 120° to the other two) radiating from equally spaced points in a surface which is perpendicular to their (the columns') direction of growth. This type of fracture is therefore a two-dimensional, or surface, phenomenon, and the extension of the columns may be regarded

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* The writer wishes to thank Mr. R. W. Sayles for bringing this dike to his notice, and Professor Chas. Palache and Professor J. B. Woodworth, who discovered the dodecahedral jointing, for valuable suggestions.

† Similar jointing has recently been seen by the writer in trap dikes on Ragged Island, Casco Bay, Maine.

as the result of the regular inward advance of successively cooler planes, for each of which the temperature is uniform throughout.

If, on the other hand, we conceive of a *solid* which is losing heat equally in all directions and in such a way as to be subjected to a homogeneous strain, *six-way* fracture will develop instead of the *three-way* fracture of the cooling *surface*, and the resulting geometrical form will be a *dodecahedron* instead of a *hexagon*.

As hexagonal fracture may be illustrated by considering a series of equal tangent circles compressed uniformly from all directions in the same plane, so dodecahedral jointing may be experimentally demonstrated by subjecting a group of equal tangent balls, arranged in superposed horizontal layers, to equal pressure from every direction. Those spheres which were originally in contact with twelve others will, it is true, be dodecahedral; but whether they become regular rhombic dodecahedra or forms which, to borrow from crystallography, resemble a regular rhombic dodecahedron twinned parallel to an octahedral face, will depend on whether the centers of the balls of a given horizontal layer were above the centers of the spaces, or of the spheres, of the second layer below. In either case, prior to the compression, the conditions of unoccupied space and of equal distance between the centers of spheres will be fulfilled.

The literature appears to be lacking in references to the particular kind of jointing described. Much of the work on this subject was done several decades ago. At that time hexagonal jointing received considerable attention and was correctly explained as the result of uniform strain in a surface. Spheroidal structure, which was shown by Bonney to be often unrelated to fracture systems, was, however, held to be the analogous phenomenon in a solid, and perlitic structure was consigned to the same catagory. Bonney thus states his views:[*] " A hexagon is the figure which will result from uniform contraction in two dimensions, a sphere from contraction in three dimensions." The case in point, however, leads to the conclusions: (1) that hexagonal columnar jointing is caused by equal tension in all directions in a surface at right angles to which the strain is differential; and (2) that uniform contraction in a solid must, under corresponding conditions of homogeneity, give rise to dodecahedral jointing. The sphere cannot be the exact analogue of the hexagon.

Cambridge, Mass.

[*] Bonney, T. G., On Columnar Fissile, and Spheroidal Structure. Quart. Jour. Geol. Soc., Lond., xxxii, p. 152, 1876. On this subject see also Jukes, J. B., and Geikie, A., Student's Manual of Geology, 3d ed., 1872, pp. 182, 183, 311; Mallet, R., Phil. Mag., Ser. 4, vol. i, pp. 122, 201; Scrope's Volcanoes of Central France, p. 92; Iddings, J. P., The Columnar Structure in the Igneous Rock on Orange Mountain, New Jersey, this Journal, (3), xxxi, p. 321, 1886, and Iddings, J. P., Igneous Rocks, N. Y., 320, 1909.

Art. XI.—*Restoration of Paleolithic Man;* by Richard Swann Lull. (With Plate I.)

An attempt has recently been made by the writer to restore in plastic form the type of mankind dwelling in Europe during a portion of the Paleolithic period and variously known to science under the names of *Homo primigenius, neanderthalensis* or *mousteriensis.* The restoration, which is life size, is a tentative one and will be kept in the clay for a time in order that authoritative criticism may be met before it is cast in plaster (cf. Plate I).

The model is based mainly upon what is known as the " Man of Spy No. 1 " ; one of the two specimens found at Spy in Belgium, of which the museum contains excellent plaster casts. The illustrations of the remains of man found at Krapina in Croatia and described by Professor Gorjanovic-Kramberger in his " Der Diluviale Mensch von Krapina in Kroatien " 1906, were largely used, together with certain other measurements, such as the estimate for total height, etc. For the use of the casts and the assembling of data, together with kindly criticism, I am indebted to Dr. George Grant MacCurdy, Curator of Anthropology in this museum, while to Professor Joseph Barrell, who has taken a very lively interest in the work, I wish also to acknowledge my gratitude.

My conception of *Homo primigenius* is that of a man of low stature, standing only five feet three inches in height, but of great physical prowess as indicated by the robustness of the limb-bones and especially of their articular ends. The great paunch of the higher anthropoid apes, which are almost exclusively vegetarians, is lacking and in its place is shown the clean-cut, athletic form of torso such as one sees in the typical North American Indians, for I imagine food conditions were much the same. We have abundant evidence that Paleolithic man was a crafty hunter, for the remains of various animals which he slew for food are found in the bone breccias of the caverns wherein his own relics are entombed. Great power is indicated, however, in the upper portion of the trunk and in the arms, compensating this ancient type for his lack of adequate tools and weapons.

The knees are somewhat flexed as the curved thigh bone would indicate, and probably should be more so, and the trunk is only partially erect, for the inward curves of the back bone, so characteristic of modern man, are but feebly developed, as in the case of babes of the present day or in individuals bowed down by the weight of years. The shin is relatively short, as with certain present-day races, and the great toe somewhat offset though having long since lost its ape-like opposability.

The head shows the prominent supra-orbital ridges above the deep-set eyes; the low, flat forehead; the broad, concave, nasal bridge and the somewhat prognathous jaws. The lower jaw is deep and powerful, and lacks the characteristic chin prominence of modern man. Other restorations give a greater prognathism than mine, and it may be that here I am in error in showing too great a refinement of countenance as compared with the low type of calvarium. The contour of the jaw is based upon actual measurement of one of the Krapina specimens and one should bear in mind that the far older jaw recently brought to light at Heidelberg, though of a more brutal type than any yet known, shows less dental prognathism than do the modern negroes, indicating a very great antiquity for the radiative evolution of the several human stocks.

In all probability the men of that day were much more hairy than the model would indicate, as they had little or no clothing and the climate, during part of their racial career at least, was severe. They were, however, cave dwellers and knew the use of fire. I have purposely refrained from indicating this conjectural character, as it would, to a certain extent, conceal the conformation of the underlying parts.

A jaw of the cave bear, *Ursus spelæus*, a contemporary animal, though now long since extinct, is borne in the left hand, while the right contains a chipped stone implement from one of the typical stations, thus indicating the cultural plane of the race.

This type dwelt in Europe before the last glacial period, estimated at from 100,000 to 200,000 years ago, and continued for a long period of time, for his remains are found entombed successively with both cold and warm climate animals. The relics are found within or near rock shelters and caves, the best known of which are those of Neanderthal, Germany; Spy, Belgium; Krapina, Croatia; Le Moustier and La Chapelle-aux-Saints in France. As a race *Homo primigenius* is to-day entirely extinct, though whether he was blotted out or absorbed by the invading horde of the superior *Homo sapiens* we have no certain knowledge. Occasionally, however, something of his type appears in modern man, notably in St. Mausberg, a medieval Bishop of Toul, and in Lykke, a scientific Dane of the eighteenth century, as well as among Australians and Melanesians, the lowest living races of mankind. These may be looked upon as instances of atavistic reversion.

The "Man of Spy," while showing more pithecoid characters than his successor, was nevertheless eminently human, representing as he does the type just preceding modern man, and one far removed from a true ape-like ancestry. In the popular conception "Prehistoric man" should be gorilloid, or at any rate distinctly simian; against this misconception the model stands as a silent protest.

RESTORATION OF PALEOLITHIC MAN.

Art. XII.—*Bismite ;* by W. T. Schaller and
F. L. Ransome.

In the Goldfield district in Nevada, bismite occurs in the
January, Combination, Sandstorm, and probably also in other
mines, as minute, pearly scales with brilliant luster and of
silvery whiteness. The luster of the scales is almost metallic
and suggests at first glance delicate and untarnished crystals of
native silver. The mineral is limited to the oxidized zone,
is usually accompanied by limonite and is frequently associated
with rich ore. It occurs as single glittering scales or specks
on the walls of cavities in spongy limonite or rusty ledge-
matter, as delicate frost-like films on the same materials and as
spongy aggregates with quartz. In the last-named form it is
clearly pseudomorphous after bismuthinite, the material having
consisted originally of a mass of bismuthinite prisms held
together by a siliceous gangue. The prismatic structure of
the bismuthinite is retained as hollow casts in the quartz, lined
or partly filled with scales of bismite.

As natural crystals of bismite do not appear to have been
found hitherto and as the mineral has been assigned to the
orthorhombic system in Dana's and Hintze's mineralogies on the
basis of Nordenskiöld's work on artificial crystals in 1860 and
1861, considerable interest attaches to the Goldfield occur-
rences on account of the crystallinity of the material.

When examined under the microscope in gently powdered
material the crystals appear as thin colorless scales, with occa-
sionally a suggestion of hexagonal outline. On account of
their tenuity, it is rare that an edge view of a scale is obtain-
able. The larger flat-flying scales are dark in all positions
between crossed nicols and give a negative uniaxial figure with
convergent light. There are no colored rings and the double
refraction is apparently not great. The refractive index, on
the other hand, is rather high, being greater than that of
anorthite. The mineral has a perfect basal cleavage and the
scales, viewed without the analyzing nicol, commonly show
delicate interference colors due to the refraction and reflection
at the surfaces of the exceedingly thin cleavage sheets.

Some of the best material obtainable was analyzed with
results as follows:

	1	2	3	Average
Insol. in HCl, mostly quartz gangue	78·95	78·87	79·01	78·94
Bi_2O_3	17·29	17·00	16·84	17·04
H_2O (loss on ign.)	3·96	----	----	3·96
Fe_2O_3	0·36	0·50	0·21	0·36

100·30

The results show that the mineral is either bismite or else a hydrous oxide of bismuth. If the latter be the case, the mineral is a new species (providing, of course, that Bi_2O_3 is the correct formula for the bismuth ocher found in nature and called bismite). Attempts to isolate a sufficient quantity of the pearly scales from the gangue for separate analysis were not successful.

The minute, tabular crystals are too incomplete to allow of a determination of their geometrical form by crystallographic measurements alone. From the uniaxiality of the crystals, their hexagonal outline, triangular markings on the base and distribution of the faces as far as seen, reference of them to the rhombohedral division of the hexagonal system appears to be justifiable. ·

The value of the c axis, derived in a manner presently to be described, is 0·5775. Seven faces are determined as present; the base, five positive and one negative rhombohedra. Besides these, there are indications of two more positive rhombohedra. A brief description of these forms follows.

c {0001}. Always very large, even, and highly polished. Sometimes shows triangular markings or striæ, the faces parallel to these markings being taken as positive.

o {10$\bar{1}$6}. Occurs on two crystals, as broad faces giving, however, poor reflections. One face was considerably striated, giving two signals a degree apart.

q {10$\bar{1}$5}. Broad faces giving fairly good reflections.

u {10$\bar{1}$4}. Narrow faces, one striated with a fair reflection, and one as a line face giving a very poor reflection.

k {10$\bar{1}$3} Usually as a line face, striated and giving a very poor reflection.

? {20$\bar{2}$5}. A doubtful face, narrow, giving no distinct signal.

? d {10$\bar{1}$2}. Another doubtful face, broad, giving no distinct reflection.

y {20$\bar{2}$1}. Line faces, giving exceedingly faint reflections.

z {01$\bar{1}$1}. The only negative rhombohedron observed. Very faint line faces, giving no reflection. Its negative position could be determined only on crystal No. 6.

The measurement of the forms are shown below.

			Meas.		Calc.
(0001)	:	(10$\bar{1}$6)	6° 37′	، 6° 41′	6° 21′
"	:	(10$\bar{1}$5)	7 33	7 36	7 36
"	:	(10$\bar{1}$4)	9 31	9 31	9 28
"	:	(10$\bar{1}$3)	12 11	12 26	12 32
			13 18	12°–14°	
"	:	(20$\bar{2}$1)	54°	54°	53 08
"	:	(01$\bar{1}$1)	35°	32$\frac{1}{2}$°	33 42

Doubtful forms: Meas.   Calc.

   (0001) : (20$\bar{2}$5),   15°   14° 56′

      "   : (10$\bar{1}$2),   16°–20°   18 26

The value for the c axis was obtained from three measurements that were considered as the most accurate. The others gave values agreeing fairly well with the one adopted, as is shown below. The crystals were measured on the two-circle goniometer and the ρ angle for these forms is the angle between that form and the base.

The three best measurements are:

ρ {10$\bar{1}$5} = 7° 33′ p_0 = ·6627   cryst. No. 1
ρ {10$\bar{1}$5} = 7 36   " = ·6672   "   " 4
ρ {10$\bar{1}$4} = 9 31   " = ·6706   "   " 2

<div align="center">Av. p_0 = ·6668 ; c = 0·5775.</div>

An average of the other measurements gave values closely agreeing. Thus:

ρ {10$\bar{1}$6} = 6° 37′ p_0 = ·6960   ·cryst. No. 3
     "   = 6 41   " = ·7031   "   " 6
ρ {10$\bar{1}$4} = 9 31   " = ·6706   "   " 6
ρ {10$\bar{1}$3} = 12 11   " = ·6477   "   " 6
     "   = 12 26   " = ·6614   "   " 4
     "   = 13 18   " = ·7102   "   " 1

<div align="center">Av. = ·6815</div>

The following measurements of faces giving no distinct reflections also showed close agreement:

ρ {10$\bar{1}$3} = 12°–14° (av. 13°) p_0 = ·69   cryst. No. 1
ρ {20$\bar{2}$5} = 15°   " = ·67   "   " 2
ρ {10$\bar{1}$2} = 16°–20° (av. 18°)   " = ·65   "   " 1
ρ {01$\bar{1}$1} = 35°   " = ·70   "   " 5
     "   = 32$\frac{1}{2}$°   " = ·64   "   " 6
ρ {20$\bar{2}$1} = 54°   " = ·69   "   " 1
     "   = 54°   " = ·69   "   " 6

The values for p_0 just given show that the interpretation of the forms is the correct one.

Of the six crystals (all incomplete) that were measured, only two need to be briefly described.

Fig. 1a is an orthographic projection of a crystal (No. 1), showing the trigonal distribution of the rhombohedra, and the triangular markings on the base.

Fig. 1b shows a similar projection of cryst. No. 6, with a negative rhombohedron.

An odd feature of these crystals is that the development of the faces is so uneven, that no two faces of the same form are present on the upper half of a crystal, though this is in part due to the incompleteness of each crystal.

From the foregoing observations it appears that the natural bismite is not orthorhombic but belongs to one of the uniaxial
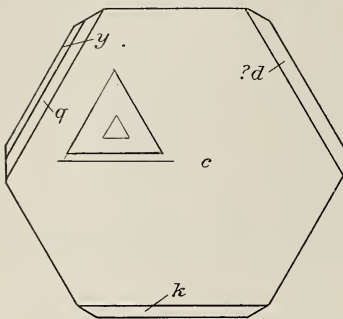
FIG. 1*a*.   FIG. 1*b*.
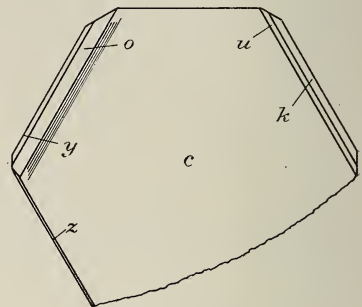
systems, probably the hexagonal.   Its presence in oxidized ore appears to be uniformly indicative of bismuthinite in the original sulphide ore.   Some migration, however, has taken place during oxidation and the scales of bismite do not always occupy the exact positions of the parent needles of bismuthinite.

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

ART. XIII.—*Contributions to the Mineralogy* of Franklin
Furnace, N. J.;* by CHARLES PALACHE.

THE purpose of this paper is to present in brief form some
of the more interesting results obtained in the study, con-
tinued through several years, of the minerals of Franklin
Furnace, New Jersey. The complete results of the study will,
it is hoped, appear soon in monograph form, but it seems desir-
able to place on record without further delay the chemical
analyses made for the most part in the laboratory of the Geo-
logical Survey. These analyses are either of minerals not
before recorded from this locality or of species concerning
which our information is incomplete. With these are also
included crystallographic notes on a number of species and a
list of additional minerals whose presence at Franklin Furnace
has not hitherto been recorded.

Arsenopyrite: Crystal Form, Composition.

Brilliant crystals of arsenopyrite up to an inch in length
were found in several of the limestone quarries at Franklin
Furnace in 1905. They are associated with pyrite, pyrrhotite,
spinel, humite, tourmaline and phlogopite. The crystals are
completely developed, showing besides known forms the new
pyramids (532), (112), (143), and (132), the first present on all
crystals and characteristic for the locality.

The following analysis by E. C. Sullivan, U. S. G. S., was
made of selected crystal fragments:

		Ratio	
Fe	32·48	·581 } 1	
Co	1·16	·02 }	
As	48·72	·650	1·08
S	18·80	·587	·98

The ratio shows a normal composition. The presence of
cobalt is interesting; it has been shown by Kraus & Scott† to
be present in about the same proportion in pyrite crystals in
the same limestone. Tests for cobalt made on the associated
pyrrhotite showed no trace of this element and hardly more
than a trace of nickel.

Fluorite: Composition.

The following analysis of fluorite by G. Steiger, U. S. G. S.,
was made in the belief that it was a manganiferous variety.

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* Published by permission of the Director of the U. S. Geological Survey.
† Zeitschr. für Kryst., xliv, 144, 1907.

The material was pale red and granular, the matrix of frank-linite grains.

Ca	51·21	Al	0·18
Mg	0·24	F	45·85
Fe	0·27	Cl,Co_2	none
Mn	0·09		
			97·84

Mr. Steiger remarks that the deficiency in the analysis is doubtless due to fluorine.

The manganese content is insignificant. If the total deficiency, 2·16 per cent, is calculated as fluorine, there is still slightly less than is required to form RF_2 with all bases, but almost exactly enough to satisfy the calcium. This suggests, but of course does not prove, that the bases other than calcium are present as impurities in the form of unknown compounds.

Manganosite: Occurrence, Composition.

This rare substance, known hitherto only from two Swedish localities, was found in a single specimen in the Harvard Mineralogical Museum. The specimen consists of a granular aggregate of franklinite, zincite and manganosite. The latter is in irregular grains showing cubic cleavage, dark green in the mass, emerald-green in thin fragments. The material analyzed contained traces of zincite and minute black films of manganese oxide. The specific gravity was 5·364.

1. Manganosite: analysis by George Steiger, U. S. G. S.
2. Same corrected for ZnO and MnO_2 known to be present.

	1	2
MnO	94·59	99·61
MnO_2	1·30	
ZnO	3·41	
FeO $\}$ Fe$_2$O$_3$ $\}$	0·26	0·27
MgO	0·11	0·12
H_2O-	0·38	
H_2O+	0·40	
	100·45	100·00

The material is thus shown to be very nearly of the theoretical composition of manganosite, MnO.

Zincite: Crystal Form.

Measurements of natural crystals of zincite are very few and poor and the generally accepted axial ratio for the species is based on artificial crystals. The writer obtained measurements

on one crystal of zincite from Franklin Furnace, however, which were very satisfactory; he has therefore calculated an axial ratio based on them and in the following table gives all the measurements made on natural crystals and the corresponding angles calculated from (1) the new ratio, (2) Dana's ratio, (3) Traube's ratio based on artificial crystals. The author's measurements were on four faces of the pyramid (40$\bar{4}$5), the angle to the base (average) being 55° 42′ with deviation of but 4′. A single reading (0001) to (10$\bar{1}$1) was also obtained, in close agreement.

Angle	Calculated			Measured				
	Dana $a:c=$ 1:1·6219	Traube $a:c=$ 1:1·6077	Palache $a:c=$ 1:1·5870	Dana '86	Grosser '92	Moses '95	Palache	
							Contact	Reflexion
0001∧10$\bar{1}$1	61°54′	61°41′	61°23′	----	----	----	62°00′	61°2$\bar{2}$′
10$\bar{1}$1∧01$\bar{1}$1	52 21	52 14	52 ·04	----	.. ..	----	52 00	* ----
0001∧40$\bar{4}$5	56 17	56 03	55 42	----	55°38′	55°40′	----	55°42′
40$\bar{4}$5∧04$\bar{4}$5	49 09	49 00	48 48	----	48 50	----	----	----
0001∧50$\bar{5}$4	66 52	66 41	66 25	65°20′	----	----	----	----
50$\bar{5}$4∧05$\bar{5}$4	54 46	54 40	54 33	53 53	----	54°42′	----	----

Gahnite, variety Dysluite: Composition.

Following is an analysis of a gahnite crystal supplied by Mr. Canfield from the locality at Sterling Hill which yielded the enormous crystals in the Canfield Collection. This is the type of the variety dysluite but has not been before analyzed. Specific gravity 4·56.

1. Analysis of dysluite, W. T. Schaller, U. S. G. S., 1906.
2. Same omitting SiO_2, CO_2 and equivalent of CaO, and H_2O. State of oxidation of iron and manganese not known.

	1	2	Mol. Ratio	
Al_2O_3	47·27	48·81	·478	·542=1
Fe_2O_3	9·90	10·22	·064	
ZnO	37·10	38·3i	·472	
MnO	0·93	0·97	·013	·523=1·04
MgO	1·09	1·12	·028	
CaO	1·01	0·57	·01	
CO_2	0·38	----		
SiO_2	1·47	----		
H_2O	1·21	----		
	100·36	100·00		

The composition of dysluite is very like that of the gahnite from Franklin Furnace analyzed by Brush, both being very high in zinc.

Franklinite: Form, Composition.

Small implanted crystals of franklinite of quite abnormal appearance were seen in two specimens believed to have come from the Hamburgh mine, Franklin Furnace. The crystals are of adamantine luster and on edges or where splintered show a deep red color. The prevailing habit is cubo-octahedral with occasional planes of the forms (101), (311), (211) and (310). The unique color and habit of these crystals suggested a new type of the spinel group, but the analysis below by W. T. Shaller, U. S. G. S., shows them to be of ordinary franklinite composition. Specific gravity 5·09.

*Fe_2O_3	66·58	CaO	0·43
*MnO	9·96	MgO	0·34
ZnO	20·77	H_2O	0·71
			99·51

Hetærolite: Form, Composition.

Reëxamination of this mineral, which has been a doubtful species because of Moore's incomplete description, establishes the correctness of his characterization as a zinc hausmannite.

Tetragonal, shown by optical behavior of the fibers under the microscope. Indistinct prismatic cleavage, specific gravity 4·85.

Composition $ZnO.Mn_2O_3$, as shown by the following analysis of material furnished by E. P. Hancock:

1. Hetærolite, analysis by W. T. Schaller, U. S. G. S., 1906.
2. Same corrected for the small amount of SiO_2 and for water probably contained in a slight admixture of chalcophanite.

	1	2	Ratio.	
Mn_2O_3	60·44	63·85	·405 }	1
Fe_2O_3	·77	0·83	·005 }	
ZnO	33·43	35·32	·435	1·06
SiO_2	1·71			
H_2O-	2·47			
H_2O+	1·42			
	100·24	100·00		

Hausmannite, $MnO.Mn_2O_3$
Hetærolite, $ZnO.Mn_2O_3$

Pyroxenes: Composition.

Manganese- and zinc-bearing varieties of pyroxene are characteristic both of the granite and of the intruded rocks near the contacts at Franklin Furnace and Stirling Hill. The dis

* State of oxidation of iron and manganese not known.

tinctions between these pyroxenes are not sharply defined. Jeffersonite, the most abundant of them, contains manganese zinc and iron in addition to lime and very little magnesium. Zinc schefferite differs in the practical absence of iron and in the increase of calcium and magnesium at expense of manganese and zinc. Schefferite, close to the last named, contains no zinc, little iron and a larger proportion of magnesium. Schefferite was found only in well-defined crystals in limestone from Stirling Hill. The analyses here given are of a very fresh jeffersonite from Parker shaft, Franklin Furnace, and of schefferite which has not been before described from this region.

1. Analysis of jeffersonite, Steiger, U. S. G. S., 1906.
2. Analysis of schefferite, Schaller, U. S. G. S., 1907.

	SiO_2	CaO	MgO	MnO	ZnO	FeO	Al_2O_3	Fe_2O_3	H_2O-	H_2O+	Na_2O	CO_2
1	49·03	19·88	5·81	7·91	7·14	3·95	0·86	4·22	0·60	0·70	----	----
											[100·14	
2	49·80	21·07	12·35	9·69	tr.	1·61	0·26	1·46	1·55	1·31	0·9	0·43

[F = 0·31 = 99·93 less ·13 = +

Nasonite: Crystal Form.

The crystal form of nasonite could not be determined by Penfield in the absence of crystals, but he concluded that it was tetragonal because of chemical analogy with ganomalite— a tetragonal mineral.

Crystals of nasonite were intrusted to the writer by Mr. Canfield, who had recognized their hexagonal character. One of them proved measurable and showed the forms a (11$\bar{2}$0), m (10$\bar{1}$0), p (10$\bar{1}$1) and x (90$\bar{9}$2), the hexagonal symmetry being well defined. The axial ratio, based on two measurements of angle $c \wedge p = 56° 40'$, is $a : c = 1 : 1·3167$.

Angle $c \wedge x$, calculated 81° 41′, measured 81° 36′.

The faces of m are cavernous except at the prism edges, where they are well defined and generally truncated by a. The prism rounds over into the pyramid p on most of the small crystals seen, the form x representing a plane face t in this surface on one crystal. The faces of p were dull on all except the measured crystal. This was afterwards tested qualitatively and gave the reactions of nasonite.

Glaucochroite: Crystal Form.

Terminated crystals were not present in the original specimens of glaucochroite described by Penfield, but he obtained an approximate axial ratio by measurement of the inclination of individuals in twin position.

Two terminated crystals were secured from a specimen loaned by the Foote Mineral Co. which yielded fair measurements, determining the following axial ratio and forms.

$$a : b : c \ = \cdot4409 : 1 : \cdot5808$$
$$= \cdot440 \quad : 1 : \cdot566 \text{ (Penfield).}$$

Forms : a (100), b (010), m (110,) s (120), x (103), h (021)
e (111), f (121).

Combinations :   1. b. m. s. x.
　　　　　　　　 2. a. b. m. s. k. e. f.

Angles :	Calculated		Measured		
	ϕ	ρ	φ	ρ	
111	66°12′	55 13	66 13	55 15	2 faces good
121	48 36	60 12	49 22	60 29	1 face poor
110	69 12	90 00	66 09	90 00	4 faces good
120	48 36	90 00	49 14	90 00	poor

Bementite: Composition, System.

The description of bementite by Koenig was incomplete and its relations were not clear.   Study of a later find of better material from the Parker shaft, Franklin Furnace, establishes its close relationship to tephroite in system and composition.

System orthorhombic, shown by three pinacoidal cleavages at right angles but unequally perfect ; and by a symmetrical biaxial interference figure with small axial angle seen on plates parallel to the best cleavage.

The analysis given below agrees closely with that of Koenig, but the water is shown to be constitutional, coming off for the most part at a red heat.   It leads to the formula H_6Mn_5 $(SiO_4)_4$, with more or less replacement of manganese by iron, zinc and magnesium.   This is analogous to the formula of tephroite, which may be written $Mn_8Si_4O_{16}$; in bementite three molecules of manganese are replaced by constitutional water. That it is not a simple case of partial hydration is shown by the optical homogeneity of the bementite crystals.

1. Analysis of bementite, Geo. Steiger, U. S. G. S., 1906.

2. Same recalculated to 100 per cent after omitting Al_2O_3, Fe_2O_3 and H_2O— and substituting for FeO, MgO, CaO, and ZnO, equivalent amounts of MnO.

3. Theory for H_6Mn_5 $(SiO_4)_4$.

	SiO_2	MnO	FeO	ZnO	MgO	CaO	H_2O+	H_2O-	Al_2O_3	Fe_2O_3	
1	38·36	39·22	4·94	2·93	3·35	0·62	8·01	0·60	0·96	0·71	99.70
2	37·93	53·56					8·51				100·00
3	37·18	54·53					8·29				100·00

Willemite: Axial Ratio, Refractive Indices.

No accurate measurements of willemite crystals from New Jersey have been hitherto recorded.   The fundamental angle employed by Dana was based on contact measurements of troostite.   Other authors use the element determined by Lévy on crystals from Moresnet, on which the sole form is a rhombohedron not found on Franklin crystals.   A number of measurable crystals, all from the Parker shaft, Franklin Furnace,

passed through the writer's hands and the data secured from them permit the establishment of a satisfactory axial ratio. The five measured crystals were colorless or pale green prisms terminated by the base and one or both of the rhombohedrons e $(01\bar{1}2)$ and r $(10\bar{1}1)$.

Angle $c \wedge e$, 19 readings average $20° 47'$, limits $20° 35'—21° 04$
" $c \wedge r$, 14   "   " $37° 35'$,   " $37° 20'—37° 40'$

Whence $a : c = 1 : 0.6612$
Lévy   " $= 1 : 0.6696$
Dana   " $= 1 : 0.6775$

Calculated angle, $c \wedge e = 20° 53'$
"   " $c \wedge r = 37° 22$

Refractive indices, measured on a prism $\|$ c'.
Sodium light, $\omega = 1.69390$ $\epsilon = 1.72304$
Lithuim   " $\omega = 1.68897$ $\epsilon = 1.71812$

Friedelite: Occurrence; Composition.

Friedelite has not been before described from America. It was identified by the writer on a single specimen from Buckwheat mine, Franklin Furnace, in the Kemble Collection, and in minute amount on specimens from the Parker shaft. The mineral occurs in scales or tabular crystals with the unit rhombohedron and base, not measurable.

The analysis, with others for comparison, follows :

1. Friedelite, Franklin Furnace, Schaller, U. S. G. S., 1906.
2. Same recalculated to 100 per cent after removing $H_2O—$ and substituting equivalents of MnO for FeO, MgO, ZnO and CaO.
3. Average of four analyses of friedelite (Dana, System and 1st Appen.) recalculated as in number 2 above.
4. Theory for $H_9 (MnCl) Mn_7 (SiO_4)_6$
5. Theory for $H_{20} (MnCl)_2 Mn_{14} Si_{12} O_{49}$
6. Theory for $H_{16} (MnCl)_2 R_{11} Si_{10} O_{40}$ (Zambonini).

	1	2	3	4	5	6
SiO$_2$	34.69	34.95	34.14	34.73	34.43	34.84
MnO	48.00	53.22	54.35	54.86	54.33	53.60
Cl	3.43	3.45	3.42	3.42	3.39	4.12
H$_2$O +	9.08	9.15	8.84	7.82	8.60	8.36
H$_2$O —	1.94					
FeO	1.45					
MgO	.98					
ZnO	1.05					
CaO	.63					
	101.25	100.77	100.75	100.77	100.75	100.92
Less O = Cl	.77	.77	.75	.77	0.75	.92
	100.48	100.00	100.00	100.00	100.00	100.00

The Franklin friedelite agrees closely in composition with that of other localities, as shown by comparison of columns 2 and 3. Groth's formula for the mineral, used by Dana, does not well express the results of these analyses, which uniformly give a higher content of manganese or its equivalents and a lower content of chlorine than demanded by it. The formula adopted here, $H_9(MnCl)Mn_7(SiO_4)_6$, is satisfactory as to all constituents save water, for which it is too low. The formula $H_{20}(MnCl)_2Mn_{14}Si_{12}O_{49}$, obtained by adding one-half molecule of water to the latter, comes nearest to the exact equivalent of the analytical data but was rejected as not being reducible to the orthosilicate form. Zambonini[*] has derived for pyrosmalite and friedelite the formula

$$RCl_2.12RO.10SiO_2 + 8H_2O$$
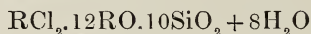
an expression which takes no cognizance of the fact that the water in these minerals is combined. The above formulas, reduced to this form of expression, are:

(1) $RCl_2.15R_2O.12SiO_2 + 9H_2O$
(2) $RCl_2.15RO.12SiO_2 + 10H_2O$
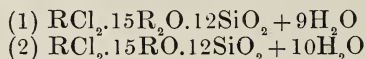
This formula of Zambonini gives a composition very similar to (2) and quite as close to the analytical results except for chlorine, which is too high. It is better than (1) as to water but is no closer in regard to other constituents.

Vesuvianite, variety Cyprine: Analysis.

Bluish green fibrous vesuvianite corresponding in character with the Norwegian cyprine was found in 1905 in granite from the Parker shaft. The material was carefully freed from minute specks of metallic copper and had a specific gravity of 3·451. The analysis by Steiger, U. S. G. S., 1907, follows:

SiO_2	36·41	PbO	trace
Al_2O_3	17·35	Na_2O	0·44
Fe_2O_3	} 1·86	K_2O	0·50
FeO		H_2O-	0·24
MgO	1·38	H_2O+	3·51
MnO	1·75	F	0·36
ZnO	1·74		
CuO	1·85		100·23
CaO	33·21	less O = F	0·17

Sum 100·06

This analysis agrees closely with that of the cyprine from Tellemarken save in the greater amount of water and less fluorine. It corresponds to the formula:

* Zeitschr. Kryst., xxxiv, 554.

$$H_8(Al,Fe)_6Ca_{12}Si_{10}O_{45}$$
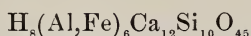
with part of the lime replaced by a number of oxides.

Datolite: Crystal Form.

Datolite has been known for some time from the Parker shaft, Franklin Furnace, but crystals have not hitherto been described from there. Complex crystals were found in a specimen in the Harvard Collection on which were observed a number of forms including several new to the species. In the following list new forms are marked with an asterisk :

a (001) e (023) x (101) $\gamma\cdot$ (221) $\epsilon\cdot$ ($\bar{1}$11) f : (241) k : ($\bar{2}$45)
c (100) M (011) *I (304) $\Lambda\cdot$ (111) $a\cdot$ ($\bar{2}$21) j : (243)
g (110) o (021) ϕ (102) $\theta\cdot$ (112) $Q\cdot$ (121) *d (263)
m (120) *q: (701) ζ ($\bar{1}$01) $Y\cdot$ ($\bar{2}$23) $\mu\cdot$ ($\bar{2}$11) *$k\cdot$ (475)

Symbols and letters after Goldschmidt, Winkeltabellen.

The pyramid d (263), new to datolite, is present on all the crystals with characteristic form.

Cuspidine: Occurrence ; Composition.

The occurrence of this mineral, known hitherto solely from Vesuvius, at Franklin Furnace is established by the following analysis, for which the writer is indebted to Dr. C. H. Warren.

The material, which occurred with nasonite, was isolated by hand-picking and heavy solution and analyzed by him at the time (1899) Penfield and Warren were working on nasonite and other peculiar silicates from the Parker shaft. At the time no satisfactory interpretation of the analysis was hit upon, the identity of the mineral remained hidden, and, all the material having been used in analysis, the matter was put one side. The material analyzed consisted of glassy white crystal fragments of specific gravity between 2·965 and 2·989.

I. Analysis of cuspidine, C. H. Warren, 1899.

II. Same recast and recalculated to 100 per cent after substituting equivalents of Ca for Mn, K, and Na.

	I		II	Molecular Ratio	
SiO_2	32·36	Si	15·10	·539	1
CaO	61·37	Ca	44·63	1·115	2·05
MnO	0·71	F_2	9·05	·238 ⎫ 2·189	4·06
Na_2O	0·48	O	31·22	1·951 ⎭	
K_2O	0·27				
F	9·05				
	104·24				
Less O = F_2	3·81				
	100·43				

The ratio Ca : Si : (O+F$_2$) = 2 : 1 : 4 very nearly, leading to the formula Ca$_2$Si (O, F$_2$)$_4$. This is the formula suggested by Dana (System, 529) for cuspidine, in which fluorine is treated as replacing oxygen. No other treatment of the analytical data gave a satisfactory ratio. It is much to be regretted that no further material remains for more complete physical determination of this interesting species.

Humite: Crystal Form.

Minerals of the humite group have long been known from Franklin under the name of chondrodite. They have not been analyzed nor till recently have good crystals been found. In 1906 were found orthorhombic crystals of deep orange-red and pale yellow color which yielded contact measurements accurate enough to prove the material to be humite.

Forms : *b* (010), *o$_2$* (210), *m* (110), *e$_\delta$* (102), *n$_a$*(112), *r$_4$* (214).

Combinations :

1. *b*, *o$_2$* *n$_a$*, *r$_4$*.
2. *b*, *o$_2$*, *e$_\delta$*, *n$_a$*, *r$_4$*.
3. *b*, *o$_2$*, *m*, *e$_\delta$*, *n$_a$*, *r$_4$*.

Leucophœnicite: Crystal Form.

Leucophœnicite was described by Penfield, whose material did not permit him to determine the system to which the crystals belong. From its relation in composition to the humite group he believed it to be monoclinic.

Crystals of measurable quality very kindly placed in the writer's hands by Mr. Canfield, furnished data for the determination of system and forms.

System, monoclinic:—Axial ratio : *a : b : c* = 1·1045: 1 : 2·3155. β = 76° 44′.

Forms :

c (001)	*s* (120)	*x* (103)	*y* ($\bar{1}$03)	*l* (121)	*d* (123)
b (010)	*e* (101)	*r* ($\bar{1}$01)	*o* (011)	*n* ($\bar{1}$21)	*h* ($\bar{1}$23)
a (100)	*f* (102)	*i* ($\bar{1}$02)	*f* (012)	*u* ($\bar{1}$22)	*q* ($\bar{1}$24)
m (110)					

The crystals are of epidote habit, elongated parallel to the *b*-axis, the orthodome zone deeply striated. Crystals are twinned on a face in this zone which was taken as the basal pinacoid, the two individuals frequently interpenetrating. The form series is peculiar and could not be correlated in any way

with that of any member of the humite group to which leuco-phœnicite is related chemically.

The presence at Franklin Furnace or at Stirling Hill of the following minerals, not hitherto recorded, has been established: Marcasite, millerite, pyrrhotite, aurichalcite, hydrozincite, psilomelane, göthite, albite, chlorite, ganophyllite, manganese pectolite, descloizite, anglesite and native silver.

With these additions and the omission of a number of species of the older lists which could not be verified, the number of minerals recorded for this locality becomes ninety-three.

Harvard University, October, 1909.

SCIENTIFIC INTELLIGENCE.

I. Chemistry and Physics.

1. *The Formation of Colloidal Solutions by the Action of Ultra-violet light upon Metals.*—It was observed by Lenard and Wolf in 1889 that certain substances, particularly metals, were resolved to dust by the action of ultra-violet light. This effect was detected both by the roughening of the surfaces and the detection of the detached particles in the adjacent layers of air. It was found that different metals gave different degrees of this action, that the electrical condition of the metallic plate exerted a pronounced influence upon the action, as did also the nature of the source of light employed. These investigators did not attempt the preparation of colloidal solutions by this means, but they observed, when experimenting with a zinc plate, that a layer of water held back the zinc dust. Svedberg has now made use of this phenomenon in preparing colloidal solutions of various metals in various liquids. He placed the metal, the surface of which must be freed from layers of oxide, in a shallow dish, placed the liquid upon it, and exposed it to the rays of a Heraeus' quartz-mercury arc lamp at a distance of a few centimeters. After a few minutes the liquid when examined by the ultra-microscope showed the characteristic appearance of a colloidal solution. Different metals and different liquids behaved very differently. Silver, copper, tin and lead gave colloidal solutions easily, while platinum, aluminium and cadmium showed little or no effect. The action with lead was particularly strong. When water was used this metal gave a milky liquid in five minutes, probably colloidal hydroxide, while with ethyl alcohol the same metal gave a colloidal metallic solution. Further experiments with lead and silver in water and six different organic liquids indicated that

the size of the particles is very different in the various cases, and that this depends upon the nature of the liquid employed. It was especially interesting to find that it was possible to produce solutions with particles of very small, uniform size which displayed the Brownian movements in a very lively manner. Further study of this matter, which the author is undertaking, promises to be of great interest, and he suggests that it may be of importance in explaining the mechanism of common photochemical reactions.—*Berichte*, xlii, 4377.   H. L. W.

2. *Potassium Percarbonate.*—Much uncertainty has arisen in regard to the true constitution of the product prepared in 1897 by Constam and von Hansen by the electrolysis of concentrated potassium carbonate solutions to which the percarbonate formula, $K_2C_2O_6$, was ascribed by the discoverers. Up to the present time this product has always been obtained in an impure condition, containing carbonate, bicarbonate and water, and since it yields hydrogen peroxide and potassium carbonate when dissolved in water, it has been possible to regard it as potassium carbonate with hydrogen peroxide of crystallization, instead of a true percarbonate. Moreover Tantar has obtained a well crystallized product by the combination of sodium carbonate and hydrogen peroxide, to which he gave the formula $Na_2CO_4 + \frac{1}{2}H_2O_2 + H_2O$, regarding it as a percarbonate combined with both hydrogen peroxide and water.

Riesenfeld and Reinhold have now succeeded in preparing the electrolytic product in a nearly pure anhydrous condition by the use of special precautions. The absence of hydrogen in this preparation proved that it was not a hydrogen peroxide addition product and analyses confirmed the formula $K_2C_2O_6$. They have also found a means for distinguishing between percarbonate and hydrogen peroxide in the fact that the former liberates iodine immediately from a neutral potassium iodide solution, while hydrogen peroxide acts only slowly upon such a solution. By means of this reaction they found that Tantar's product contains no percarbonate, so that its formula should be given as $Na_2CO_3 + 1\frac{1}{2}H_2O_2$.—*Berichte*, xlii, 4377.   H. L. W.

3. *A Practical Application of Radium.*—In connection with a research on a revision of the atomic weights of iodine and silver, Baxter and Tilley found it necessary to determine small quantities of water in the iodine pentoxide which they were analyzing. This water was absorbed and weighed in glass U-tubes containing phosphorus pentoxide. The usual difficulty in weighing glass apparatus, due to electrical disturbance from wiping it, was avoided here by placing in the balance a few milligrams of radium bromide of radio-activity 10·000 to dispel electrical charges. Under these conditions no difficulty was experienced in weighing the tubes within a few hundredths of a milligram, since they quickly came to constancy in the balance case and retained their weights unchanged for days at a time.— *Jour. Amer. Chem. Soc.*, xxxi, 212.   H. L. W.

4. *Volumetric Determination of Selenious Acid.*—L. MARINO has devised a method for this purpose which he prefers to those previously in use. The solution of the selenious acid is made slightly alkaline with sodium hydroxide solution, then a specially prepared alkaline permanganate solution is added gradually, until after heating to boiling a strong violet color is permanent for 4 or 5 minutes. After cooling somewhat the liquid is acidified with dilute sulphuric acid, and an oxalic solution is run in until all the manganese dioxide has dissolved. Then, finally, the excess of oxalic acid is titrated with the permanganate solution. The test-analyses given show very satisfactory results. A special method is given for the removal of nitrates in order that this method may be applied.—*Zeitschr. Anorgan. Chem.*, lxv, 32.   H. L. W.

5. *A Contract for Radium.*—It is stated on the authority of the London Times that a contract has recently been entered into between the British Metalliferous Mines (Limited) and Lord Iveagh and Sir Ernest Cassel for the supply of 7½ grams of pure radium bromide at the rate of four pounds per milligram (total about $150,000). The source is pitchblende from the company's mine in Cornwall. This radium bromide is to be presented by Lord Iveagh and Sir Ernest Cassel to the Radium Institute, which will be under the direction of Sir Frederick Treves, for use in the treatment of cancer.— *Chem. News*, xci, 303. H. L. W·

6. *Absolute Measurement of High Pressure with the Amagat Manometer.*—PETER PAUL KOCH and ERNST WAGNER have described in a previous paper a method of measuring accurately high pressures which gave very satisfactory results; but in order to reach a higher degree of exactness they concluded to measure the pressures directly by a height of mercury. The tower of the Laboratory in Munich afforded a height of 25^m, and they describe the arrangement of steel tubes by means of which they contained the mercury. A comparison is given of the results of the Amagat manometer, with the results obtained by direct measures, obtained from the height of the mercury column. A constant of correction is given.—*Ann. der Physik*, 1910, No. 1, pp. 31–50.
                                                         J. T.

7. *A Relation Between Absorption and Phosphorescence.*— The observations of M. G. Lecoq de Boisfaudran and M. G. Urban show that the best known phosphorescent bodies result from a *phosphorogène* in a solvent or diluent. M. L. BRÜNING-HAUS points out a very simple relation between absorption and phosphorescence. The light emanating from the *phosphorogène* molecules situated in the depths of the medium suffer absorption by the superficial layers, and the radiations observed at the surface are only those for which the *phosphorogène* is relatively transparent.— *Comptes Rendus*, Dec. 13, 1909, pp. 1124–1129.
                                                         J. T.

8. *Mass of Moving Electrons.*—The new theories of electrons are concerned with hypotheses of change of mass with velocity.

Abraham supposes electrons unchanged by velocity, while the Lorentz-Einstein theory is based upon the relativity principle. E. HUPKA in his investigation endeavors to decide which theory is the most probable. The article is interesting principally from the view of technic : for the author describes minutely the method by means of which he excited electron streams in high vacua. Although he did not attain to the velocity of the β ray, he succeeded in producing rays of great homogeneity, suitable for measurement. The vacua were produced by liquid air and the use of charcoal, and he used potentials as high as 90,000 volts. The paper contains many tables and plotted charts, giving comparisons of results on the Abraham or solid sphere theory and the Lorentz-Einstein relativity principle. The measurements agree better with the latter theory than with the sphere theory of Abraham.—*Ann. der Physik*, 1910, No. 1, pp. 169–204.

<div align="right">J. T.</div>

9. *Hertz's Photoelectric Effect.*—M. EUGÈNE BLOCH criticizes the conclusion that this effect coincides in greatness with the Volta series, the metals, more photoelectric, being the more electropositive, and believes that the order can be reversed when one passes from one wave length to another.— *Comptes Rendus*, Dec. 13, 1909, p. 1110.

<div align="right">J. T.</div>

10. *Influence of Thunder on Size of Raindrops.*—V. J. LAINE has studied the changes in rainbows which apparently follow peals of thunder. He describes as follows a typical case : Between six o'clock and five o'clock in the evening he observed in the East a rainbow accompanied by a secondary bow. During thunder the colors of both bows trembled to such a degree that the color limits and the edges of the bows were entirely weakened, and one observed very quick vibrations over the entire rainbow. This occurred with each peal of thunder. The change in color Laine attributes to changes in size of raindrops. The size before peals of thunder was under 0.1^{mm}, and during the thunder it increased to 0.5^{mm} and to 1^{mm}. The author attributes the change to the acoustical vibration of the thunder.—*Physikal. Zeitschrift*, Dec. 1, 1909, pp. 965–967.

<div align="right">J. T.</div>

11. *Conduction of Electricity through Gases and Radioactivity ;* by R. K. MCCLUNG. Pp xvi + 245. Philadelphia, 1909. (P. Blakiston's Son & Co.)—This is a "text-book with experiments" designed to introduce college classes to the fascinating and important subjects indicated by the title. There has been so great a development during the past twelve years in our knowledge of the ionization of gases and the properties of the newly discovered radiations that ample material exists for an interesting and instructive course for students. The present book is the first to be written with this end in view, and it seems well adapted to the purpose. The descriptive portions though very concise are fairly satisfactory and many useful directions are given for performing experiments in this field.

<div align="right">H. A. B.</div>

12. *Die Strahlen der positiven Elektrizität ;* von E. Gehrcke. Pp. xi + 124. Leipzig, 1909. (S. Hirzel.)—This is an excellent and timely account of a class of radiations which have of late years come to be of great importance in physics. The rays which consist of positively charged particles include the canal rays discovered many years ago by Goldstein, certain other rays which are observed in ordinary vacuum tubes, the α-rays from radioactive substances and the "anode rays" (recently discovered by Gehrcke and Reichenheim), which are given out by anodes consisting of the salts of various metals. The properties of all these rays and their accompanying phenomena are described in detail, and the book forms a very useful collection of data upon an important subject.   H. A. B.

II. Geology and Natural History.

1. *United States Geological Survey, Thirtieth Annual Report, 1908–1909, of the Director,* George O. Smith. Pp. 128, with two plates.—This report contains a statement of the work done by the various divisions of the Survey during the fiscal year ending June 30, 1909. Besides the progress in geologic investigations and topographic mapping, for which the Survey was initially organized, the special lines of work which Congress has delegated to it are worthy of note. The classification of public lands has been carried forward with great activity, resulting in a proper valuation of land according to the use for which it is most valuable. As a consequence the government is deriving a revenue from the sale or lease of said lands many times greater than the cost of the surveys. Fraudulent entries are made more difficult and monopolistic control is prevented, but immediate utilization is fostered ; the present system resulting in the greatest good to the nation at large.

The division of mine accidents has been organized within the year, studies have been carried on in Europe and in this country and already large results begin to show toward the prevention of the destruction of both human life and mineral resources.

The technologic branch by its investigations of materials used in government contracts has, during the year, guarded the expenditure of tens of millions of dollars and saved millons to the government.

Because these additions to the work of the Survey are so immediately important and popularly recognized as of great value, conscious effort should be maintained to prevent their encroachment upon the equally valuable purely scientific work upon which such developments ultimately rest. That Congress does not fully appreciate this broader view is shown by the fact that the Survey was only granted $100,000 for stream measurements, whereas $250,000 was appropriated for testing fuels. For topo-

graphic surveys $300,000 was appropriated, for geologic surveys $200,000, as during the previous year. The entire appropiation for the year was $1,590,680.
<div align="right">J. B.</div>

2. *Fifth Biennial Report. State Geological Survey of North Dakota ;* A. G. Leonard, State Geologist. Pp. 278, plates xxx. Bismarck, North Dakota.—The purposes of the reports of the survey are educational in the teaching of physical geography and elementary geology, and developmental of the economic resources of the state. In this volume, besides the administrative report, there are papers on the geology of southwestern North Dakota with special reference to the coal, by A. G. Leonard ; the geology of northeastern North Dakota with special reference to cement materials, by John G. Barry and V. J. Melsted ; the geological history of North Dakota, by A. G. Leonard ; the Bottineau gas field, by John G. Barry, and a paper on good roads and road materials, by W. H. Clark. The papers in general meet well the purposes for which they are planned and the survey by such a report demonstrates its value to the state. The paper on the geological history of North Dakota could, however, have been improved in a number of particulars.

It was prepared for the use of schools and the general reader, yet there is no statement in it of the fundamental conception that geologic time embraces tens of millions of years. Yet without such discussion the general reader is apt to preserve the inherited notion that time is antediluvian and postdiluvian and the whole embraced in some thousands of years. This, however, is a minor point in comparison with definite errors retained from an earlier period in geology. For example, it is sweepingly stated that "granites are examples of Archean rocks." Whereas they are now known to occur as massive intrusive rocks of any age up to middle Tertiary. Further, it is stated "that the oldest part of the continent, that which was the first to be raised above the sea, was a U-shaped land mass, the two arms of the U enclosing Hudson Bay. At the beginning of the Paleozoic Era by far the greater part of our continent, with the exception of the above land, was beneath the sea." This statement may be compared with Walcott's well-founded conclusions, published in 1891, that the area of the pre-Cambrian Algonkian continent was larger than at any succeeding period until the Mesozoic, and that the Cambrian sea did not begin to invade the great interior continental area until late Middle Cambrian time. It is true that these and other important conceptions have not been properly emphasized in many text-books, but that cannot be regarded as good reason for their further perpetuation. Their importance in geologic theory is, furthermore, such as to warrant calling attention to their occurrence in this report. The idea, however, of publishing in state reports popular expositions of geologic structure and history, as is here done, is a most valuable one from the educational point of view, and one which state surveys have largely neglected.
<div align="right">J. B.</div>

3. *The Figure of the Earth and Isostasy from Measurements in the United States ;* by JOHN F. HAYFORD, Inspector of Geodetic Work, and Chief, Computing Division Coast and Geodetic Survey. Pp. 178, plates and figures 17. Washington, 1909.— This report is one of great interest to geodesists and geologists, for though the principal conclusions have been previously published by Hayford, this is the first appearance of the complete work. The author points out that earlier computations upon the elements of the spheroid have regarded the deflections of the vertical as accidental errors, an assumption which is evidently untrue. By considering them as due to the known irregularities in topography largely counterbalanced by the unknown irregularities in subsurface densities, a solution is reached giving the character of the latter, and by thus allowing for constant errors attaining more correct and larger values for the dimensions of the spheroid. By assuming in the solution the existence of certain deficiencies of mass underlying elevated tracts, the weight of the new determination of the terrestrial dimensions becomes 1·7 times that derived otherwise. This may be taken as a mathematical demonstration of isostacy. Hayford furthermore finds that isostatic adjustment is so nearly complete that the deflections of the vertical average are less than a tenth of what they would be if due to topographic irregularities alone and the stress differences in the crust are not more then one-twentieth what they would be if isostacy did not prevail. Consequently the United States is not maintained in its position above sea level by terrestrial rigidity but is in the main buoyed up, floated, in each of its parts, because it is composed of material of deficient but irregular density. The solution further shows that the flotation is not due to a lighter crust resting upon a fluid and denser substratum and that the isostatic compensation is approximately satisfied within a hundred miles of the surface. This report brings forth the results of a monumental labor and its author and the organization which he represents are to be congratulated upon its completion. The results will be most interesting if gravity determinations are now made in order to throw further light upon the variations in subsurface densities extending to the depth at which isostatic compensation becomes complete.

The reviewer would point out that the conclusion, that the various physiographic provinces are now so closely compensated that the unbalanced stresses in the earth are not more than a twentieth as great as they would be if isostatic adjustment did not prevail, is seemingly at variance with the geological evidence that the crust is able to remain unwarped during long periods of time, permitting the wide development of base-leveled surfaces. The reconciliation of these two well-founded conclusions of modern geology is one of the larger problems awaiting solution in the future. Although, as Willis has suggested, the present epoch may be one of unusually complete isostatic adjustment, how comes it that if so complete at present, at other times the crust could for so long have resisted the stresses due to widespread erosion ? J. B.

4. *Geological Survey, Cape of Good Hope;* by A. W. ROGERS, Director; 13th Annual Report, Cape Town, 1908.— The 1908 Report of the Geological Commission contains the following papers: (1) Report on the Geology of parts of Prieska, Hay, Britstown, Carnarvon and Victoria West, by A. W. Rogers and A. L. du Toit; pp. 9–109, figs. 13; (2) The kimberlite and allied pipes and fissures in Prieska, Britstown, Victoria West and Carnavon, by A. L. du Toit; pp. 111–127, 3 figs.; (3) Notes on a journey to Knysna, by A. W. Rogers; pp. 129–134, 1 plan.; (4) The Tygerberg anticline in Prince Albert, by A. W. Rogers; pp. 135–139. Field work in Prieska and adjoining regions included a study of areas previously mapped, with the result that errors were found to have been made in the determination of structural and stratigraphic relations. This present report, therefore, replaces in large part the report for 1899. (This Journal, xiii, 413.) New occurrences of Dwyka beds are described and petrographic studies have been made of a number of igneous and metamorphic rocks including an unusually large variety of granulites, the origin of which is in doubt. An interesting economic feature is the fact that the water supply is found in decomposed dikes of kimberlite, etc., rather than in the shales and other sedimentaries. H. E. G.

5. *The Devonian fauna of the Ouray limestone;* by E. M. KINDLE. Bull. 391, U. S. Geol. Survey, 1909; pp. 60, plates 10.— This Upper Devonic fauna characterized by *Plethorhyncha endlichi* and *Spirifer* cf. *whitneyi* is now known to extend from southern New Mexico to the north line of Colorado. It is composed of 40 species, most of which are restricted to this biota. The strikingly new element is a brachiopod related to *Syringothyris,* for which is here proposed the new generic name *Syringospira.*

The author does well in removing for western faunas the name *Spirifer disjunctus,* but he should have gone a step farther and renamed the so-called *S. whitneyi,* as these Colorado shells are not identical with the typical Iowa individuals. The reviewer has seen the Ouray species also in the Three Forks of Montana and in British Columbia north of the Canadian Pacific Railway. C. S.

6. *Lower Paleozoic Hyolithidæ from Girvan;* by F. R. COWPER REED. Trans. Royal Soc. Edinburgh, 47, 1909; pp. 203–222, pls. 3.—From the Ordovician and Silurian beds of the Girvan district the author describes 10 new species of Hyolithes, 4 Orthotheca, 2 Ceratotheca, and 5 Pterotheca. C. S.

7. *Die asiatischen Fusulinen. Die Fusulinen von Darwas;* von GÜNTER DYHRENFURTH. Palæontographica, Band 56, 1909, pp. 137–176, pls. 13–16.—In this work, which is a continuation of Ernst Schellwien's contemplated Monographie der Fusulinen, are described with great care six forms of Fusulina illustrated by many microphotographs. The geologic occurrence is also fully given. C. S.

8. *Paläozoische Seesterne Deutschlands. I. Die echten Asteriden der rheinischen Grauwacke ;* Friedrich Schöndorf, Palæontographica, 56, 1909, pp. 38–112, pls. 6–11.—Here are described in detail 12 species of Lower Devonic starfishes of the family Xenasteridæ. These are grouped in the genera *Xenaster* (4 species), *Spaniaster* (1), *Agalmaster* n. gen. (3), *Rhenaster* n. gen. (1), *Trimeraster* n. gen. (1), *Eifelaster* n. gen. (1), and *Asterias.* The drawings are somewhat diagrammatic but illustrate the characters far better than would photographs.

In all the genera the ambulacrals are directly opposite one another and do not alternate. The ambulacrals and adambulacrals are also opposite each other. The mouth opening is bounded by 5 pairs of mouth plates and 5 pairs of slightly modified ambulacrals. No ocular plates are preserved, according to the author; the reviewer has seen none in these old starfishes before the time of the Lower Cariboniferous.   c. s.

9. *La Vallée de Binn* (*Valais*). *Étude géographique, géologique, minéralogique et pittoresque ;* par Léon Desbuissons. Pp. viii, 324 ; 51 illustrations, etc. Lausanne, 1909 (G. Bridel & Co.).—This is a popular work on a mineralogical locality which occupies a unique position in the interest of the occurrence and the almost inexhaustible variety of new and rare species which it has afforded. These facts are briefly summarized here, and many illustrations give an admirable idea of the scenery of the valley.

10. *Catalogue of the Fossil Bryozoa in the Department of Geology, British Museum of Natural History.* The Cretaceous Bryozoa, Volume II ; by J. W. Gregory. Pp. xlviii, 346, 9 plates, 75 figures.—The first volume of this catalogue was published in 1899 and the appearance of the present volume has been delayed in consequence of the retirement of the author from the staff of the British Museum. In the years which have intervened a large amount of material has been added to the collections of the Museum, so that the whole work has been expanded and when complete will embrace a third concluding volume. It is expected that this will be shortly prepared by Mr. W. D. Lang, who succeeded Dr. Gregory as Assistant in charge of this section of the Museum.

11. *A Hand-List of the Genera and Species of Birds* [*Nomenclator Avium tum Fossilium tum Viventium*] ; by R. Bowdler Sharpe. Volume V. Pp. xx, 694.—This volume of the British Museum Handlist of Birds deserves to be especially noted, since it completes a large and most important labor begun in 1898. The author and those who have worked with him deserve the congratulations of zoologists for what they have done in this way to advance the study of ornithology.

12. *Physiologische Pflanzen-Anatomie ;* von Dr. G. Haberlandt. Pp. xviii, 650. Vierte Auflage. Leipzig, 1909 (Wilhelm Engelmann).—This is the fourth and enlarged revision of a very important work. A quarter of a century has passed since Professor Haberlandt, then as now at Graz, published the first

edition. The treatise was recognized from the outset as opening up fresh fields of research on the borders between three allied departments of Botany. The relations which exist between form, function, and origin are sometimes exceedingly obscure, and this obscurity was deepened in many instances by the neglect of some gross morphologists to investigate the minute anatomy of the organs in question. To Schwendener and Haberlandt is due a large part of the credit for stimulating observers to enter upon this middle ground in the right way. The present volume by Haberlandt is in many respects a great improvement upon the previous editions, since it enters more boldly upon the field of œcology and brings up some of the very attractive questions in the domain of what we may term applied physiology. It is truly surprising to notice the small number of changes in the statement of facts which the author has been compelled to make in the period of twenty-five years. The extreme caution which characterized the early edition has borne good fruit in the later ones, since there have been practically no mistakes to recall. The treatise in its enlarged form is of great value to morphologists, anatomists, and œcologists, and, in a general way, to systematists, as well.

The publisher has wisely reprinted as a separate, the pages devoted to the irritable organs of plants, since the subject of sensitiveness is attracting at the present time a good deal of attention. A few physiologists will not agree with some of Haberlandt's conclusions, but even they must admit his fairness and clearness.   G. L. G.

III. Miscellaneous Scientific Intelligence.

1. *Report of the Secretary of the Smithsonian Institution,* Dr. Charles D. Walcott, *for the year ending June 30, 1909.* Pp. 95.—The annual report of the Secretary of the Smithsonian Institution for the year ending June, 1909, has recently appeared. It gives the usual interesting summary in regard to the activity of the Institution in its varied functions. Dr. Walcott draws attention to the fact that in the estimates for the present year there is an increase of $10,000 for the Bureau of Ethnology, to be used in connection with researches among the tribes of the Middle West and also in Hawaii and Samoa. A larger appropriation is also called for to carry on the work of the Astrophysical Observatory, for the Zoological Park, and particularly for the new building of the National Museum, which is now nearing completion. In regard to the latter it is stated that the entire stone work of the outer walls is completed, as also the roofs and skylights, and much progress has been made in the interior, that it was expected that some of the halls and work-rooms would be ready for use early in the autumn (1909). The International Tuberculosis Congress, in the autumn of 1908, utilized

for its meetings and exhibitions a large part of the first and second floors. A full statement in regard to the National Museum as a whole is given by Dr. Rathbun in the volume noted below.

A brief summary is given of the first accessions to the Museum from the Roosevelt expedition in Africa. The results have been even more important than anticipated, including many excellent specimens, particularly of the skins of the larger mammals. Special funds were provided by friends of the Institution to pay for the outfit and expenses of the naturalists who accompanied Col. Roosevelt, while his own expenses, with those of his son, have been met by himself. Mr. W. W. McMillan of Juja farm near Nairobi, East Africa, has presented an exceptionally fine collection of living African animals.

Of other scientific work carried out under the auspices of the Institution may be mentioned the continued explorations by the Secretary, Dr. Walcott, in Montana and the Canadian Rockies, having as their object the study of Cambrian geology and paleontology. Professor J. P. Iddings is now carrying on researches on a Smithsonian grant in Japan, Eastern China, and Java. Miss Alice Eastwood, also as the result of a grant, has re-collected the botanical species from the region of Santa Barbara secured by Thomas Nuttall in 1836. Under the Hodgkins fund several investigations have been prosecuted. The statements in regard to the Library, the Gallery of Art, the Zoological Park, etc., are all interesting, but cannot be summarized here. As usual, Mr. C. G. Abbott, director of the Astrophysical Observatory, gives a summary of the work carried on under his direction at Washington, at Mt. Wilson, and on Mt. Whitney.

2. *Annual Report of the Board of Regents of the Smithsonian Institution, showing the Operations, Expenditures, and Condition of the Institution for the Year ending June 30, 1908.* Pp. x, 801, with 23 plates, 25 figures, and 4 charts.—The Secretary's Report, which forms the opening portion of this volume, was noticed a year since (see vol. xxvii, p. 196). The general Appendix (pp. 113–801) contains as usual a large series of papers on scientific subjects, covering many lines of scientific activity and discovery. No more well-selected and useful presentation of recent scientific memoirs, in a form to interest the intelligent public, can be found in a single volume. The opening paper is devoted to aeronautics and is profusely illustrated; aviation in France and wireless telephony follows, then phototelegraphy, and the gramophone; while on the Natural History side we find reproduced (from this Journal, xxv, 169) the important paper by Dr. Lull on the Evolution of the Elephant, with another on Angler Fishes by Dr. Gill. The volume closes with several biographical papers.

Recent publications from the Smithsonian Institution are noted in the following list:

Report on the Progress and Condition of the U. S. National Museum for the year ending June 30, 1909. Pp. 141.—This is a full and very interesting account of the Museum, its buildings,

collections, and library, by Dr. RICHARD RATHBUN, Assistant Secretary of the Smithsonian Institution.

The National Gallery of Art : Department of Fine Arts of the National Museum ; by RICHARD RATHBUN. Pp. 140, 26 plates.— Dr. Rathbun has given here a full history of the development of the department of Fine Arts in the National Museum, begun in 1840. The bequest of Mrs. Harriet Lane Johnston in 1903 and the gift of Mr. Charles L. Freer of Detroit have given the National Gallery a notable position in the country ; a suitable building for its preservation must be provided later. The concluding chapter of this volume gives a preliminary catalogue of the collection with numerous reproductions of important pictures.

Bureau of American Ethnology, Bulletin 38. Unwritten Literature of Hawaii. The Sacred Songs of the Hula ; collected and translated, with notes and an account of the Hula ; by NATHANIEL B. EMERSON. Pp. 288, 24 plates, 3 figures.

Bulletin 39. Tlingit Myths and Texts ; recorded by JOHN R. SWANTON. Pp. viii, 451.

Bulletin 41. Antiquities of the Mesa Verde National Park : Spruce-Tree House ; by JESSE WALTER FEWKES. Pp. 57, 21 plates, 37 figures. Washington, 1909.

Bulletin 42. Tuberculosis among certain Indian Tribes of the United States ; by ALES HRDLICKA. Pp. vii, 48, 22 plates.

3. *National Antarctic Expedition, 1901–1904. Magnetic Observations.* Prepared under the Superintendence of the Royal Society. Pp. vii, 274 ; 13 figures, and 43 plates, map and sketches. London, 1909.—The earlier volumes containing the records of the Antarctic Expedition of 1901–1904, under Captain R. F. Scott, R. N., have already been noticed in this Journal (xxvi, 588 ; xxvii, 271) ; that on Physical Observations included a report on a portion of the magnetic work. The present volume completes this subject, giving detailed tables of hourly values of the magnetic elements with an exhaustive discussion of the same. Dr. Charles Chree of the Kew Observatory has taken an important part in the elaboration of the observations.

Among the special topics discussed may be mentioned a comparison of Antarctic disturbances and the aurora, and also an examination of disturbances simultaneous in the Antarctic and Arctic, from October, 1902, to March, 1903, by Prof. Kr. Birkeland. The sketch map which forms the frontispiece shows a portion of the coast of South Victoria land with the winter quarters of the " Discovery " on Ross Island. On it are noted the positions of the south magnetic pole as given by three successive recent expeditions. The close agreement between these, the distance varying from a maximum of about 80 miles to a minimum of about 40 miles, is particularly noteworthy. The latitude and longitude of these three positions are as follows :

Position found by the				Lat.	Long.
Position found by the		" Southern Cross,"		72° 40′ S	152° 30′ E
"	"	"	" " Discovery,"	72° 51′	156° 25′
"	"	"	Lieut. Shackleton,	72° 25′	155° 16′

4. *The Evolution of Worlds;* by PERCIVAL LOWELL. Pp. xiii, 262. New York (The Macmillan Co.).—This book is a revised edition of lectures delivered in February and March, 1909, before the Massachusetts Institute of Technology, in which institution the author is non-resident professor of astronomy. The lectures present the most recent facts and speculations regarding the past and future of the Solar system, illumined by the play of the author's active imagination and colored by an astonishing vividness of language. We do not remember to have met in any of Dr. Lowell's previous essays any such freedom in the use of English. Some of the theories which he explains are startling, but the language in which they are set forth is much more so. If we all permitted ourselves such liberties with our mother tongue it would speedily descend to a chaos and darkness such as Dr. Lowell predicts for the solar system itself.

We quote at random from the first few pages.

"Unimpressing our senses," "grandiose vicissitudes spectrally revealed," "stars cuticle," "ambidextrous impartiality of space," "The culmination of Coalition"—"the acme of accretion."

But such mishandling of language, though it irritates the reader and mars his enjoyment, does not vitiate the logic or destroy the substance of the book.

The first two chapters, entitled "Birth of a Solar System," and "Evidences of the Initial Catastrophy," will excite most interest. The author considers that the initial stage of our solar system, or rather the beginning of the cycle of change through which it is now passing, was that of a spiral nebula. From this the present order arose and to it in some distant age and region it may again return, to repeat the cycle indefinitely. Such an enormous program, which explains everything but the origin of matter and provides for its eternal activity, satisfies the mind and makes us wishful that it may be true.

Space forbids a discussion of it further than to say that the spiral form in a nebula is held to be due to action from without rather than from within, in fact to a tidal disruption caused by the passage of a large body close to the previously quiescent mass. Thus an old and worn out sun may be torn up within a few days into a meteoric nebula, heated by collisions of its fragments and developing under gravity into a planetary system.

W. B.

5. *Hyperbolic Functions*, prepared by GEORGE F. BECKER and C. E. VAN ORSTRAND. Pp. li, 321. Smithsonian Mathematical Tables, No. 1871. Washington, 1909.—In the systematic study of mathematics hyperbolic functions do not receive the attention which their practical importance as a tool of investigation warrants. Invented or first employed by Mercator in the development of his system of projection, on which to this day all deep sea navigation depends, they have come to play an important part in many branches of applied mathematics. Thus in physics whenever an active entity is extinguished or absorbed (e. g. light, velocity, radio-activity) the decay is represented by some form of

hyperbolic function. Mechanical strains also are most simply expressed in this form. Hence the study of geological deformations always requires the use of these functions; and it is for this reason that the overseers of the U. S. Geological Survey, Messrs. Becker and Van Orstrand, have prepared this most complete and scholarly treatise.

The book has a two-fold value. The tables, eight in number, furnish everything that a worker with hyperbolic functions can need, and they are preceded by an admirable exposition of the theory of hyperbolic function. The subject is developed both from an analytic and independently from a geometrical basis and the relation to elliptic functions is described and also the connection with the geometry of the pseudo sphere. An historical sketch adds greatly to the breadth of view of the subject and fifteen pages are given to formulas which the writers designate as "those most likely to be needed by computers."

This description should make it evident that the book furnishes the most satisfactory treatise on this subject that has hitherto been published. w. b.

6. *Robbins's Plane Trigonometry*; by EDWARD R. ROBBINS. 8vo, pp. xiii, 153. New York (American Book Company).—A book well adapted for the secondary school course. It represents the experience of a mature and careful teacher whose first object is to get the essentials of the subject into the head of the average boy as quickly and firmly as possible. The learner is introduced to the solution of trigometric equations sooner than usual, in fact in the first chapter, but the treatment of identities is postponed until quite late for the reason that the author aims to give his followers strength and courage for the assault of this formidable enemy of the weak trigonometer. The distinction between an identity and an equation, however, is not explicitly stated.

w. b.

7. *Experimental Dairy Bacteriology*; by H. L. RUSSELL and E. G. HASTINGS. 147 pages; illustrated. Boston 1909 (Ginn and Co.).—The purpose of this book is to present an elementary course in general dairy bacteriology. Though brief and somewhat limited in its scope, it is complete in itself. The sources of milk contamination, the biological changes that take place in milk, with methods of identifying milk bacteria, the preservation of milk, butter-making, cheese, and milk as a vehicle of disease, are some of the important topics discussed. A thorough mastery of the book should enable the student to pursue intelligently more advanced work in connection with the problems of dairy bacteriology or dairy manufactures. l. f. r.

8. *Bref och Skirfvelser af och till Carl von Linné*; af TH. M. FRIES. Pp. iv, 342. Stockholm, 1909.—This third part of the first volume of the correspondence of Linnaeus contains letters Nos. 459 to 573; they are arranged alphabetically, according to the names of the recipient or writer, from A to B. This important publication is being carried on under the auspices of the University of Upsala, and the librarian of the University asks that any persons possessing letters of Linnaeus communicate with him on the subject.

Established by **BENJAMIN SILLIMAN** in 1818.

THE

AMERICAN

JOURNAL OF SCIENCE.

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FOURTH SERIES

VOL. XXIX—[WHOLE NUMBER, CLXXIX.]

No. 171—MARCH, 1910.

NEW HAVEN, CONNECTICUT.

1910.

NEW ARRIVALS

BRAZIL. I have just received from this locality an excellent shipment which includes the following specimens : An exceptionally large Tourmaline, green and pink, showing good color and form with its crystal attached to a quartz crystal ; deep green Tourmaline CRYSTALS, gem quality with very steep rhombohedral terminations ; a fine lot of EUCLASE CRYSTALS showing sharp crystal faces and good form ; a number of the new gem PHENACITE CRYSTALS and GROUPS which show better quality for this mineral than has ever before been found, and some excellent AMETHYSTS, deep in color, in good crystal form.

SOUTH CALIFORNIA. From here a new lot of Tourmalines, green and brilliant pink in color; some showing both colors together, others in groups; a fine lot of beautiful TOURMALINE SECTIONS ; and fine TOPAZ CRYSTALS from Ramona, clear, sharp and symmetrical.

HADDAM, CONN. From an old collection which I secured complete I have a fine lot of Tourmalines showing beauty in color and form not to be found elsewhere.

NEW MEXICO. From this place a lot of beautiful BLUE TURQUOISE in the matrix.

Besides these additions I have still on hand a number of AWARUITES, as announced and described in the February issue.

I am still receiving small shipments of Franklin Furnace Minerals, consisting of excellent Rhodonite, Willemite, Franklinite, Zincite specimens, etc.

ICELAND. Some very fine specimens of Iceland Zeolites, including Stilbite, Heulandite, Ptilolite, Quartz geodes, etc., are still in my possession.

AUSTRALIAN MINERALS. I have received a small lot of these which included : Atacamite, Cerussite and precious Opals, both cut and in the rough also a few Tasmania Crocoites ; one very fine, with large crystals.

Prices on application.

Having an exceptionally large lot of common and rare SEMI-PRECIOUS and PRECIOUS Stones, both cut and in the rough, I am in a position to satisfy the wants of all my customers.

I also have a fine collection of Antique CAMEOS, cut in Malachite, Coral, Lava, etc.

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AMERICAN JOURNAL OF SCIENCE

[FOURTH SERIES.]

———◆◆◆———

Art. XIV.—*The Armor of Stegosaurus;* by Richard S.
Lull.

I. Introductory.

The American genus *Stegosaurus*, first made known to
science by Professor Marsh, includes the most bizarre and
grotesque of armored dinosaurs; a group apparently quite
apart from the glyptodon-like Ankylosauridæ with heavy mail
developed over the entire body, for in *Stegosaurus* the striking
armament was confined to certain regions and, so far as our
knowledge goes, but little developed elsewhere.

Stegosaurus, while belonging to the Morrison, the beginning
of the Lower Cretaceous (Lull, this Journal, vol. xxix, p. 15),
was highly specialized and evidently represented a senile race,
and was, as Beecher has shown with other spinescent forms, on
the verge of extinction, for it shortly disappears entirely from
our records.

II. Character of armor.

The known armor of *Stegosaurus* includes five types of
structures, all dermal in origin, of which the first are the small,
rounded ossicles (gular plates) found *in situ* beneath the skull.
These form a continuous, pavement-like investiture protecting
the throat (fig. 1) and doubtless extending over a considerable
portion of the body as well, though not elsewhere preserved,
for it is unreasonable to suppose that an armored reptile would
have any portion of the skin bereft of scutes or scales of some
sort. These throat ossicles increase in size as one goes back-

FIG. 1.
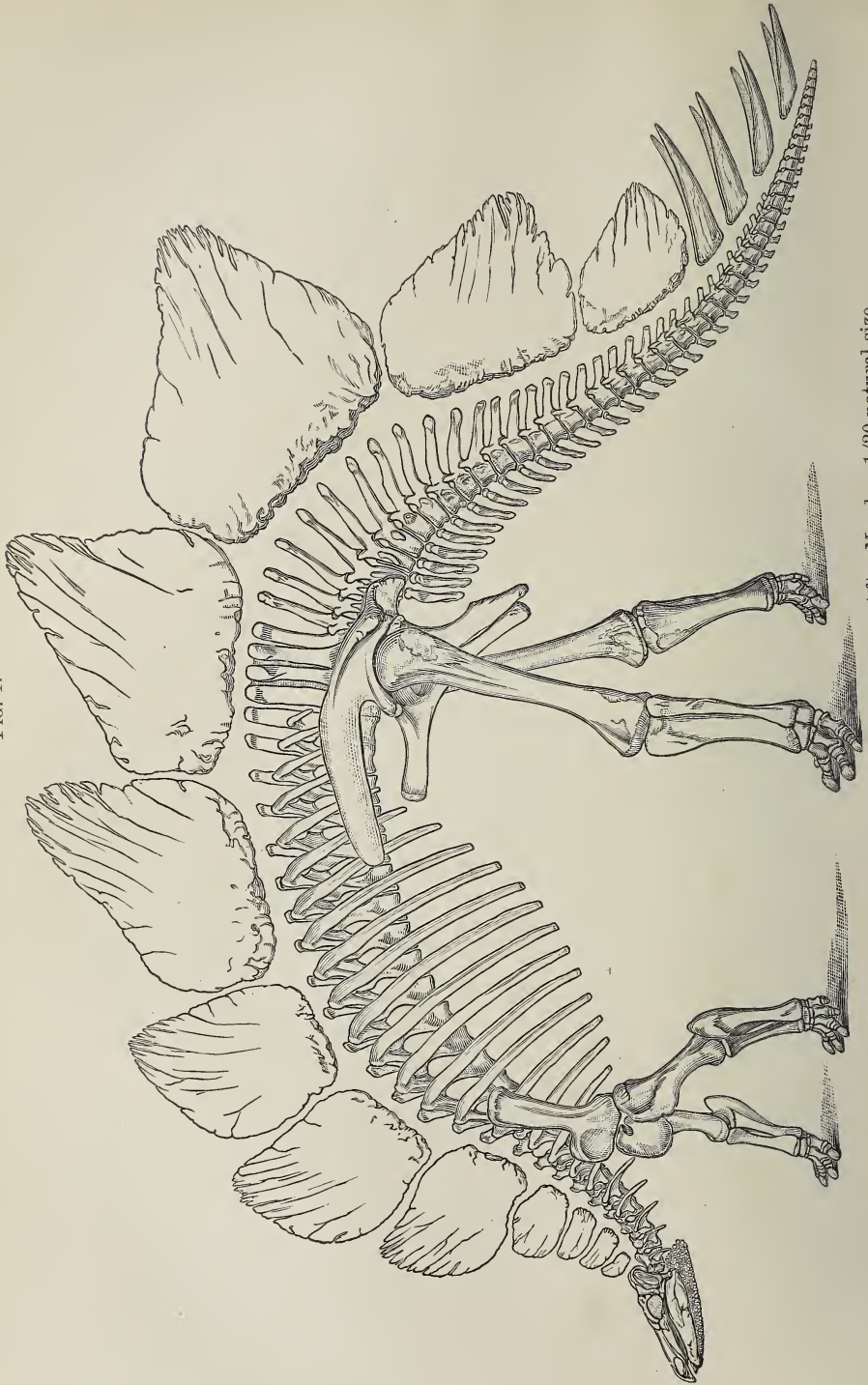
FIG. 1. Restoration of *Stegosaurus ungulatus.* After Marsh. 1/30 natural size.

ward from the apex of the jaw, the largest of them being not
less than 25^{mm} in diameter.

The dorsal armor consists in turn of four distinct shapes, two
apparently defensive and two offensive, with a marked differ-
entiation in form as well as in function. Of these the first
(fig. 2) are more or less oval, with a base divided longitudinally

FIG. 2.
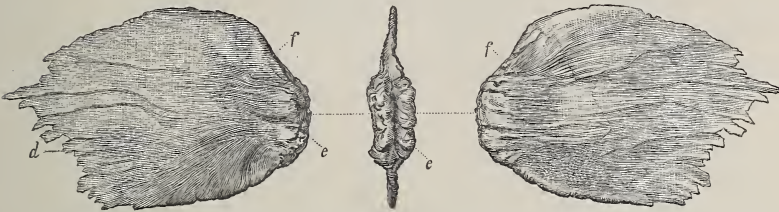
FIG. 2. Cervical plate of *Stegosaurus ungulatus.* After Marsh. 1/12
natural size. *a*, side view ; *b*, inferior view of base ; *c*, opposite side; *d*, thin
margin ; *e*, rugous bases ; *f* and *f¹*, surface marked by vascular grooves.

by a deep cleft so as to be distinctly bifid and of very short fore
and aft extent compared with the expanse of the plate. These
plates show a very rapid increase in size, though the largest of
them in *Stegosaurus ungulatus* is only about half the height
and one-third the antero-posterior diameter of the largest of the
next type. These bifid based plates seem to have been borne
on the neck, the largest oval one here figured (fig. 2) being
near the point of junction between the neck and the trunk.

The second type are the large, thin, rectangular or somewhat
triangular plates with a thick base but without the median
longitudinal cleft. They doubtless stood in pairs along the
trunk region and upon the proximal portion of the tail (fig. 3).

FIG. 3.
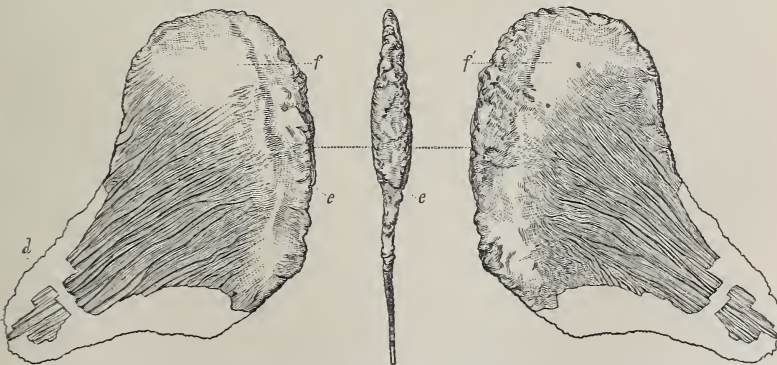
FIG. 3. Dorsal plate of *Stegosaurus ungulatus.* After Marsh. 1/12
natural size. *a*, right side ; *b*, thick basal margin ; *c*, left side ; other letters
as in fig. 2.

Stegosaurus ungulatus as represented by the specimen (Cat. No. 1853) now being mounted at Yale was apparently the best endowed with offensive weapons of any of its relatives, for there are associated with the one skeleton no fewer than four pairs of spines and three odd, sharp-edged, spine-like plates, one of which is so much larger than the other two that it seems to imply that at least one intervening size is missing.

The spine-like plates are characterized by a very oblique, flat base, by sharp edges fore and aft and, like the others, by the impression of blood-vessels over the side expanse (fig. 4). In
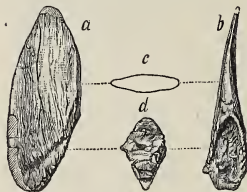
FIG. 4.   FIG. 5.
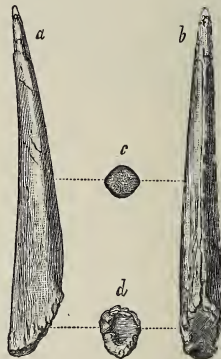
FIG. 4. Caudal spine-plate of *Stegosaurus ungulatus.* After Marsh. 1/12 natural size. *a*, side view; *b*, posterior view; *c*, section; *d*, inferior view of base.

FIG. 5. Caudal spine of *Stegosaurus ungulatus.* After Marsh. 1/12 natural size. *a*, side view; *b*, dorsal view; *c*, section; *d*, inferior view of base.

common with the dorsal plates they give evidence of having been deeply imbedded in the integument and underlying connective tissue, but, unlike the latter, they show a better surface for the attachment of muscles to give rigidity to their position.

Of the caudal spines (fig. 5) the anterior ones are the larger and more deeply embedded, being lodged in a thicker portion of the tail, and in common with all of the plates give evidence of having been ensheathed with a close-fitting integument, probably of a horny character as in the modern horned toads (*Phrynosoma*) and in *Moloch horridus.*

III. Morphology of the plates.

Upon comparing a given plate with a scute of a crocodile, or that of such a dinosaur as *Ankylosaurus* or *Stegopelta*, it at once becomes apparent that the great expanse of the first represents merely an enormous hypertrophy of the median ridge

or carina of the latter. This expanse is practically alike on both sides, with blood-vessel impressions and no indication that either one side or the other was in contact with the creature's

Fig. 6.

Fig. 6. Dermal plate of *Ankylosaurus.* Figured by Marsh as that of *Triceratops* and showing the median carina. 1/8 natural size.

flesh. On the other hand, the base, the morphological equivalent of the body of the scute in crocodile or Ankylosaur, is always somewhat asymmetrical even when divided into two portions by the longitudinal cleft of those of the cervical region. This base in the great dorsal plates particularly is extremely rugous, implying either a heavy pad of cartilage or a very thick connective tissue between the plate and its underlying skeletal support. There is in no instance any indication of a true articulation with the subjacent bones.

IV. Position of the Armor.

The position of the armor plates has given rise to an animated discussion as to whether they were in one row or two, opposite or alternating, erect or procumbent. The evidence seems to point to a double row of paired, erect plates, though toward the end of the tail the aggressive series evidently stood out at a decided angle from the perpendicular. It is quite possible that they were provided with an erectile musculature to give them greater rigidity especially in time of use, as is the case with the nasal horn of the rhinoceros. This seems to have been particularly true of the tail.

Professor Marsh (this Journal, xxxiv, 1887, p. 415), who first described and figured the dermal armor of *Stegosaurus*, says : "The upper portion of the neck, back of the skull, was protected by plates *arranged in pairs* [italics mine] on either side. These plates increased in size farther back and thus the trunk was shielded from injury. From the pelvic region backward, a series of huge plates stood upright along the median line, gradually diminishing in size to about the middle of the tail."

In his restoration of *Stegosaurus* (fig. 1), first published in 1891, however, Marsh places the entire series of plates in a single row along the mid-line of neck, back, and tail, although the caudal spines are represented as paired.

Evidence for pairing of the entire series is shown in two specimens preserved in the U. S. National Museum, in one of which the plates alone are represented while in the other they are actually in association with the underlying bones. These plates if placed consecutively would measure twice the length of the neck and back, the proportion being 16 to 8 feet. This evidence, together with the fact that each individual plate as shown above is in itself not symmetrical, indicates that the plates were not median but lateral structures and were arranged in at least two rows.

The first restoration showing the plates in two rows is given in a drawing made by Charles R. Knight under the direction of F. A. Lucas and published by the latter first in his book "Animals of the Past," New York, 1901, fig. 24, and again in the Smithsonian Report for 1901, plate IV. Later, under Mr. Lucas's direction, a model was made by Mr. Knight in which the number of caudal spines was reduced to two pairs and the plates were placed in such a way as to alternate along the back. The reasons given for this arrangement were two-fold : first, that the plates did actually alternate as they lay embedded in the rock, and second, that no two of them were precisely similar in exact shape or dimensions. Against the argument that no known reptile has alternating dermal elements was urged the apparent fact that this did not render it an impossibility in *Stegosaurus*. It seems to me, however, that the position of the plates in the rock is hardly conclusive, for the series of one side might easily have shifted forward or backward slightly during maceration or in the subsequent movement of the rocks, as an oblique crushing of fossil bones is a very familiar phenomenon.

The slight disparity of size and shape in the two plates of a pair is not surprising when one considers that the entire hypertrophy of the plate is in a sense abnormal and is comparable to the growth of the antlers of deer of which those borne by an individual are rarely if ever precisely similar in size, weight, form, or even in number of points. I should consider a *precise matching* of the stegosaur plates remarkable rather than the reverse. The fact that in no other reptile the lateral dermal elements alternate seems too weighty an argument to be lightly dismissed.

The evidence in favor of an erect rather than a procumbent or imbricating position is the morphology of the plate itself, as described above, and the fact that in the crocodile and gavial one can witness the actual hypertrophy of the median keel in the two rows of scutes, which finally merge into one along the mid-dorsal line of the distal half of the tail. The elevation of the keel becomes more and more pronounced beginning with

Fig. 7.
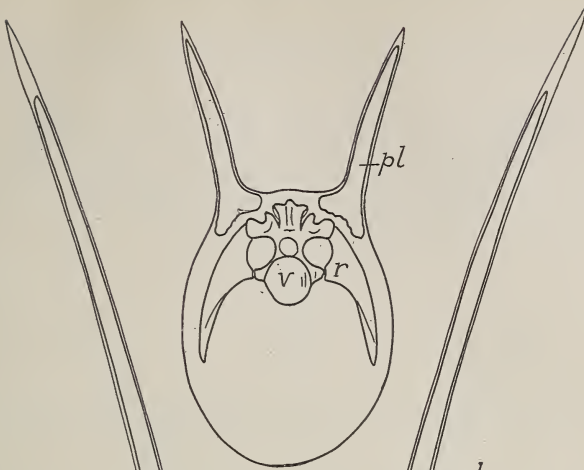
Fig. 8
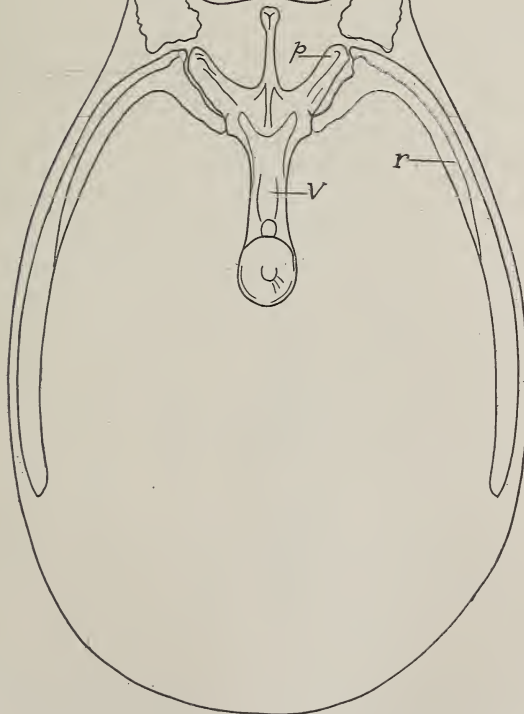
FIG. 7. Section of neck of *Stegosaurus ungulatus*. *pl*, plate; *r*, rib; *v*, vertebrum.

FIG. 8. Section of the trunk of *Stegosaurus ungulatus*. *p*, transverse process; other letters as in fig. 7.

the second quarter of the tail, reaching its maximum where the two rows merge into one and finally dwindling again toward the tip.

In the specimen of *Stegosaurus stenops*, No. 4934 of the National Museum, the last three plates, those over the sacral region, lie as though they had fallen to the right, the anterior ones to the left, a thing manifestly impossible in plates naturally procumbent on either side.

Fig. 9.
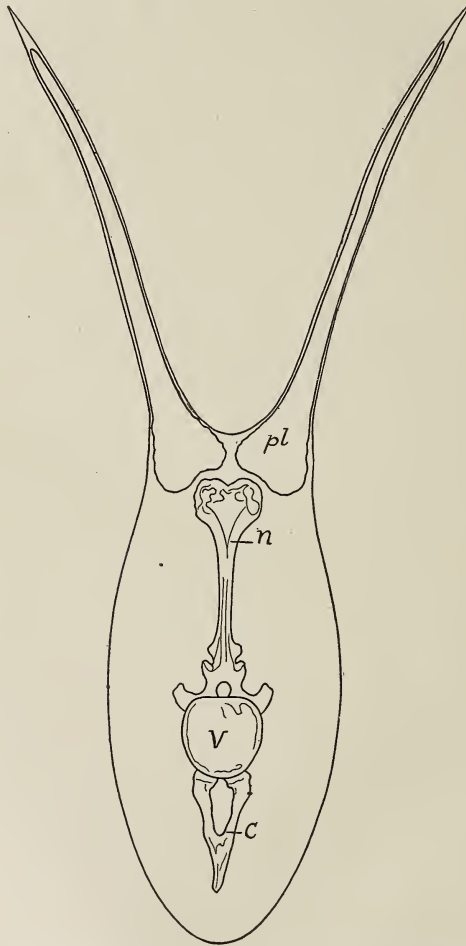
FIG. 9.　Section of the proximal part of the tail of *Stegosaurus ungulatus*. *c*, chevron ; *n*, neural process; other letters as in fig. 7.

Fig. 10.
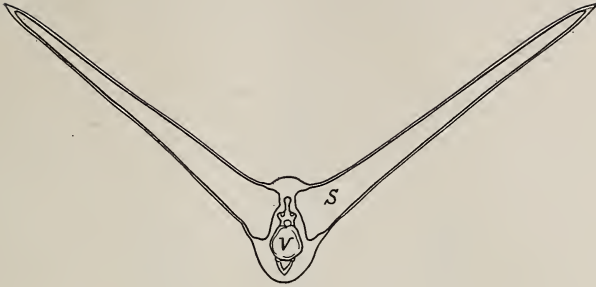
Fig. 10. Section of the distal portion of the tail through the spines. *s*, caudal spine ; other letters as in fig. 7.

The four sections of *Stegosaurus* which I present will show the relationship of the plates to the underlying skeletal elements. The first section (fig. 7), that through the neck, shows the plates with bifid base astride the transverse process of the vertebra, and the second, that through the trunk (fig. 8), the immense broad-based plates borne over the transverse process and ribs. A beautiful mechanical device is shown in that the transverse process is triangular and the rib T-shaped in cross section in the armor-bearing region, giving the maximum of strength, a wide bearing surface and a minimum expenditure of material. The significance of the great elevation of the transverse process is also apparent.

In the sacral and anterior caudal region the bases of the two rows of plates are approximated, and now the summit of the neural process broadens out to support their weight, as indicated in the third section (fig. 9). This broad-topped type of neural process ceases with the proximal third of the tail and indicates the beginning of the flexible aggressive weapon of offense bearing the sharp-edged spine-plates and caudal spines which are inserted obliquely into the muscular mass on either side in the angle formed between the neural process and the centrum (fig. 10).

Some of the larger spines, notably that described by Marsh as the type of *Stegosaurus sulcatus,* have the base divided by an asymmetrically placed longitudinal ridge (fig. 11) into two facets which seem to have borne against the neural process and centrum of the vertebra. This character is only present in very large spines which have a deep insertion into the underlying tissues. Ordinarily the insertion seems to be too shallow to give rise to the facets.

Owen has figured what he calls the "carpal spine" in *Dacentrus (Omosaurus) hastiger* from the Kimmeridgian of Wiltshire (Mon. Brit. Fos. Repts. pl. 77), which shows precisely

Fig. 11.
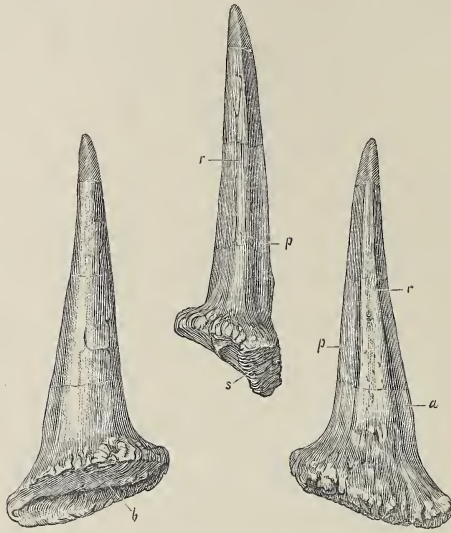
Fɪɢ. 11.   Caudal spine of *Stegosaurus sulcatus.*   After Marsh.   1/12 natural size.   Dorsal, anterior and ventral aspects.   *b,* the base showing longitudinal ridge.

this same structure of the base as in *Stegosaurus sulcatus. Dacentrus* is the probable Old World ancestor of *Stegosaurus,* but while the caudal spines are known, the presence of the armor plates has not as yet been demonstrated.

Art. XV.—*Times of Fall of Meteorites;* by O. C. Farrington.

The times of fall of meteorites may be studied with reference to the year, month, day and hour. The yearly falls should give evidence as to the frequency of the occurrence and exhibit periods if any occur. The falls by months should show the relation of meteorites to well-established star showers and the portion of the earth's orbit where meteorites are most frequently encountered. The falls by days should exhibit periodicity if any exists and variation in the uniformity of supply. Finally, the hours of fall should give the direction of movement of meteorites. Since new falls occur yearly, data for study of these points are obviously constantly on the increase. It is desirable, however, to make comparisons at intervals in order that any changes may be discerned. At the present time the admirable catalogues of Wülfing* and others afford excellent means for the collection of such data. From these catalogues, with such additions and corrections as could be made from other sources, the writer has obtained record of 350 well authenticated meteorite falls of which the year and month are known, 327 of which the day is known, and 268 of which the time of day is known. In this number it has been sought not to include finds referred by residents of a locality to meteors which they had seen a year or more before, since the residents of most localities can, on the occasion of a meteorite find, recall a large meteor seen in that locality at some previous time. To connect this, however, without further reason with the meteorite found seems an unreliable method of procedure.

Considering the falls by years, it is well known that previous to the nineteenth century little reliable record of meteorite falls is available. Single falls are known for the years 1492, 1668, 1715, 1723, 1751, 1766, 1773, 1785, 1787, 1790, 1794, 1795 and 1796, and two falls each for the years 1753, 1768 and 1798. Also for the early part of the nineteenth century the record is not very complete, since during that period the possibility of meteorite falls was yet much doubted. However, the record may as well begin with 1800. From that year to the present, 331 falls may be accepted as well authenticated as to their month and year. During this period eleven years show no falls whatever. These years are—1800, 1801, 1809, 1816, 1817, 1832, 1839, 1888, 1906, 1908, and 1909. Of these the years of the present decade will probably have falls to their

* Die Meteoriten in Sammlungen, Tubingen, 1897.

credit after a time, since the record of falls usually lags several years behind their occurrence. The largest number of falls shown in any year during the period is 11, in 1868. The years 1865, 1877 and 1886 show 7 each. All the other years show from 1 to 6 falls each. On the whole, therefore, the record seems to indicate a comparatively uniform supply of meteorites, which is the more remarkable when one considers the various chances affecting the observation of their fall. The record seems to afford no evidence of cycles or periodicity which can be traced with certainty. Still the record of years is perhaps not as satisfactory for establishing conclusions in this regard as is that of other periods. As the writer has shown else-where,* at least 900 meteorites probably reach the earth yearly. Of these only an average number of 3 is recorded, so that it is evident that a large allowance must be made for unrecorded ones. Yet it is fair to presume that those recorded are typical of the whole, because while opportunities for observation of meteorite falls have probably continually increased in number since 1800, the record by decades shows that the decade from 1860 to 1870 considerably exceeded in number of falls either of the two succeeding ones.

Passing from the falls by years, the falls by months may be examined. Such an examination should have an especial sig-nificance in showing the relations which meteorites may have to well-known star showers. Two of the best known of these showers occur in August and November. If meteorites are related to these, these months should show a larger fall than others. If meteorites are not related to these, no special increase for these months should be shown. On compiling the results the latter proves to be true. The months exhibiting the greatest number of falls are May and June. The number for November falls below the average and that for August rises only slightly above. The evidence from this record is therefore that meteorites are not related to the best known star showers. It is fair to presume that the record by months will be somewhat influenced by the time that observers are most abroad. Most of the observations of meteorite falls are made in the northern hemisphere and in this hemisphere observers are more likely to be out of doors and hence more likely to observe the fall of meteorites in the summer than in the winter months. The record shows that as a whole the number of falls recorded *is* less for the winter than the summer months, yet the number of falls cannot be influenced by that alone since the high record for May and June drops to nearly half that number in July. Further the months of August, September and October are

* Pop. Sci. Mon. 1904, pp. 351–354.

Fig. 1. Falls of meteorites by months.

equally favorable as regards weather for observations of meteorite falls with those of April, May and June, yet the latter period much excels the former in number of falls. The excess of falls in May and June must, therefore, be due to other causes than favorable conditions of observation and seems to indicate that in the portion of the earth's orbit passed through in these months there is an unusual number of meteorites. The full record for the different months is as follows:

Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
25	24	22	32	44	45	23	36	30	24	24	21 = 350

This record is shown graphically in the accompanying diagram, fig. 1.

Comparison of the falls of meteorites by months as here given with those of falling stars and fireballs as given by W. H. Pickering[*] shows a marked difference of distribution. According to Pickering's list the falling stars and fireballs are much more uniformly distributed through the year than are meteorites, and the period of greatest number is from July to November. In May and June their number is at its minimum. Hence the record seems to show a difference in character between meteors and meteorites and furnishes *per se* a ground for questioning the gradation that has been supposed to exist between meteors and meteorites.

[*] Popular Astronomy, No. 165.

Tabulation of meteorite falls by days of the year seems to show little of significance. The largest number of falls for any one day is five on October 13, and this is a month when the total number of falls is not large. Four days of the year show four falls each and 158, or nearly half the total number, no falls at all. The days without falls seem to be scattered indiscriminately through the year, without marked grouping or arrangement. The days showing falls aside from those mentioned have from one to three falls each without any marked grouping that is apparent. Such a record seems also to indicate that to refer a meteorite falling on the day of a star shower to such a shower is unsafe, especially if the observations are not sufficient to assign the two to the same radiant. Meteorite falls are so distributed throughout the year that the two occurrences might easily be coincident without being otherwise related.

Of all times of fall of meteorites the most satisfactory for study are probably the hours of fall, since the ratio of number of falls to number of hours is larger than to days, months or years. As is well known, the hours of fall show the direction of movement of meteorites, since (with a few minor possible obvious exceptions) meteorites falling from noon to midnight, or afternoon falls, must be moving in the same direction as the earth; while those falling between midnight and noon are moving in a direction opposite to that of the earth or else at a speed so slow that they are overtaken by it. While the hour of fall is not known of as many meteorites as is the year and month, yet of 268 sufficiently satisfactory records are available. Of these 268 falls 180 occurred in the time from noon to midnight, and 88 from midnight to noon. Meteorites, therefore, in the proportion of at least two to one, have direct motion and overtake the earth. Of the others it is probable that the majority have retrograde motion, since observations indicate that but few, comparatively, are traveling at so slow a speed as to be overtaken by the earth. As in the case of the months and the years, it is quite likely that here also considerable allowance should be made for conditions of observation. It is reasonable to expect that the number of falls recorded in the early morning hours would be less than that for other times, since mankind is generally asleep then. That some such allowance must be made is indicated by the records, for the number of falls from midnight to 6 a.m. is only 21, while from 6 a.m. to noon it is 67; from noon to 6 p.m. 122, and from 6 p.m. to midnight 58. Hence it seems probable that some of the diminution in the number of falls is due to lack of observers, although Newton* concluded from studies of the orbits of the morning falls that the lack of observers had little to do with their scarcity.

*This Journal (3), xxxvi, p. 10, 1888.

During the other periods of the day, however, the figures should be little affected by conditions of observation and there seems much reason for reaching the conclusion that the majority of meteorites have direct motion and travel at a velocity greater than that of the earth, or 18 miles per second. Here again meteorites differ from meteors, since the larger number of meteors fall in the morning hours. In times of fall by months, days and hours, therefore, the majority of meteorites differ from meteors. Their position in space, orbits and direction of movement must, therefore, differ correspondingly also.

Field Museum of Natural History,
    December 15, 1909.

Art. XVI.—*Note on the Occurrence of Astrophyllite in the Granite at Quincy, Mass.;* by L. V. Pirsson.

The interesting note of Professor Warren on the finding of a pegmatitic facies of the alkalic granite of Quincy,[*] and of the minerals it contains, recalls to the writer that he has recently noticed in a specimen of this rock the mineral astrophyllite. The occurrence is entirely a microscopic one and the crystals are too minute to be detected and tested megascopically, but as the real home of this rare and peculiar species, as shown in the few places in which it has so far been found— Langesund fiord, South Norway; southern Greenland, and St. Peter's Dome, Colorado—is in the pegmatites of the alkalic rocks, it seems worth while to call attention to the occurrence in order that it may be placed on record, and that attention may be directed to the Quincy pegmatites in the hope of finding it in megascopic crystals. This is more especially necessary since from its dark or brownish color and excellent micaceous cleavage it is apt to be mistaken for biotite and overlooked. A chemical test for titanium will, however, serve to distinguish it readily from ordinary biotite and zinnwaldite, while lepidomelane, which might be expected in such associations of minerals, rarely contains more than a trace of this element. In this connection it might be stated that the writer has not observed any of the dark micas in the study of a considerable number of sections of the Quincy rock, although White[†] mentions it as occurring at times in minute flakes.

[*] This Journal, vol. xxviii, p. 449, Nov. 1909.
[†] T. G. White, Petrography of the Boston Basin, Proc. Bost. Soc. Nat. Hist., vol. xxviii, No. 6, p. 131, 1897.

The astrophyllite was found in a rock of the usual Quincy type consisting of riebeckite, aegirite, microperthite and quartz, with zircon as the most common accessory mineral. It is in minute, elongated laths grouped into bunches and associated with the riebeckite. It was also observed intergrown with the riebeckite in such a way that the axis of elongation parallel to the cleavage was parallel with the vertical axis of the riebeckite; hence in section it appears as if wedged in between the hornblende cleavages. It was noticed that the riebeckite in this case had on its margin with the feldspar what the writer has drawn and figured as the interdented texture,[*] indicative of crystallization from eutectic conditions.

The astrophyllite was found to have the following properties: cleavage, excellent micaceous, and accepting this cleavage as the pinacoid b (010) the direction of elongation of the crystals is on the c axis and the directions of elasticity are $a = c$; $b = a$ and $c = b$; strongly pleochroic, a, red-orange, c, lemon-yellow; absorption $a > c$; refractive index > 1.7; extinction parallel to the cleavage cracks; birefringence high > 0.04. In convergent light a single biaxial optic axis was obtained on the edge of the field; the limited number of crystals and their nearly parallel orientation did not permit of further investigation of the optic scheme.

These are the properties of astrophyllite and definitely determine it; from the micas, which it resembles in thin section, it is easily distinguished by the much higher relief, the reversal of the absorption scheme referred to the cleavage and the wide optic angle indicated.

There is yet much to be learned concerning this interesting mineral, whose formula is still uncertain, but which Brögger[†] believes to be $\overset{I}{R}_4\overset{II}{R}_4Ti(SiO_4)_4$ in which $\overset{I}{R} = H$, Na, K and $\overset{II}{R} = Fe$, Mn, and a new occurrence well investigated might be expected to throw much light upon its composition.

Sheffield Scientific School of Yale University,
　New Haven, Conn., Nov. 1909.

[*] Contributions to the Geology of New Hampshire. No. III, On Red Hill, Moultonboro; this Journal, vol. xxiii, p. 273, 1907.
[†] Zeitschr. für Kryst., xvi, p. 212, 1890.

Art. XVII.—*The Crystallization of a Basaltic Magma from the Standpoint of Physical Chemistry ;* by Clarence N. Fenner.

Introduction.

Within the last few years petrographers have recognized the important aid which might be rendered to the interpretation of the structure and history of igneous and metamorphic rocks by an application of the principles of physical chemistry. The discoveries which have been made regarding the laws governing the crystallization of solutions, the application of the phase-rule of Gibbs and of the law of mass-action, and the new conception of the phenomena of solid solutions, are believed to be capable of rendering very great assistance in interpreting the meaning of the structures with which petrographers have become familiar.

Although the applicability of these principles is generally conceded, very little has yet been done in applying them to specific cases.

In making a study of certain peculiar phases of the basalt which forms the Watchung Mountains in New Jersey, it came to be recognized that the rather unusual conditions which had attended its solidification had produced results which illustrated certain laws of the crystallization of solutions more perfectly than could be hoped for from the most elaborately devised laboratory experiments.

In a previous article[*] the author has shown that the Watchung sheets were surface flows poured out over areas in which Triassic shales and sandstones were accumulating under conditions of continental sedimentation in structural valleys.[†] At most points the basalts present the dense, holocrystalline texture normal to this type of rock, but in certain areas the flows appear to have spread over the sites of shallow lakes, and

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[*] Features Indicative of Physiographic Conditions Prevailing at the Time of the Trap Extrusions in New Jersey. Journ. of Geol., vol. xv, No. 4, May-June, 1908.

[†] See also J. V. Lewis, Annual Report N. J. State Geol. Survey for 1906.

many modifications of structure resulted. The chief effect, as regards the features which will be considered in this paper, was that the fused magma was rapidly chilled and rendered viscous. In places the stiffening liquid accumulated in masses of rounded or bowlder-like forms similar to the "pahoehoe" of Hawaiian flows. The progress of crystallization was checked at various stages and the bowlder-forms were crusted with basaltic glass, in which examination with the microscope shows few phenocrysts, while the more slowly cooling interiors of the bowlders assumed the normal texture. Between the two types transitions occur, by which one may trace the passage of the microlites of the vitrophyrs into the well-developed crystals of normal basalt.

The glass-encrusted bowlders are especially well developed in an area lying between Paterson and Montclair Heights. Quarries have been opened at several points, as it has been found that this variety of trap is easily blasted and crushed for road-material. It has therefore been possible to obtain material for petrographic study unacted upon by weathering.

Scope of the Article.

Two principal features of the Watchung basalt will be considered, and in accordance with this the article is divided into two parts. Part I will deal with the order of crystallization of the constituent minerals, and it will be shown that, contrary to certain prevalent ideas regarding the order of succession of the minerals of a basaltic rock, the three constituents, plagioclase, diopside, and magnetite, began to appear almost simultaneously from the magma and continued to crystallize side by side until complete solidification was attained. In order to show that this result is demanded by the laws of crystallizing solutions, a very brief outline of these laws will be given as a preliminary to the petrographic study.

In Part II resorption-phenomena will be considered in connection with the resorption of olivine, a minor feature as regards the constitution of the rock, but very significant in its interpretation.

The law of mass-action will be considered in this connection, and the author will endeavor to show that the usual explanation of resorption is inadequate to explain certain phases of the phenomenon, but that a very satisfactory explanation may be derived from an application of van't Hoff's law.

Part I.

Process of Crystallization as demanded by the Laws governing Eutectiferous Solutions.

In order that the crystallization of a magma may proceed strictly along the lines indicated by eutectic laws, it is essential that

there shall be little or no reaction going on within the magmatic solution from the time that the initial crystals appear until the process of solidification is complete. In such cases the progress of solidification is very regular. Each compound present in the fusion has its temperature of solidification depressed according to the number of mols (gram-molecules) of other substances present and begins to appear at the appropriate point in the process of cooling. That mineral will first appear which, under the conditions stated regarding fusing-point, still has the highest temperature of fusion.

The first mineral may be regarded as that which is present in greatest excess over the eutectic ratio. Within a certain range of temperature it alone will be thrown out of solution. At a certain point, however, it will be joined by a second mineral, and these two in turn by a third. The composition of the solution approaches the eutectic ratio by the elimination of those constituents which are in excess. A sudden chill at any stage of the process causes a great increase of viscosity, which acts as a very effectual check to further crystallization. The result is the production of the greatly undercooled liquid of immense viscosity which is termed a glass. The composition of the glass depends upon the stage of progress toward the attainment of the eutectic ratio which has been reached. If no such interruption occurs, at the eutectic point the group of minerals forming the eutectic will crystallize out in the proper ratio. No further depression of the temperature of solidification can occur, and the loss of heat will be merely that due to the latent heat of fusion given up by each mineral in passing from the liquid to the crystalline phase. An application of the phase-rule of Gibbs confirms this conclusion, for at the eutectic point the number of phases exceeds the number of components by one, and no change of temperature or composition of the system can occur.

It is doubtful whether the solidification of a magma is ever quite such a simple process as is expressed in the form described, but though complications may ensue, the underlying principles of eutectics hold and should constitute a guide of great value in interpreting rock structures and history. In the solidification of the Watchung magma the reactions which would tend to obscure the process were of such nature that their results do not offer great obstacles. The only one of moment is that by which olivine was crystallized out and later was resorbed by the magma and did not again appear. This phenomenon will require explanation, but it is due to other physico-chemical laws, and the reaction was so nearly complete before the three final constituents, diopside, plagioclase, and magnetite, began to appear, that its effects may be disregarded for the present.

Petrographic Description of the Watchung Basalt.

In those portions of the Watchung flow in which chilling was most rapid the surfaces of the pahoehoe-like bosses were crusted with much glassy material. Apparently, however, judging from the study of a great number of slides, crystallization was under way and phenocrysts had begun to appear in the mass of flowing lava before the sudden chill occurred which stiffened it into a glass. The resultant glass shows a typical vitrophyric texture. The well-developed phenocrysts are surrounded by isotropic glass or by a groundmass in which glassy material is more or less mixed with the feathery forms of microlites. Under the generally accepted hypothesis, in a typical diabase consisting of magnetite, plagioclase, and diopside, the magnetite would be first to form, and its elimination from the magma would be complete before the plagioclase began to appear. These two are held to be followed by the third constituent, diopside, which occupies the space left by the other two. On the other hand, the manner in which the minerals should crystallize out, as demanded by the principles of eutectiferous solutions, is quite different, and in every case the sections examined conform to the latter requirements. No matter to what degree glass may be present in the slide, plagioclase and diopside appear side by side. It is evident that almost from the beginning of crystallization these two constituents were being eliminated simultaneously. At times it appears that the diopside is in somewhat preponderant amount, and at other times the plagioclase.

With regard to the magnetite the evidence is more obscure. The proportion of magnetite in the magma is not large and it seems to appear first as a dark dust. The exact point at which elimination from the fusion began is not clear, but it is certain that growth of magnetite grains continued while diopside and plagioclase were still forming.

Slide No. 105 shows a typical development of glass and phenocrysts. (See fig. 1.)

Probably three-fourths of the section is isotropic glass, uniformly pale green or light olive-green in the thin section. Scattered throughout are numerous phenocrysts of plagioclase and diopside. The plagioclase is in typical lath-like crystals reaching an ordinary maximum of $0.2 - 0.3^{mm}$ long by $.05^{mm}$ wide. The diopside is developed in more nearly equidimensional forms of a characteristically stouter appearance. An exceptionally large crystal measured 0.6 by 0.2^{mm}. The outline is sometimes octagonal, but in general irregular. In many cases the plagioclase and diopside are closely associated, small clusters of mutually intergrown individuals lying in groups surrounded by glass. It is noticeable in such cases

that while the plagioclase laths are indented by the diopside crystals, the characteristic elongated form of the plagioclase is maintained.

These phenocrysts of diopside and plagioclase are bordered by dark plumose growths, or hair-like tufts, fading out at the

Fig. 1.

Fig. 1.   Typical structure of the vitrophyric phase resulting from quick chill.   (Slide No. 105.)   Elongated crystals plagioclase, stouter forms diopside, matrix light-green glass, perfectly isotropic.   Actual diameter of field 1·5^{mm}.

periphery into the surrounding glass.   Under the high-power objective they are resolved into innumerable microcrystalline growths, straight or curved, sometimes branching in lattice-like forms, thrown out from the boundaries of the phenocrysts. With the high magnification they exhibit the development sketched in fig. 2.

Fig. 2.
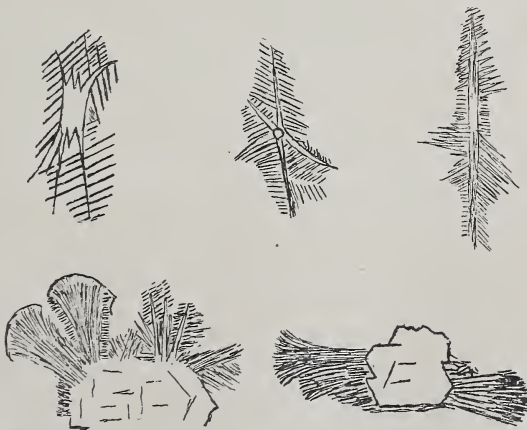
Fig. 2.   Microlitic growth of plagioclase and diopside, greatly magnified.

The phenocrysts were probably formed during rather slow cooling in the flowing mass of lava, and the bordering microlitic growths represent the continuation of the crystallization during the initial stages of chilling, before increasing viscosity put a stop to the process. Their brown color seems best explained by the separation of magnetite dust at the same time that diopside and plagioclase were crystallized out. If this is true, the eutectic ratio had been reached, and if normal crystallization had been followed the continuation of the process would have taken the form of simultaneous growth of crystals of diopside, plagioclase, and magnetite. This was prevented by the increasing viscosity of the liquid, with which crystallization could not keep pace.

The almost simultaneous appearance of diopside and plagioclase at the initiation of crystallization, attended or followed after only a short interval by magnetite, would appear to demonstrate that the composition of the magma as erupted did not differ greatly from that required to form a eutectic of the three.

The only other feature of interest in the slide is the presence of a number of olivine crystals, which have been strongly attacked and resorbed by the magma. This phenomenon will be taken up later.

Slide No. 1 is almost a duplicate of No. 105 and exhibits the same set of phenomena, except that there is no evidence of olivine grains, and that the glassy groundmass shows with high magnification abundant brown dust. Diopside phenocrysts are a very minor constituent but plagioclase is abundant.

In No. 57 the chilling was apparently a little less sudden, for the phenocrysts have a tendency to blend with the plumose microlitic borders and a smaller proportion of the slide is occupied by strictly undifferentiated glass.

Slides 30, 85, and 90 are other examples showing essentially the same relations of phenocrysts, microlites, and undifferentiated glass. In No. 132 (fig. 3), the microlites are seen to be spreading over a greater portion of the field, and in No. 2 a further stage is shown.

This latter slide was taken from the same hand specimen as No. 1, but whereas the portion of the rock from which No. 1 was taken presented a decidedly vitreous appearance, that from which No. 2 was prepared was a little farther removed from the chilled crust and was of a felsitic character. Microscopic examination confirms the deduction which would naturally be drawn. In No. 1 the phenocrysts are merely bordered by plumose microlites and a large part of the section is undifferentiated glass. In No. 2 the microlites have spread over the entire field not occupied by the phenocrysts and no glass can

be perceived. Instead there is a beautiful development of tufts and sheaves of feathery microlites occupying the entire groundmass. The phenocrysts, as before, show groups of diopside and plagioclase in mutual intergrowth. The general dark brown color of the groundmass appears to be due to dust

Fig. 3. Fig. 4.

Fig. 3. Microlitic additions to phenocrysts of diopside and plagioclase. (Slide No. 132.) Diameter of field $1·5^{mm}$.

Fig. 4. Intermediate texture between microlitic and holocrystalline. (Slide No. 58.) Diameter of field $1·5^{mm}$.

and grains of magnetite developed along the lines of growth of the feathery microlites and outlining their form.

In slides No. 96 and No. 58 (fig. 4) a step in advance is shown toward the holocrystalline texture of a normal basalt resulting from moderately slow cooling. The sharply defined outline of the phenocrysts has been lost and their borders fray out into the finely crystalline groundmass. The groundmass itself is coarser than in the earlier described sections and the subhedral crystals are comparable in size to the phenocrysts. Some of the magnetite is in distinct grains, but much of it is still in the form of a dark dust lying between the lighter minerals.

Nos. 98, 99, and 18 (Photograph, fig. 5) show successively coarser phases of crystallization, and Nos. 23, 24, and 25 show the normally developed texture of these basalts. Nos. 47 and 64 represent the maximum of coarseness of crystallization attained.

In the normally crystallized basalt the essential constituents are plagioclase, pyroxene (diopside), and magnetite, the first two in crystalline forms, the last in dust, granules, or trellis-like groups. (See fig. 6.)

The plagioclase is in lath-shaped crystals, euhedral to subhedral, generally showing two or three stripes of albite-twinning lamellæ. Pericline twinning is rarely present. Its average

dimensions are ·15 by ·03ᵐᵐ, but occasionally crystals of larger size up to 1ᵐᵐ in length, and more nearly equidimensional, are scattered through the mass. It comprises, roughly speaking, two-fifths of the whole.

Fig. 5.
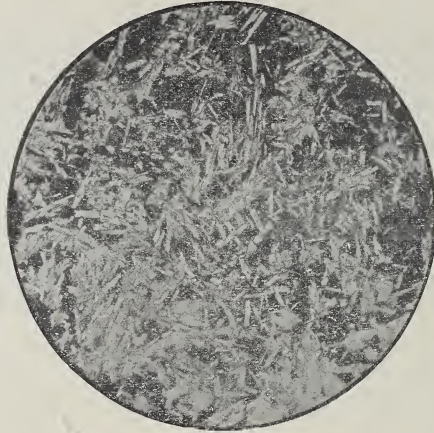
Fig. 5. Photograph of normally crystallized basalt. (Slide No. 18.) Diameter of field $2\frac{1}{4}$ᵐᵐ.

Fig. 6.

Fig. 6. Ophitic texture of normally crystallized basalt. (Slide No. 47.) Plagioclase laths, diopside granules, and crystals and dust of magnetite in mutual intergrowth. The magnetite is mostly included in the diopside, but partly also in the plagioclase. Diameter of field 1·5ᵐᵐ.

Extinction angles measured on symmetrically extinguishing albite twins give maxima of 33–34 degrees. This indicates a medium labradorite of about the composition Ab 40 An 60.

The pyroxene is in stouter forms of an irregularly angular outline. The grains show a tendency to coalesce in groups of

individuals of different extinction. Single units show dimensions of 0·2 by 0·15^{mm} with occasional larger grains up to 0·5^{mm} in size. The crystals are almost colorless, with a faint tinge of brown or green. In many slides twinning is a common characteristic. Twinning and composition plane the orthopinacoid (100). Polysynthetic basal twinning is absent. Optical character biaxial and positive. No difference in dispersion between red and violet can be perceived. Prismatic cleavage often poor in the small grains but well developed in the larger. Birefringence 0·020 − 0·022.

Extinction measured from the ortho-pinacoidal twinning plane to the axis of minimum elasticity, Z, gave angles of 45 degrees. The mineral is evidently not pure diopside, but whether it varies toward hedenbergite or toward augite would be difficult to determine without chemical analysis. It is referred to as diopside. The quantity is somewhat in excess of the plagioclase.

The magnetite is seldom in euhedral crystals, more often in fine dust or in trellis-like or fir-tree groups. During the crystallization of the plagioclase and diopside the magnetite appears to have been mechanically pushed aside until the last stages of crystallization were reached, and then included within the final crystals of the lighter constituents, to which it gives a dark brown color. Even in the final stages the plagioclases seem to have had the power to free themselves of the magnetite dust fairly effectually, and most of it is included within diopside grains. A small portion is enclosed within irregular patches of light-green chloritic material, which may represent resorbed olivines subsequently chloritized.

In addition to these essential constituents there are a number of well-defined areas of what was originally olivine, but which show strong resorption and later alteration to serpentine and chlorite.

The magnetite in these rocks is probably titaniferous, as it gives rise on decomposition to milky-white leucoxene.

In examining those slides which have the texture normal to basalts the plagioclases appear to have the crystals developed in more nearly euhedral forms than the diopside, and it might be argued that this is confirmatory of the generally accepted view that the growth of the plagioclases was finished before that of the diopside began, and that the latter mineral molded itself around the plagioclase. It is only necessary, however, to devote a little study to the question to determine that this is emphatically not the case. In those vitrophyric rocks first described (e. g. No. 105 and No. 57) in which plagioclase and diopside undoubtedly developed while swimming freely in a

liquid, the plagioclase is bounded by plane faces, while the diopside has irregular outlines, and it appears that this difference in development is due to the mode of growth, the cause of which is not germane to the subject. When, in the more glassy types, the plagioclase and diopside form groups of intergrown crystals, as they often do, the characteristic form is shown in fig. 7, a notable feature of which is the manner in which the plagioclase laths wedge out toward the central portion of the diopside grains.

FIG. 7.

FIG. 7.   Intergrowth of diopside and plagioclase.   (Slides Nos. 2 and 57.)

These features are apparent in all phases of development of the basalt from glassy to holocrystalline, and alone would be

FIG. 8.

0·5 m m.

FIG. 8.   Modification of forms of plagioclase and diopside resulting from simultaneous crystallization.   A few magnetite grains (black) and some chlorite (gray) are also present (Slide No. 64).

almost conclusive evidence of simultaneous growth of the two minerals.

In the holocrystalline phases the plagioclase gives, at first, an impression of being much more euhedral than the diopside, but it is almost impossible to find a crystal in which the symmetry is not destroyed by encroachment of diopside, and the extremely irregular growth of plagioclase sketched in fig. 6 (Slide No. 47) and fig. 8 (Slide No. 64) is entirely normal and characteristic.

Fɪɢ. 9.

Fɪɢ. 9   Intergrowth of magnetite, diopside, and plagioclase (eutectic structure—Slide No. 23).

The magnetite is often in such fine grains that no conclusions can be drawn regarding its period of growth, but in No. 23 it is found in better developed crystals, which show unmistakably a simultaneous deposition with plagioclase and diopside.   Fig. 9 shows the general relations.

Part II.

The Crystallization of a Magma as affected by the Law of Mass-Action.

It was pointed out on a preceding page that in order that the crystallization of a magma should follow strictly the laws of eutectiferous solutions the compounds present in the fusion-solution should have no inter-reaction during crystallization, but that simply the freezing-point of each should be depressed by the presence of the others and each should begin to crystallize at the appropriate temperature as thus modified.   In the Watchung magma it appears that this ideal course was nearly realized as regards the final products of crystallization, and in many other cases this is probably true, especially where the range of temperature from the beginning of crystallization until the final consolidation of the eutectic is not large and where great variations of pressure do not occur.   Reference was made, however, to resorbed olivines which appear in certain slides, and resorption-phenomena are of common occurrence in the study of igneous rocks.   Their chief features are explainable by the law of mass-action.

It is well understood that when substances capable of reaction are brought together in a solution the reaction does not ordinarily proceed to completion, but that in principle every reaction is reversible and the degree to which a reaction will proceed under given conditions of temperature and pressure is dependent primarily upon the concentrations or active masses of the substances participating.

In solutions of molten silicates it is recognized that we have very little knowledge of the extent to which reactions proceed to attain equilibrium; but we know that the state of equili-

brium, i. e., the proportions in which various mineral compounds exist in the solution, depends upon the concentrations of the various oxides present.

If we imagine that in a solution of this nature in which equilibrium has been attained, crystallization begins, it is seen that a disturbing factor is introduced; for the removal by crystallization of one or more compounds is constantly changing the relative proportions of the substances left in the mother-liquor. It is evident that certain substances which may have been present in small amount in the original magma may reach a high degree of concentration in the residual dregs of mother-liquor. The conditions of equilibrium are completely shifted. New compounds are formed, while those compounds which were present in preponderant amount in the original magmatic solution may be entirely broken up and destroyed. As a result the crystals first deposited become unstable in contact with the mother-liquor and are either taken up by the solution or react with it to form zones of new minerals. This consequence of the principle of mass-action is well understood. Pirsson has thus explained reaction-rims of enstatite and biotite surrounding olivine crystals and separating them from alkali feldspar in the shonkinite of the Little Belt Mountains, Montana.[*]

While it is possible to account for certain phases of the phenomena of resorption in this manner, there are others which cannot be brought into line with this explanation. Magmas consolidating at depth frequently exhibit a different association of minerals from magmas of the same composition consolidating on the surface; and a magma in which intra-telluric crystallization has begun may, when erupted at the surface, attack the minerals first deposited and take them more or less completely into solution, and in the final consolidation these minerals may not re-appear. In the Watchung magma olivine crystals of the intra-telluric period were attacked and in most cases almost completely resorbed before any notable development of the three final products of surface crystallization appeared. In this case it is obvious that the phenomenon cannot be explained by reference to a concentration of material in a residual mother-liquor. To account for such occurrences the author would offer another explanation, based upon the displacements of equilibrium which take place within a solution under conditions of simultaneous diminution of pressure and temperature.

Displacements of equilibrium within a solution effected by changes of temperature and pressure—van't Hoff's law.—The extension of the law of mass-action to include changes of tem-

[*] L. V. Pirsson: 20th Ann. Rept. U. S. Geol. Sur., 1898–99, p. 482.

perature was developed by van't Hoff. The principle is of great importance, but it does not appear to have received the attention it merits in the study of petrological problems.

The basic principle of van't Hoff's law is that change of temperature displaces the equilibrium within a solution. If, then, crystallization of a magma can be brought about, in one case at a higher and in another case at a lower temperature, the chemical state of the solution as regards compounds existing within it will be different in the two cases. Change of pressure between the depths of the earth and the surface is an effective agent in changing the temperature at which crystallization begins. Pressure alone, as has been pointed out by several writers,[*] is not capable of causing great variations in the melting-points of minerals; but it is quite conceivable, and in fact probable, that within a complex solution the variation of the temperature of crystallization caused by relief of pressure is often attended by displacements of equilibrium, such that reactions proceed further in one direction or another and the relative proportions of the various compounds present is altered. These displacements of equilibrium find corresponding expression in the point at which crystallization is initiated and in the minerals deposited. The change thus begun tends to progress continuously in the same direction and may result at the final consolidation in an association of crystallized products quite different from what would be found under conditions of greater pressure.[†]

[*] A. Harker: The Natural History of Igneous Rocks, New York, 1909, pp. 163 and 194.

[†] The effects of temperature and pressure upon reactions within a system of the nature of a magmatic solution are expressed by two fundamental equations. The first is van't Hoff's formula

$$\log K' - \log K = \frac{q}{R}\left(\frac{1}{T'} - \frac{1}{T}\right)$$

in which K' and K are the constants of mass-action at the (absolute) temperatures T' and T, q is the heat of the reaction per unit considered, and R is the gas-constant ($= 2$ cal.)

From this equation it follows that with decrease of temperature (T greater than T') a reaction which evolves heat (q positive) is driven forward or in that direction in which heat is given out. (It will be noted that this is in accord with Le Chatelier's theorem.)

If, for example, two substances, A and B, unite to form AB with evolution of heat, the formation of the compound AB will increase as the temperature is lowered, and the greater the value of q the greater will be the amount of the compound formed.

The effect of pressure in inducing crystallization at a higher temperature is expressed by the formula

$$\frac{\Delta p}{\Delta T} = \frac{w}{T(v_1 - v_2)}$$

in which Δp is the pressure required to cause crystallization to begin at the temperature increased ΔT degrees above the normal crystallizing point, w is the latent heat of fusion, T is the absolute temperature, and v_1 and v_2 are the specific volumes of the substance in the liquid and solid forms respectively.

Resorption of Olivine in the Watchung Basalt.

In hand specimens, both of the vitreous and the aphanitic varieties of the Watchung basalt, small, dark-green spherulitic bodies can often be seen. They appear in many of the thin sections and are found to be built up of concentric shells of lighter and darker material of chloritic or serpentinous nature. A typical example is shown in slide No. 105 (fig. 10).

The diameter of the spherulite is about 0.2^{mm}, but larger ones are not uncommon. The central portion is composed of

Fig. 10.

Fig. 10. Chloritic nodule in vitrophyr (Slide No. 105).

comparatively large blades of radial chlorite, decidedly birefringent. The outer shells are very feebly polarizing and appear to be made up of minute scales of chlorite mingled with isotropic glass. Beyond the border of the spherulite the normal vitrophyric structure is found, consisting of small crystals and grains of feldspar and diopside and brown microlitic tufts, set in the paste of glass. In this case resorption and alteration have progressed so far that there is almost nothing suggestive of the manner in which the spherulite originated, but in other cases the evidence is plain. Outlines of some original mineral are left, to whose resorption by the magma the spherulites are attributable. None of the mineral itself remains,

Fig. 11.

Fig. 12.

Fig. 11. Partially resorbed olivine, subsequently altered. (Slide No. 105.)
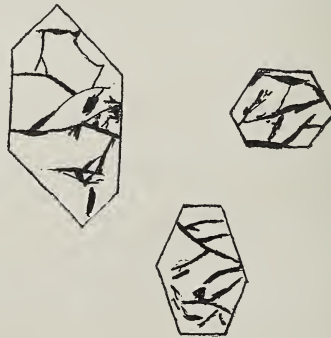
Fig. 12. Separation of oxide of iron along cracks in olivine crystals which have been replaced by secondary products.

the crystal outlines being filled with chlorite, calcite and other alteration products. These retain certain features, however, which point strongly to olivine.

All stages of resorption appear in different parts of this slide. An example is sketched in fig. 11. Without the analyzer the corroded forms shown in heavy lines in the sketch (now replaced by calcite) are all that appear, but with crossed nicols the crystal form, almost complete, is brought out in serpentine. Immediately adjacent are remnants of several other crystals which the crossed nicols similarly outline.

In fig. 12 the typical manner in which oxide of iron has separated along cleavage cracks of the original mineral is shown, although nothing but alteration products survive. The resemblance to olivine is obvious.

From such examples one may pass by gradual transition to the results of almost complete resorption, in which the rounded and blurred outlines convey only a vague suggestion of the original form of the crystal, and upon whose areas, spreading out into the glass, microlites are encroaching. The color in such cases is practically the same as that of the surrounding glass, but crossed nicols show the presence of aggregates of minute chlorite scales.

The stages of the process and the relations which the olivines bear to the plagioclase and diopside are sketched in fig. 13. Similar phenomena are shown in slide No. 83, in No. 30, and in No. 48. In No. 57 the several steps can be followed very perfectly.

Fig. 13.
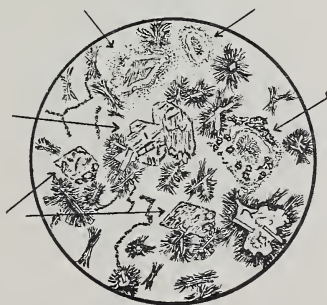
Fig. 13. Breaking-up and resorption of olivine. Several stages, found in various portions of the slide, are brought together. (Slide No. 105.) Diameter of field 1·5^{mm}.

In No. 54 the outline of an original olivine crystal is preserved, but most of the area within the boundary of the original crystal is occupied by a mixture of brown glass and irregular grains of a dark brown color. This form of attack upon the olivine, by which the crystal has been broken up into many fragments, appears to have been common, and the brown grains show up in many of the slides, at times associated

with chloritic areas retaining a suggestion of a crystal unit, and again scattered through the glass.

FIG. 14.
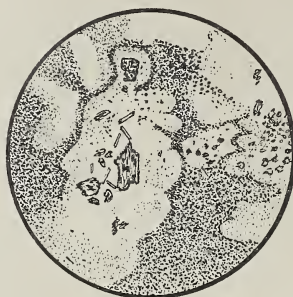
FIG. 14.   Inclusions in glass, resulting from the breaking-up of olivine crystals.   (Slide No. 17.)   Diameter of field 1·5ᵐᵐ.

These effects are shown in slide No. 17, sketched in fig. 14. The greenish glass is filled in places with brownish inclusions, arranged in crescentric or cusp-like figures. The inclusions appear to be in part surviving fragments of olivine, and in part magnetite dust set free in the reaction. The figures

FIG. 15.

FIG. 15.   Effects of resorption of olivine accentuated by secondary alteration.   (Slide No. 54.)   Diameter of field 1·5ᵐᵐ.

assumed would appear to be due to the manner in which the resorbed material was diffusing in the surrounding magma when increasing viscosity terminated the process. Diopside and plagioclase are present in minor amount.

A slight degree of subsequent zeolitic alteration of glasses containing partially resorbed olivines serves to accentuate the features described. This is seen in slide No. 54 (fig. 15) and in many other cases. Even in advanced stages of secondary alteration traces of these features persist.

In all cases the olivine shows unmistakably that corrosion had attacked it and that it was in process of resorption by the magma, from which plagioclase, diopside, and magnetite were beginning to crystallize. At some point in the history of the magma the olivine which was first deposited became unstable and would undoubtedly have gone completely into solution if sufficient time had been allowed. It is noticeable that in the later crystallization olivine did not again appear as one of the products. It must follow, therefore, that the olivine molecule which was absorbed underwent some change within the solution by which it entered into new combinations.

Considered from the standpoint of the principles previously developed, the most probable explanation of the resorption of the olivine appears to be the following: Before extrusion the magma had cooled sufficiently so that crystallization had begun. Inasmuch as most rock-forming minerals occupy less volume in the solid than in the fused condition, the great pressure to which the magma was subjected aided crystallization, so that it was initiated at a somewhat higher temperature than would be the case under less load. The effect upon the crystallization of a given mineral would vary inversely as the heat of solution and directly as the difference in volume between the two states. Pressure may also have had an appreciable effect upon the direction of reaction within the fusion-solution.

Olivine was the chief mineral deposited under these conditions but there are indications that a little plagioclase had also begun to crystallize out. (In slide No. 47 a large plagioclase crystal shows some indication of zonal structure, most probably developed during this period.)

When extrusion of the magma occurred it was attended by great changes in all the physical conditions.

Diminution of load would be a factor of prime importance in causing the minerals which had crystallized out to be resorbed. The loss by volatilization of aqueous and other vapors also affected the combinations existing within the solution. It can hardly be supposed that the vapors evolved existed in the solution entirely in the combinations in which they were given off. Undoubtedly a portion of the vaporized material was combined with the nonvolatile portion and its removal from the system necessitated more or less readjustments of equilibrium throughout.

Under these circumstances it is not surprising that most of the olivine which had been deposited was taken up by the magma. Still if the olivine molecule continued its existence in the re-fused mixture it would be redeposited when the appropriate temperature was reached under the new conditions, but it appears that the lower temperature to which the initiation

of crystallization was carried, together with the other disturbing factors, resulted in an entirely new chemical arrangement. The olivine molecules which were resorbed thereby lost their entity, being distributed among other compounds in a manner which cannot be completely followed, and olivine as such did not reappear among the products of crystallization.

The fact that remnants of the olivine persist is due to lack of time given for resorption before increasing viscosity put an end to the process. Under somewhat different conditions, easily conceived, the less complete resorption of a mineral would be attended by the formation of reaction rims, or replacement by an aggregate of other minerals; or its slow solution in a magma in which crystallization was far advanced would constantly change the composition of the mother-liquor, with consequent displacements of equilibria. In the case studied the resorption or solution was nearly complete before the second period of crystallization began, and the effect as regards complexity of results was almost a minimum.

Petrographic Laboratory,
        Columbia University,
                Nov., 1909.

Art. XVIII.—*Notes on Goethite** (Abstract); by V. Gold-
schmidt (Heidelberg) and A. L. Parsons (Toronto).

In the summer of 1908 Mr. Parsons collected some speci-
mens of goethite which occurs in veins in carboniferous shale
at Walton, N. S. The veins are brecciated and the center
filled with calcite. When the calcite was dissolved in hydro-
chloric acid the goethite was left as a druse of bright crystals.
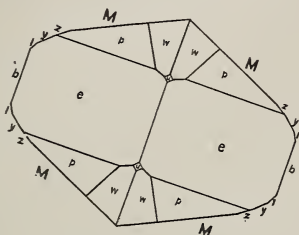
Fig. 1.   Fig. 2.
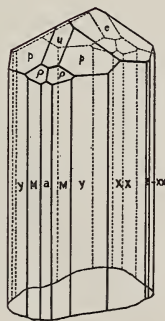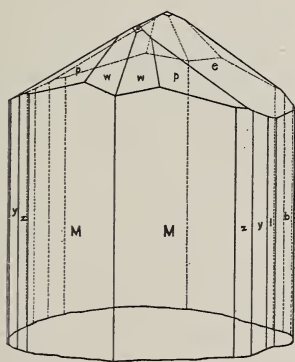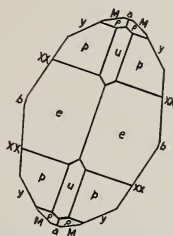
Three crystals were measured. The observed forms are:
$b = 0 \infty (010)$; $M = 2 \infty (210)$; $a = \infty 0 (100)$; $y = \infty (110)$;
$XX = \infty 4 (140)$; $e = 01 (011)$; $u = 10 (101)$; $p = 1 (111)$; $\rho =$
$31(311)$. The form designated as XX appears in all the crys-
tals as the face with the greatest development. This face is
striated lengthwise and is not a single face but a transition

* Abstract of a paper in Groth's Zeitschrift für Krystallographie.

face or " Scheinflaeche," and it gives a bright band of light in the prism zone with the angle ϕ varying from 3° to 20°. In this band are bright points which imperfectly indicate the positions of the faces $\infty 3$ (130), $\infty 4$ (140), $\infty 5$ (150), $\infty 6$ (160), ∞ (180), $\infty 12$ (1·12·0). The harmonic discussion of the characteristic indices in this series gives $\infty 3$, $\infty 4$, $\infty 6$, and $\infty 8$ as the points of best position, but no characteristic letter is assigned to them until they have been determined by single distinct reflecting faces. The symbol XX is used for the series and in figure 2, $\infty 4$ represents the series.

For comparative purposes three crystals from Lostwithiel, Cornwall, were measured and the habit and faces are shown in figure 1. The observed forms are $b = 0\infty$ (010); $M = 2\infty$ (210); $x = \frac{4}{3}\infty$ (430); $y = \infty$ (110); $l = \infty 2$ (120); $u = 10$ (101); $e = 01$ (011); $p = 1$ (111); $w = \frac{4}{3}\frac{1}{3}$ (413). All the forms except x were present on every crystal. The new form $x = \frac{4}{3}\infty$ (430) was present on two crystals and for the best reflections gave angle ϕ 55° 6' and 55° 33'. A poor reflection gave one face as 57° 27'. Angle ρ was in every case 90°. The calculated angles are ϕ 55° 26', $\rho = 90°$. The face is small but well defined, and may be regarded as well established. The form $w = \frac{4}{3}\frac{1}{3}$ (413) is also new and is present on all three crystals with four faces on each. The faces reflect well and give a distinct signal cross, but it is worthy of remark that the reflection is slightly yellow while the others are white. The angles agree well among themselves, but in every case the angle ρ is 20' to 69' less than the calculated angle. The calculated angles are $\phi = 77° 4'$, ρ 42° 6'. Considering the good character of the reflection and the sharpness of the faces, this difference is not easily understood, but the form may be considered as well established.

Heidelberg, Aug. 14, 1909.

ART. XIX.—*On the Velocities of Certain Reactions between Metals and Dissolved Halogens;* by R. G. VAN NAME and GRAHAM EDGAR.

[Contributions from the Kent Chemical Laboratory of Yale Univ.—ccvii]

IN a reaction between a liquid and a solid, according to the so-called diffusion theory of reaction velocity, a thin layer of liquid adhering to the solid remains unaffected by stirring, and the reaction is maintained by the transport of dissolved substances across this layer by diffusion. When the diffusion is sufficiently slow compared with the other stages of the reaction, the velocity of the whole will be determined by the rate of diffusion alone.

This theory was proposed by A. A. Noyes and W. R. Whitney,* in 1897, for the special case of the solution of a solid in a liquid, but Nernst and E. Brunner† were the first to suggest its general applicability to the various types of heterogeneous reactions. It was tested by Brunner for cases of simple solution, neutralization, action of acids on metals, and for several electrolytic processes, and has since been accepted by various other investigators as giving the best explanation of the facts in the case of a number of other types of reactions,‡ including even gas and enzyme reactions.

On the other hand, the validity of the diffusion principle in the case of reactions between metals and acids has been disputed by Ericson-Aurén and Palmaer,§ and R. Marc‖ has shown that the crystallization of supersaturated solutions of certain salts seems to follow a different mathematical relation. Recently the theory has been vigorously attacked by M. Wilderman,¶ who holds that the hypothesis of a diffusion layer is improbable and unnecessary, and shows that the same velocity equation can be derived without it. Furthermore, Wilderman has found that the rate of solution of gypsum is not constant as the theory would require, but varies widely with its physical state, and is different on different surfaces of the same crystal.

The experiments to be described deal with the rate of reaction between dissolved iodine and the metals mercury, copper, silver, cadmium, and zinc, also with those between bromine and mercury, and between cupric bromide and mercury. The work was undertaken with a view to testing the applicability

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* Zeitschr. phys. Chem., xxiii, 689.   † Ibid., xlvii, 52 and 56, 1904.

‡ Senter, ibid., li, 696; Teletew, Dissertation, Heidelberg, 1906; Jablczinsky, Zeitschr. phys. Chem., lxiv, 748: Spear, Jour. Am. Chem. Soc., xxx, 195; Bodensteln and Fink, Zeit. phys. Chem., lx, 1; Schleuderberg, Jour. Phys. Chem., xii, 583.

§ Zeitschr. phys Chem., lvi, 689.   ‖ Ibid., lxi, 385; lxvii, 470.

¶ Ibid., lxvi, 445.

of the diffusion theory, and the results have proved to be in agreement with its requirements in all essential details. A similar field was covered by the work of Schükarew,[*] in 1891, on the reaction velocities between metals and halogens, but the failure to provide for effective and constant stirring renders Schükarew's results uncertain. So far as known to the present writers, a few experiments by Brunner,[†] on the rate of solution of pure electrolytic zinc in iodine, constitute the only real test of the validity of the diffusion principle for a reaction between a halogen and a metal, of which an account has been published up to the present time. Brunner does not give his results in detail but found the theory confirmed, especially in the fact the velocity constant agreed with that for the electrolytic reduction of iodine.

Apparatus and Method.

For all of our experiments the apparatus shown in the figure was employed. The liquid, an aqueous solution of iodine or
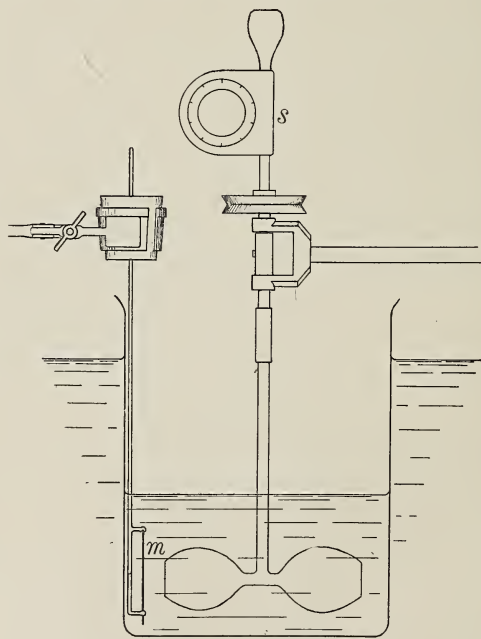
m, metal disk.
s, speed indicator.

bromine with a large excess of the corresponding potassium halide, was contained in an ordinary beaker of about 11.5^{cm}

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[*] Zeitschr. phys. Chem., viii, 76.   [†] Ibid., li, 99.

diameter and $1\frac{1}{4}$ liters capacity supported in a thermostat containing about 50 liters of water. Most of the experiments were conducted at $25° \pm 0·1°$; one, however, at $35°$. In the reaction vessel was a two-bladed glass stirrer of the form illustrated, the blades standing at an angle of about $45°$ to the vertical stem. The latter was attached to a brass shaft running in a bearing rigidly supported above the beaker and terminating in a horizontal pulley. A speed indicator provided with a bell which sounded every 100 revolutions was attached above the pulley and kept permanently in position.

The different metals were taken for experiment in the form of circular disks 40^{mm} in diameter and usually $0·6^{mm}$ in thickness. For the experiments with mercury the disk was of pure gold heavily amalgamated. The holder for the disks was made of a thin glass rod provided at its lower end with three branches bent at right angles to the stem and tipped with an easily fusible glass, which grasped the disk at three points on its circumference. By softening one or more of these tips in the flame the disk was inserted so as to be firmly held with the minimum of contact between glass and metal. The glass stem was mounted in a cork which fitted into a brass socket in the form of a vertically slotted ring held by a stationary support above the beaker, so that the disk with its glass holder could be quickly removed from the apparatus or returned to exactly the same position. When in place the disk was held as shown in the figure, with its plane vertical, opposite the blades of the stirrer and $5–7^{mm}$ distant from the wall of the beaker, so that the liquid circulated freely behind it. Care was taken that the relative position of disk, stirrer, and beaker should be the same in all the experiments. The stirrer was driven by an electric motor of $\frac{1}{8}$ horse power, and the different speeds obtained partly by interposing pulleys of various sizes and partly by adjustment of a rheostat in series with the motor. Variations in the speed of the stirrer were small and for the most part negligible in comparison with the other errors of experiment.

The rate of fall in concentration of the free halogen was determined by removing samples of the liquid with a pipette at definite intervals and titrating. From each two successive titrations the value of the expression $\dfrac{v}{t_2 - t_1} ln \dfrac{c_1}{c_2}$ was calculated and found, as required by the theory, to be practically constant throughout each series; c_1 and c_2 being the concentrations of the halogen at times t_1 and t_2, and v the volume of the solution, which remains constant during the interval in question.

From the point of view of the diffusion theory the mechanism of the reaction is as follows : The weight of bromine or iodine which reaches and reacts with the surface of the metal in the time interval dt is the amount which can diffuse through the adherent layer of liquid in that time, that is, according to Fick's law, it is proportional to the concentration fall across the layer. Owing to the rapidity of the chemical reaction the concentration of the halogen at the surface of the metal is always practically zero. At the outer surface of the layer it is equal to c, the concentration of the main solution. Hence the concentration fall is c, and if m is the total weight of available halogen in the solution,

$$- \frac{dm}{dt} = - \frac{d(cv)}{dt} = Kc,$$

where K is the velocity constant. Integrated for constant volume this gives

$$K = \frac{v}{t_2 - t_1} \, ln \, \frac{c_1}{c_2},$$

the expression referred to above.

To assume that K is proportional to the area of the surface of contact, and to calculate upon this basis its value per unit of surface, is only permissible when the reaction takes place uniformly at every point of the surface. In the following tables this has not been done, since under the conditions of experiment the stirring could not have been equally effective on both sides of the disk.

Finally, it should be mentioned that the above equation, though a necessary consequence of the diffusion hypothesis, is by no means dependent upon it, since it is nothing but an expression of the *a priori* very probable assumption that the reaction velocity is proportional to the concentration of the halogen.

Experiments with Iodine.

The iodine solutions were initially about 0·03–0·045 equivalent normal, and contained in different cases from 100 to 800 grams of potassium iodide per liter (0·6 to 4·8 normal with respect to KI), the larger concentrations of potassium iodide being needed with the metals copper and silver to prevent the formation of a coating of insoluble iodide.

In the experiments with mercury and iodine the procedure was as follows : The gold disk was immersed in clean mercury, a known volume (500–520^{cc}) of the solution was placed in the beaker, and the stirrer adjusted to the required speed, after which a 20^{cc} sample was removed with a pipette and delivered into a glass-stoppered flask for subsequent titration. The disk

was then lifted from the mercury, the excess shaken off, and at a definitely noted time inserted in the liquid. Exactly at the end of the chosen time interval the disk was removed from the solution, rinsed with water and again inserted in the mercury, and another sample of the solution taken for titration as before. This cycle of operations was repeated as often as desired, or

TABLE I.

Rate of Solution of Mercury in Iodine at 25°.

c	Δt	v	K	c	Δt	v	K
1. 100 g. KI per liter. $r=170$				**2.** 100 g. KI per liter. $r=240$			
0·0381	5	500	6·51	0·0378	10	500	8·71
0·0356	6	480	6·30	0·0315	10	480	8·83
0·0328	5·3	460	6·36	0·0260	10	460	8·82
0·0304	5·7	440	6·25	0·0213	10	440	8·79
0·0279	5	420	6·55	0·0172	10	420	8·87
0 0257	5	400	6·59	0·0138	10	400	8·84
0·0236		380		0·0109		380	
		Average	6·43			Average	8·81
3. 200 g. KI per liter. $r=170$				**4.** 200 g. KI per liter. $r=210$			
0·0343	5	510	(6·92)	0·0283	10	510	8·49
0·0319	10	490	7·13	0·0238	10	490	8·64
0·0274	10	470	7·23	0·0198	10	470	8·65
0·0233	10	450	7·26	0·0163	10	450	8·49
0·0197	10	430	7·20	0·0134	7	430	8·45
0·0165		410		0·0116		410	
		Average	7·21			Average	8·54
5. 200 g. KI per liter. $r=240$				**6.** 200 g. KI per liter. $r=300$			
0·0372	10	500	9·55	0·0346	10	520	11·33
0·0305	10	480	9·51	0·0276	10	500	(12·92)
0·0248	10	460	9·73	0·0211	10	480	11·34
0·0199	10	440	9·63	0·0165	10	460	11·31
0·0158	10	420	9·50	0·0127	10	440	10·82
0·0125	10	400	9·38	0·00984	10	420	10·82
0·00973		380		0·00751		400	
		Average	9·55			Average	11·12
7. 400 g. KI per liter. $r=170$				**8.** 400 g. KI per liter. $r=240$			
0·0332	10	·500	7·92	0·0439	10	500	10·78
0·0282	10	480	8·10	0·0350	10	480	10·43
0·0236	10	460	8·02	0·0276	10	460	10·61
0·0197	10	440	8·25	0·0219	10	440	10·52
0·0162	10	420	8·14	0·0171	10	420	10·48
0·0132	10	400	8·39	0·0131	10	400	10·30
0·01057		380		0·0100	14	380	10·23
		Average	8·14	0·00672		360	
						Average	10·48

until the volume had been reduced to 380^{cc}, which was thought to be a safe limit. Under these conditions the mercury goes into solution as the complex ion HgI_4'', and no mercurous salt appears to be formed. The samples were carefully titrated with N/20 sodium thiosulphate, using starch as indicator. The burette used had been certified by the Berlin Reichsanstalt.

In Table I are given the results of the experiments with mercury and iodine. The four columns taken in order contain: 1st, the concentration c, of the iodine in gram atoms per liter[*]: 2d, the time interval Δt (the same as $t_2 - t_1$), in minutes; 3d, the volume v, in cubic centimeters; 4th, the velocity constant, K, as calculated by the equation above. The speed of stirring, in revolutions per minute, is denoted by r. In this and the following tables abnormal values of the constant, indicated by parentheses, have been disregarded in calculating the averages. It may be stated in this connection that the experiments recorded in this article include all that were made with the exception of preliminary experiments and a few affected by known errors.

On comparing the experiments carried out with like rates of stirring it is evident that the velocity of the reaction is greater the higher the concentration of the potassium iodide. This effect of the iodide will be equally conspicuous in the experiments with other metals, and will be discussed later. An increase in the rate of stirring also accelerates the reaction, as was to have been expected, the value of the constant being here approximately proportional to the 4/5 power of r.

To obtain the temperature coefficient of the reaction a single experiment was carried out at 35° with the following result:

$$\textit{Exp. 9.—Mercury and Iodine at 35°.}$$

100 g. KI per liter. $r = 240$
K = (10·75),   11·68   11·35   11·50   11·53   11·59
                                              Average   11·53

The ratio of this constant to that of experiment 2 gives 1·3 as the temperature coefficient for 10°. This is in sharp contrast with the usual value of $\dfrac{K_{t+10°}}{K_t}$ for reactions in homogeneous systems, which is on the average about twice as large.

In the experiments with metals other than mercury the method followed only differed from that just described in that the metal disk, after its insertion into the solution, was allowed to remain in position until the close of the experiment, and the calculations were based upon the time intervals between suc-

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[*] Halogen concentrations are expressed in these units throughout this article.

cessive fillings of the pipette. As the filling process occupied less than five seconds, the time was easily defined with sufficient accuracy.

| TABLE II. | | | | | TABLE III. | | | |
| Copper and Iodine at 25°. | | | | | Silver and Iodine at 25°. | | | |
e	Δt	v	K		c	Δt	v	K
1. 400 g. KI per liter. $r=170$					1. 400 g. KI per liter. $r=180$			
0·0347	10	500	7·71		0·0405	10	500	8·35
0·0295	10	480	8·01		0·0340	10	480	8·49
0·0248	10	460	7·95		0·0283	10	460	8·14
0·0207	10	440	7·81		0·0235	10	440	8·17
0·0172	10	420	8·00		0·0193	10	420	7·88
0·0141		400			0·0159	10	400	8·05
			---		0·01285		380	
		Average	7·90					---
		Corrected	7·95				Average	8·18
							Corrected	8·23
2. 400 g. KI per liter. $r=240$					2. 400 g. KI per liter. $r=240$			
0·0277	10	620	(8·78)		0·0443	10	500	10·17
0·0239	10	600	9·86		0·0358	10	480	10·13
0·0202	10	580	9·78		0·0287	10	460	9·79
0·0169	10	560	9·69		0·0230	10	440	9·65
0·01415	10	540	9·38		0·0183	10	420	9·69
0·01181	10	520	9·53		0·0143	10	400	9·80
0·00976	10	500	9·77		0·0111		380	
0·00796		480						---
			---				Average	9·87
		Average	9·67				Corrected	9·93
		Corrected*	9·98					
3. 800 g. KI per liter. $r=240$								
0·0373	10	500	(9·91)					
0·0304	10	480	10·20					
0·0243	10	460	10·31					
0·0192	10	440	10·15					
0·0151	10	420	10·30					
0·01167	10	400	10·10					
0·00894		380						

		Average	10·21					
		Corrected	10·27					

* The disk was below standard size both in diameter and in thickness.

Table II contains the results obtained with copper. The disks were cut from a good quality of commercial sheet copper of the same diameter (40ᵐᵐ) as the gold mercury disk, but were slightly thinner at the outset, and during the experiment of course became still thinner, though the diminution of surface area from the latter cause was barely appreciable. From measurements made before and after the experiment the aver-

age thickness was estimated, and the necessary small correction calculated and applied to the mean value of the velocity constant. Where "corrected" values of the constant are given in this and the following tables the corrections have been made necessary by slight deviations of this kind from the normal dimensions. In cases where no correction is mentioned the disk was of the standard diameter and thickness.

A relatively high concentration of potassium iodide was found to be necessary in the work with copper. An experiment carried out with a concentration of 200 grams of the iodide per liter was a failure owing to the formation of a layer of insoluble cuprous iodide on the disk, which caused a rapid fall in the value of the constant. Even in the presence of 400 grams of potassium iodide per liter traces of such a film were noticed at the close of the experiment, although, as the table shows, fairly good constants were obtained. With 800 grams per liter no visible film was formed.

With silver the same difficulty was encountered. A concentration of 200 grams per liter of potassium iodide was not enough, and 400 grams per liter barely sufficient, to prevent a decided interference with the reaction by a coating of silver iodide on the metal. The disks were cut from a very pure sheet silver and were a little below the standard thickness, so that a correction had to be applied to the values of the velocity constant as in the case of copper. The results are given in Table III.

For the experiments with cadmium, recorded in Table IV, Kahlbaum's metallic cadmium was employed. This was cast into thick disks which were either rolled out to the proper thinness or ground down with emery. Experiment 1 was made with a disk of rolled metal, experiments 2 and 3 with cast and ground disks. The more crystalline nature of the latter was apparent after the action of the iodine; in fact, these two disks showed more roughening of the surface during the experiment than was the case with any of the other metals investigated. Even here, however, the roughening was comparatively slight, and seems to have affected the value of the constant but little, although experiment 2 shows a rise in the constant which may be due to this cause.

In order that the constants might be comparable with those obtained with mercury, the concentration of the potassium iodide in the work both with cadmium and with zinc was fixed at either 100 or 200 grams per liter, a much larger amount, in view of the ready solubility of the iodides of these two metals, than would otherwise have been needed.

The zinc disks used in the experiments of Table V were prepared by casting and grinding into shape from a sample of

Table IV.

Cadmium and Iodine at 25°.

c	Δt	v	K	c	Δt	v	K
1.　100 g. KI per liter.　r=170				2.　100 g. KI per liter.　r=240.			
0·0364	5	500	6·36	0·0329	5	500	8 57
0·0340	5	480	6·28	0·0301	5	480	8·55
0·0318	5	460	(5·95)	0·0274	5	460	8·60
0·0297	5	440	6·28	0·0249	5	440	8·61
0·0276	5	420	6·27	0·0214	6	420	9·03
0·0255	5	400	6·28	0·0195	6	400	8·77
0·0235		380		0·0170		380	
		Average	6·29			Average	8·69
		Corrected	6·36				

c	Δt	v	K
3.　200 g. KI per liter.　r=240			
0·0387	5	500	9·52
0·0350	5	480	9·56
0·0316	5	460	9·41
0·0283	5	440	9·52
0·0253	5	420	9·60
0·0224	5	400	9·74
0·0197		380	
		Average	9·56

metal of high purity, obtained from Kahlbaum. Experiments carried out in the same manner as those with cadmium and the other metals gave low and rapidly diminishing values of the constant. On examining the disk at the close of such an experiment a whitish semi-transparent film could be seen on its surface which proved to consist of zinc hydroxide, evidently formed by hydrolysis of the zinc iodide.

To obviate this difficulty the iodine solutions were made 1/100 normal with respect to sulphuric acid, after it had been proved by trial that sulphuric acid of this strength had no appreciable effect upon the very pure zinc of the disks. This expedient proved effective and at once gave normal values of the constant.

According to Schükarew,[*] the reaction between zinc and iodine is retarded by the presence of zinc iodide, but no figures are given in support of the statement. As the reaction is non-reversible such an effect would hardly be expected. To test this point, ten grams of zinc iodide, prepared by direct action of the two elements, was added at the outset to the solution in experiment 4, which in other respects was carried out exactly

[*] Zeitschr. phys. Chem., viii, 81.

<div align="center">

TABLE V.

Zinc and Iodine at 25°.

</div>

c	Δt	v	K	c	Δt	v	K
1. 100 g. KI per liter. $r=182$				2. 100 g. KI per liter. $r=240$			
$H_2SO_4=N/100$				$H_2SO_4=N/100$			
0·0339		500		0·0371		500	
0·0316	5	480	6·82	0·0339	5	480	8·59
0·0292	5	460	7·32	0·0309	5	460	8·53
0·0270	5	440	6·78	0 0280	5	440	8·64
0·0249	5	420	6·99	0·0253	5	420	8·50
0·0228	5	400	6·99	0·0227	5	400	8·80
0·0207	5	380	7·27	0·0202	5	380	8·77
			——				——
		Average	7·03			Average	8·64
3. 200 g. KI per liter. $r=240$				4. 200 g. KI per liter. $r=240$			
$H_2SO_4=N/100$				20 g. ZnI_2 per liter.			
0·0390		500		$H_2SO_4=N/100$			
0·0353	5	480	9·58	0·0402		500	
0·0318	5	460	9·71	0·0364	5	480	9·49
0·0285	5	440	9·43	0·0329	5	460	9·40
0·0254	5	420	9·72	0·0296	5	440	9·27
0·0225	5	400	9·77	0·0264	5	420	9·52
0·0198	5	380	9·60	0·0235	5	400	9·55
			——	0·0207	5	380	9·49
		Average	9·64				——
						Average	9·45

like experiment 3, using the same zinc disk, repolished. Unfortunately, through an oversight, the disk was not re-measured for experiment 4, so that the correction for diminished thickness can only be roughly estimated. Allowing for a correction of 0·04–0·08, the constants for experiments 3 and 4 agree to within the possible error of experiment, so that they can not be considered to confirm the observation of Schukarew. Owing to lack of time this point was not further investigated.

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Bromine and Mercury.

</div>

Bromine dissolved in potassium bromide solution of sufficient strength reacts with mercury in much the same way as iodine. Such a solution has, however, a considerable bromine vapor pressure, and to measure the rate of reaction with a metal the evaporation of bromine must either be prevented or a correction must be applied. We have followed the latter method.

If the reaction with the metal is conducted and calculated as in the case of iodine, disregarding the evaporation of bromine, a fairly good constant is nevertheless obtained. The reason for this is obvious. The vapor pressure of the bromine is approximately proportional to its concentration in the solution,

so that the rate of evaporation (for constant volume and constant free surface) must be proportional to the concentration, and will follow a mathematical expression of the same form as that which holds for the reaction with a metal. To correct the observed velocity constants it is therefore only necessary to subtract from them the velocity constants for the evaporation of bromine, as determined by separate blank experiments under like conditions.

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TABLE VI.

Evaporation of Bromine.

</div>

Temperature 25°		400 g. KBr per liter.		$r=240$	
C	C'	Δt min.	v cc.	K''	
1.					
0·02882	0·02767				
0·02418	0·02322	15	500	4·49	
0·02027	0·01946	15	500	4·52	
0·01707	0·01639	15	500	4·37	
0·01434	0·01377	15	500	4·44	
0·01218		15	500	4·09	
				Av.	4·38
2.					
0·03262	0·03117				
0·02669	0·02550	15	450	4·66	
0·02171	0·02074	15	450	4·83	
0·01766	0·01688	15	450	4·82	
0·01406	0·01344	15	450	(5·47)	
0·01145	0·01094	15	450	4·81	
0·009335		15	450	4·75	
				Av.	4·77
3.					
0·03526	0·03350				
0·02764	0·02626	15	400	5·12	
0·02165	0·02057	15	400	5·14	
0·01687	0·01603	15	400	5·27	
0·01333	0·01266	15	400	4·91	
0·01054		15	400	4·88	
				Av.	5·06

In practice the rate of evaporation of the bromine increases as the volume diminishes, owing to the increasing concavity of the surface of the solution caused by the rotary stirrer. The blank experiments recorded in Table VI were therefore carried out at constant volume, which was accomplished by adding to the liquid, immediately after withdrawing each sample for analysis, an exactly equal quantity of fresh potassium bromide solution. The resulting bromine concentrations were readily calculated, and are given in the column headed C',

while the concentrations directly indicated by the titrations are given under C. It will be observed that each C′ denotes the concentration of the bromine at the beginning of a time interval Δt, the concentration at the end of the same interval being that value of C which is found in the table on the horizontal line next below, so that the equation by which the constant K″ is calculated takes here the form

$$K'' = \frac{v}{\Delta t} \; ln \; \frac{C_1{}'}{C_2}.$$

The analyses, both here and in the later experiments with mercury, were made by running each sample from the pipette into an excess of potassium iodide solution and titrating the iodine in the usual way.

From the mean values of K″ in the three experiments of Table VI the following values were obtained by graphic interpolation:

TABLE VII.

v	K''	$\log \dfrac{C_1{}'}{C_2}$ for $\Delta t = 1$
480	4·55	
460	4·70	0·0044
440	4·84	0 0048
420	4·96	0·0051
400	5·06	0·0055
380	5·15	0·0059

In the experiments with mercury and bromine the same method was followed as in those with iodine, but with attention to certain details which were previously not important. The pipette was filled immediately after each removal of the disk from the solution, and the time during which the disk remained out of the liquid was limited to exactly one minute in each case. The concentration changes due to loss of bromine during each such interval were calculated with the aid of the above values of $\log \dfrac{C_1{}'}{C_2}$. Table VIII contains the results of two parallel experiments on the rate of solution of mercury in bromine, with the necessary corrections applied. Under c are the bromine concentrations as determined by direct analysis, under c' the (calculated) concentrations at the moment of inserting the disk. The concentrations at the beginning and end of the same reaction period Δt are therefore given respectively by c' and that value of c which stands on the next line below. K′ is the combined velocity constant for the solution of mercury and the evaporation of bromine. K is the velocity constant for the solution of mercury alone, obtained by subtracting from K′ the corresponding value of K″, as given in Table VII.

TABLE VIII.

Mercury and Bromine.

Temperature 25°　　　400 g. KBr per liter.　　　$r = 240$.

c	c'	Δt min.	v cc.	K'	K
1.					
0·03133	0·03133		500		
0·02658	0·02630	5	480	(15·77)	(11·22)
0·02188	0·02162	5	460	16·93	12·23
0·01780	0·01759	5	440	17·10	12·26
0·01434	0·01416	5	420	17·14	12·18
0·01142	0·01126	5	400	17·19	12·11
0·00900		5	380	17·03	11·88
				Av.	12·13
2.					
0·02919	0·02919		500		
0·02494	0·02469	5	480	(15·08)	(10·53)
0·02047	0·02025	5	460	17·22	12·52
0·01654	0 01634	5	440	17·79	12·95
0·01330	0·01313	5	420	17·27	12·31
0·01060	0·01046	5	400	17·13	12·06
0·00832		5	380	17·32	12·17
				Av.	12·40

Owing to the method by which they were obtained these constants are necessarily somewhat more uncertain than the iodine constants. A comparison between the two is rather unsatisfactory on account of the presence in both cases of the large excess of soluble halide, and of the pronounced effects which the potassium iodide, and presumably also the potassium bromide, exert upon their respective reaction velocities. In Table I, experiment 8 is the one which approximates most closely to the conditions of the bromine experiments. If we take equal concentrations of the potassium halide as the basis of comparison, we must allow for the fact that the halide concentration was not the same in the two cases, but was greater in the bromine experiments in the ratio 166/119. Upon the assumption, based on the results of Table I, that a doubling of the concentration of the potassium iodide increases the constant by about ten per cent, the value of the iodine constant, at the same halide concentration as the bromine experiments, would be about 11·0. So compared, the reaction between mercury and bromine would appear to be about twelve per cent more rapid than that with iodine.

As an example of a reaction of a somewhat different type the rate of solution of mercury in cupric bromide was also determined. The presence of a sufficient quantity of potassium bromide was found to effectually prevent the formation of

TABLE IX.

Mercury and Cupric Bromide.

Temperature 25°   400 g. KBr per liter.

c mol/liter	Δt min.	v cc.	K	c mol/liter	Δt min.	v cc.	K
1. $r=160$				2. $r=215$			
0·0585	10	500	4·85	0·0774	10	510	6·40
0·0529	10	480	4·86	0·0679	10	490	6·38
0·0476	11	460	5·02	0·0593	10	470	6·24
0·0420	10	440	4·92	0·0516	10	450	6·29
0·0373	10	420	4·96	0·0446	10	430	6·27
0·0330	10	400	4·94	0·0382	10	410	6·19
0·0290		380		0·0326	10	390	
			Av. 4·93				Av. 6·30

insoluble bromides, and the reaction was followed by adding samples of the liquid to a large excess of potassium iodide and titrating the iodine set free. If the solution is exposed to the air throughout the experiment some oxidation of the cuprous salt occurs, as the steady fall of the constant in the following preliminary experiment will show:

400 g. KBr per liter. $r = 220$
K = 6·59,   6·54,   6·23,   6·17,   5·62,   5·79.

This was avoided in the experiments of Table IX by saturating the cupric bromide solution with carbon dioxide at the outset and conducting, throughout the experiment, a rapid current of the gas into the upper part of the reaction vessel, so that the liquid was covered at all times by a layer of carbon dioxide. Under these conditions, as the results indicate, little or no oxidation took place.

Discussion.

In Table X the values of the velocity constants are summarized for convenient comparison. The agreement between the constants obtained for different metals under like conditions is unmistakable, and is especially striking with the metals mercury, cadmium and zinc, which show a maximum variation of less than two per cent. This can hardly be an accident and points strongly to the conclusion that the reaction velocity is independent of the metal. As compared with mercury the constants for copper and silver are uniformly slightly lower, the largest difference being about five per cent, which is more than can reasonably be ascribed to experimental error alone.

The difficulty encountered in the work with copper and with silver in entirely preventing the formation of coatings of insoluble iodide upon the metal at once suggests itself as a probable explanation of the lower constants. As stated above,

TABLE X.

Summary of Velocity Constants.

A.

Iodine with Various Metals.

r revs. per min.	Concentration of KI grams per liter.			
	100	200	400	800
170	6·43 (Hg) 6·36 (Cd)	7·21 (Hg)	8·14 (Hg) 7·95 (Cu)	
180	7·03* (Zn)		8·23 (Ag)	
210		8·54 (Hg)		
240	8·81 (Hg) 8·69 (Cd) 8·64 (Zn)	9·55 (Hg) 9·56 (Cd) 9·64 (Zn)	10·48 (Hg) 9·98 (Cu) 9·93 (Ag)	10·27 (Cu)
300		11·12 (Hg)		

* $r = 182$.

B.

Bromine with Mercury.

$r = 240$ 400 g. KBr per liter. $K = \begin{cases} 12\cdot13 \\ 12\cdot40 \end{cases}$

C.

Cupric Bromide with Mercury.

$r = 160$ 400 g. KBr per liter $K = 4\cdot93$
$r = 215$ 400 g. KBr per liter $K = 6\cdot30$

traces of such coatings were observed in some of the experiments included in the table, and it is by no means certain that their effect was wholly absent even when no sign of a coating was detected, and the value of K was fairly constant. Further evidence on this point is brought out in the two following tables.

Table XI shows the increase in K with the rate of stirring as measured by the value of n in the equation $\dfrac{K_1}{K_2} = \left(\dfrac{r_1}{r_2}\right)^n$, applied to each pair of comparable experiments carried out with one and the same metal. It will be observed that nearly all of the constants in Table X have been used in these calculations, including five of the six which stand alone in Table X and hence can not be directly compared with any others. This is important because a comparison of the values of n affords the best available test of the concordance between these isolated constants and the others.

TABLE XI.

Influence of Rate of Stirring.

Metal	Table	Experiments			K		n
Hg	I	1	&	2	6·43,	8·81	0·91
	I	3	&	5	7·21,	9·55	0·82
	I	4	&	6	8·54,	11·12	0·74
	I	7	&	8	8·14,	10·48	0·73
Cu	II	1	&	2	7·95,	9·98	0·66
Ag	III	1	&	2	8·23,	9·93	0·65
Cd	IV	1	&	2	6·36,	8·69	0·90
Zn	V	1	&	2	7·03,	8·64	0·75
Hg in CuBr$_2$	IX	1	&	2	4·93,	6·30	0·83

The values of n for copper and for silver are the lowest in the table. Except for these the agreement is about as good as could be expected; first because n is in all probability not a constant but variable with the conditions of concentration, etc., and second because n, for mathematical reasons, is rather sensitive to variations in K.

The effect upon the reaction velocity of doubling the concentration of the potassium iodide is shown in Table XII, where the ratios of the constants are given for such pairs of experiments as differed only in this respect. Here again copper shows a distinct difference in behavior from the other metals, silver not being represented in the table. The difference is unexpectedly large, but in the absence of other data to confirm it, nothing more than a qualitative significance can be attached to this single result.

TABLE XII.

Influence of Concentration of Potassium Iodide.

Metal	Table	Experiments			K		Ratio
Hg	I	3	&	1	7·21,	6·43	1·12
	I	5	&	2	9·55,	8·81	1·08
	I	7	&	3	8·14,	7·21	1·13
	I	8	&	5	10·48,	9·55	1·10
Cu	II	3	&	2	10·27,	9·98	1·03
Cd	IV	3	&	2	9·56,	8·69	1·10
Zn	V	3	&	2	9·64,	8·64	1·12

These comparisons serve to emphasize both the close agreement in the reaction velocities of mercury, cadmium and zinc, and the consistent though usually small deviations shown by copper and silver. The latter, however, are all explainable upon the assumption that the reaction is retarded to a slight extent by the presence of traces of the solid iodide at the contact surface. This explanation is a probable one and in the opinion of the writers may reasonably be accepted. We may conclude, in other words, that not mercury, cadmium,

and zinc only, but *all the five metals investigated react with iodine at practically the same rate.*

Unless we accept the diffusion theory there seems to be no reason why these reaction velocities should be the same. But even if the above result should be found to hold for a large number of metals, it would not constitute conclusive proof that the diffusion of iodine is, as it appears to be, the determining factor. Evidence of a more direct nature is needed upon this point.

As shown above, a doubling of the concentration of the potassium iodide accelerates the reaction by about ten per cent. According to the diffusion theory such an acceleration might be due to an increase in (a), the rate of diffusion (here that of the iodine), or to a decrease in (b), the average thickness of the unstirred layer, or to both together. While (a) is in general directly measurable, little can be predicted about (b) except that it would vary with the properties, especially the viscosity, of the liquid. It seems, however, permissible to assume that in the majority of cases the changes in (a) would predominate over those in (b), and especially here, since the viscosity of strong solutions of potassium iodide at 25° varies but little with the concentration.* According to this view the rate of diffusion of iodine, or more accurately, that of potassium triiodide,† ought to show a distinct increase with the concentration of the potassium iodide.

As we have been unable to find any published data which either confirm or disprove this conclusion, we have carried out a qualitative test by comparing in two Nessler tubes of the same dimensions, clamped side by side in a large water bath, the rate at which the color spread from a lower layer of iodine in potassium iodide into an upper layer of pure potassium iodide of the same strength. The potassium iodide solutions in the two tubes contained respectively 25 and 400 grams of iodide per liter, and the iodine concentrations (the same in both tubes) were similar to those used in the previous work. Several repetitions of the experiment gave the same result. After a few hours a difference was visible in the extent to which the brown color had progressed beyond the initially

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* According to W. W. Taylor and C. Ranken (Proc. Roy. Soc. Edinburgh, xxv, 231) the viscosities of 1 and 3-normal KI at 25° are 0·467 and 0·459 respectively, that of water at the same temperature being 0·501.

† With the aid of the equilibrium constant of the reaction $KI_3 \rightleftharpoons KI + I_2$, ($k = 0·0014$ at 25°), determined by Jakowkin (Zeitschr. phys. Chem. xx, 19), it may easily be calculated that in no experiment in the above tables did the proportion of free iodine exceed a few tenths of one per cent of the total iodine, i.e., that indicated by thiosulphate. A similar calculation based on Jakowkin's data for bromine shows that in the experiments of Table VIII the tribromide bromine formed in all cases more than 98 per cent of the total bromine, so that here too the diffusion velocity would be practically that of the tribromide.

sharp boundary, and in every case it was the stronger solution in which the diffusion appeared to be most rapid, thus confirming the conclusion drawn above with the aid of the diffusion theory. A confirmation based upon quantitative measurements would of course be much more satisfactory, and an attempt will be made by one of us in the near future to obtain quantitative evidence on this question. The result obtained is interesting in that it seems to be an exception to the rule of Abegg and Bose[*] according to which an electrolyte diffusing in the presence of a large excess of a salt with like cation tends to assume the velocity of its own anion. As the electrically measured velocity of I_3' ion is much less than that of K^+ ion[†], a retardation would be expected in the present case instead of the observed acceleration.

We have still to consider the application of the diffusion theory to the explanation of the observed reaction velocities of mercury with iodine, bromine, and cupric bromide respectively. The values of the iodine and bromine constants, for a potassium iodide or bromide concentration of 3·4 normal and stirring at 240 revolutions per minute, were compared on page 249. A correction for difference in the rate of stirring permits the cupric bromide constants of Table IX to be included in the comparison, which gives, for the approximate ratio of the reaction velocities, iodine 11·0, bromine 12·3, cupric bromide 6·9. Of the three solutions corresponding to these constants the last two would have practically the same viscosity; that of the iodine solution, judging by the viscosities given by Taylor and Ranken[‡] for 3-normal solutions of potassium bromide and iodide, would be slightly lower. The difference between the iodine and bromine constants is therefore in the wrong direction to be explained by difference in the thickness of the unstirred layer, so that we must conclude, first, that the rate of diffusion of potassium tribromide is somewhat greater than that of potassium triiodide, at least in the concentrated solutions here used, and second, that cupric bromide diffuses decidedly slower than either. Both of these conclusions can be tested by direct measurement, but at present experimental confirmation is lacking. Both however are plausible, especially the last, which is in full agreement with the slow rates of diffusion of copper salts in general as compared with potassium salts.

We are far from regarding the evidence presented above as in any way conclusive in favor of the diffusion theory as applied to the reactions in question, but the fact that it

[*] Zeitschr. phys. Chem., xxx, 551.
[†] See Burgess and Chapman, Jour. Chem. Soc., lxxxv, 1305.
[‡] Proc. Roy. Soc. Edinburgh, xxv, 231.

accounts for the results obtained, and so far as yet shown leads to no inconsistencies, would seem to justify its retention for the present in dealing with reactions of this class. The work will be continued along similar lines.

Summary.

1. The rates of solution of the metals mercury, cadmium, zinc, copper, and silver, in aqueous iodine solutions containing a large excess of potassium iodide, have been measured at 25° and shown to be practically equal, a slight difference observed with copper and silver being in all probability due to accumulation of the solid iodide at the contact surface.

2. The temperature coefficient for 10° (between 25° and 35°) is about 1·3.

3. An increase in the concentration of the potassium iodide produces a marked acceleration of the reaction.

4. Mercury dissolves in bromine in the presence of potassium bromide slightly faster than in iodine, but in cupric bromide much more slowly, the ratios of the velocities being about 12·3 : 11·0 : 6·9.

5. The reaction velocity was found to be proportional, on the average, to the 4/5 power of the rate of stirring.

6. So far as can be decided from the data at present available, the diffusion theory of Noyes, Whitney, and Nernst gives a satisfactory explanation of the results obtained.

Art. XX.—*A New Cretaceous Bauhinia from Alabama;*[*]
by Edward W. Berry.

In a recent note in Torreya[†] a new Cretaceous *Bauhinia*
was described from the Magothy formation of Maryland, and
the writer at that time took occasion to call attention to the
various fossil species, seven in all, ascribed to this genus of
the Cæsalpiniaceæ with their respective ages. Still more
recently Cockerell has described[‡] an additional species from
the Florissant, Colorado, shales which he calls *Bauhinia
pseudocotyledon.* While the genus is known from both the
Cretaceous and the Tertiary of Europe, no Tertiary species had
heretofore been described from North America, although the
Cretaceous forms are exceedingly well marked and characteris-
tic. The species described by Cockerell is not as characteristic
either in outline or venation as might be desired and should
possibly be compared with other genera of the Cæsalpiniaceæ
or Mimosaceæ; at the same time its relations are sufficiently
obvious to indicate the presence of a warm temperate element
in the Florissant flora. Lesquereux insisted that these deposits
which Cockerell calls late Miocene were the same age as the
Green River shales, a position no longer tenable; and in this
connection it is interesting to recall that they were originally
called Pliocene by Dr. A. C. Peale.

The occasion for the present note, however, is furnished by
the discovery of a large and striking species in the Tuscaloosa
formation of Alabama which may be characterized as follows:

Bauhinia alabamensis sp. nov.

Bilobate leaves of medium and large size, 8^{cm} to 15^{cm} in
greatest length by 11^{cm} to 18^{cm} in greatest breadth. Medial
sinus rather broad and rounded, reaching two-thirds of the dis-
tance toward the base or even more. Lobes somewhat reni-
form in outline, sublobate, rounded above and with three
broadly rounded sublobes on the outer side, the entire margin
curving upward and inward from the lower and largest lobe
to the truncate or deeply cordate base, which appears to be
slightly peltate in some specimens. Midrib comparatively
slender, 1.7^{cm} to $3.^{cm}$ in length, running to the base of the
medial sinus and sending off two branches in its upper part,
one on each side, which curve upward parallel with the inner
margin to join inwardly directed branches from the lateral
primaries. Main lateral primaries stout, sending two or three

upwardly directed branches inward and three or four longer less oblique branches outward, the latter forking and forming broad arches in the lateral lobes. One or two additional lateral primaries on each side take their origin from the common point of divergence of the palmate or bilateral system of venation of this species and are confined to the lower lateral lobe on each side along the margin of which their branches arch.

This ornate and butterfly-like species of *Bauhinia* is not uncommon in the sandy clays of the Upper Tuscaloosa near

Fig. 1.

Fig. 1.   Restoration of *Bauhinia alabamensis* Berry, 4/7 nat. size.

Havana in Hale County, Alabama, but owing to the unsatisfactory character of the matrix, which is too sandy for good collecting, and also to the fact that the plant remains had evidently been in the water a long time before entombment, only fragmentary specimens were secured. These represent, however, all parts of the leaf and are complete enough to serve as an entirely accurate basis for the complete leaf shown in the accompanying figure.

This species is markedly distinct from any of the fossil species hitherto known. In size and general appearance it

suggests *Bauhinia cretacea* Newberry[*] of the Raritan forma-
tion in New Jersey, and it may well be a descendant of that
species, which as time passed widened out and became sub-
lobate. It differs from any existing species known to the
writer in its great width and sublobate character, although
several recent smaller-leaved species approach it in the latter
respect, and it seems probable that if representative collections
of the foliage of the recent forms showing the limits of specific
variation were available for comparison, it would be found that
a tendency toward the formation of sublobes was far from
exceptional. Two recent species were noted as showing this
marginal character. These are *Bauhinia hookeri* F. v. M. of
Australia and *Bauhinia tomentosa* Linné of the West Indies.

The display of species of this modern tropical genus in the
Upper Cretaceous of the Atlantic coastal plain is certainly
remarkable, for it embraces very small and very large forms
and shows a variety almost as great as that furnished by the
existing species. Quite recently still another and very dis-
tinct species of *Bauhinia* was collected by the writer from
typical Ripley strata in Alabama and this will be described
upon a subsequent occasion.

Johns Hopkins University,
    Baltimore, Md.

Art. XXI.—*Anhydrite and Associated Minerals from the
Salt Mines of Central Kansas;* by Austin F. Rogers.[†]

In this country anhydrite, the anhydrous calcium sulphate,
seems to be a rather rare mineral. A year or so ago the
writer found it in some abundance at several of the salt mines
in central Kansas. So these must go on record as occurrences
similar to the well-known localities in Germany and Austria
where it is a common mineral. In characters and paragenesis
the Kansas anhydrite resembles the foreign anhydrite.

The anhydrite was collected from the dump-piles of the salt
mines at Kanopolis, Ellsworth Co., and at Lyons, Rice Co.
At Kanopolis rock-salt is mined in one shaft at a depth of 795
feet and in another shaft at a depth of 805 feet. The layer of
salt is about 11 feet thick. A log of the Lyons shaft and of a
deep well at Kanopolis are on record[‡] but the anhydrite evi-

[*] Newberry, Fl. Amboy Clays, p. 91, pl. xliii, figs. 1–4 ; pl. xliv, figs. 1–3,
1896.
[†] Published by permission of the State Geologist of Kansas.
[‡] Annual Bulletin on Mineral Resources of Kansas for 1898, pp. 93–4.

dently was not identified, as no record of it appears. At Lyons a 17-foot bed of salt occurs at the bottom of a shaft 1100 feet deep. At Kingman, Kingman Co., Prof. J. T. Willard of Manhattan also obtained anhydrite from the dump of a salt mine. Bailey and Failyer in their list of Kansas minerals* mention this occurrence of anhydrite, but it has evidently

FIG. 1.

a, anhydrite; *d*, dolomite; *g*, gypsum.

FIG. 2.
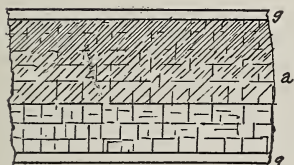
a, anhydrite.
g, gypsum.

FIG. 3.
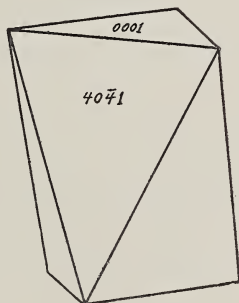
been overlooked, for no mention of it is made in any of the reports of the University Geological Survey of Kansas.

From an examination of the dump-piles it is evident that the anhydrite occurs in thin lenticular layers interbedded with shales, and probably has an appreciable vertical distribution. This is also true of the salt according to the shaft and well records cited above. Some specimens from the dumps show an intimate mixture of salt and anhydrite. The writer was also informed that at Lyons anhydrite occurs below the main

* Transactions Kansas Academy of Science, vol. xiii, p. 78, 1891–2.

salt bed. At the salt mines gypsum occurs in small quantities and probably only as a secondary mineral. The explanation of the association of anhydrite with the salt is based upon the experimental work of Rose and others. When sea-water is evaporated $CaSO_4.2H_2O$ is the first substance to crystallize out. On further evaporation NaCl forms and with it $CaSO_4$. That is, anhydrite instead of gypsum forms from a concentrated solution saturated with NaCl. Later magnesium and potassium chlorids and sulphates are formed. In the Kansas deposits these have been dissolved if ever they were formed.

The salt and anhydrite occur in the lower Permian. According to Plate V of the report on Kansas salt,[*] the salt-beds are between the Wellington and Marion formations. Not a single fossil was found on the saltmine dumps, and this is not strange when we consider the conditions under which these deposits were formed. From evidence gathered in various places it seems certain that throughout the northern hemisphere an arid climate prevailed in the Permian. The poverty of fossils, the occurrence of Red-beds, and the presence of extensive beds of gypsum and salt, all point to the fact that Kansas was like the rest of the northern hemisphere during Permian time. Now the occurrence of anhydrite with the salt is additional evidence that the Kansas Permian is like the Permian (Zechstein) of Germany during which time the salt-deposits of Stassfurt, Leopoldshall, Vienenburg, and Bernburg were formed. At all these localities anhydrite occurs with salt.

Anhydrite.—The massive anhydrite is a gray or reddish granular rock occurring in thin lenticular layers rarely over four inches thick. It resembles gypsum but is heavier (sp. gr. 2·9) and harder (h. $3\frac{1}{2}$). A microscopic examination of the rock shows an aggregate of imperfect sub-angular squares and rectangles, with bright interference colors and parallel extinction. Some of the massive anhydrite gives off water in the closed tube. This points to the presence of gypsum, which is shown in a thin section (figure 1). The mineral with high relief marked *a* is anhydrite. The spaces between the anhydrite are filled with gypsum marked *g*, which has low relief, aggregate structure and low-order interference colors. The gypsum has evidently formed from the anhydrite by hydration. Dolomite is also present, marked *d*. Cleavable and fibrous anhydrite occurs in seams often an inch or more thick. The anhydrite has the typical pseudo-cubic cleavage and one of the cleavages is usually parallel to the plane of the seam. The seams are often fibrous in an oblique direction. The explanation of this is shown in figure 2, which represents a cross-section of a seam. The fibrous structure is due to polysynthetic twinning parallel to an

[*] Annual Bulletin of the Mineral Resources for 1898.

oblique face. The twinning is probably secondary, as it apparently begins at one side of the seam and gradually causes the mineral to take on a fibrous structure. A few minute pseud-cubic crystals of anhydrite were found in close association with halite. These are doubtless secondary and on account of the halite crystallized as anhydrite instead of as gypsum.

Gypsum.—Gypsum is present as a subordinate mineral and apparently is always secondary. It occurs in some of the massive anhydrite as an alteration product (figure 1). Also coats seams of cleavable anhydrite but as sharply defined layers (figure 2). On the surface of some of the anhydrite specimens are small gray crystals of gypsum mixed with clay. These have evidently been formed since the material was thrown on the dump-piles.

Dolomite.—Dolomite occurs in minute crystals disseminated through some of the massive anhydrite (see *d*, figure 1). In habit the crystals are unusual, the forms being $(40\bar{4}1)$ and (0001) as represented in figure 3. Similar crystals occur in gypsum at Hall in the Tyrol.

Celestite.—A heavy reddish mineral, occurring in masses of imperfect tabular crystals and also in small fibrous forms in the cleavable anhydrite, proves to be celestite. This intimate connection with anhydrite would perhaps indicate that the celestite is a direct deposition from sea water.

Quartz.—Quartz occurs in small (2 or 3 mm.) pale reddish crystals imbedded in the massive anhydrite. It has the usual faces $(10\bar{1}1)$, $(01\bar{1}1)$, and $(10\bar{1}0)$ and the habit is like that of the Suttrop, Westphalia crystals.

Pyrite.—Pyrite is found in minute brown oxidized crystals in the anhydrite. It is coated with a yellow alteration product resembling copiapite.

Halite.—Halite occurs in clear cubic cleavages up to three or four inches in size. Negative crystals filled with a liquid and moving bubbles are common. A red fibrous halite occurs at Kanopolis. Halite is directly associated with anhydrite and is sometimes embeddded in it.

Careful search was made for the other Stassfurt minerals but none was found. A reddish fibrous mineral very much resembled polyhalite but proved to be celestite.

Stanford University, California,
      December, 1909.

SCIENTIFIC INTELLIGENCE.

I. Chemistry and Physics.

1. *The Purple Dye of the Ancients.*—In an address delivered at Frankfort a. M., P. Friedlaender has given an interesting account of the highly prized purple dye of the ancients, together with a solution of the mystery of its chemical nature. It appears that Greek and Roman literature supplies abundant information concerning the history of this dye, but the technical details of the lost art of applying it are almost wholly lacking. It is hardly possible that the process was a secret one, since it was employed by nearly all Mediterranean peoples in many localities, hence the lack of information seems to be due to the low social status of the dyers of ancient times. The species of mollusks employed in the preparation of this royal purple are well known, both from ancient descriptions and the remains of broken shells still existing in heaps at places where the dye was prepared, and it appears that the sea-snails or periwinkles now known as *murex brandaris, murex trunculus,* and *purpura haemostoma* were those chiefly used. It is known also that only a very small organ of the snail was utilized. From ancient statements concerning the value of the dyed material the calculation is made that the value of the dyestuff must have been something like $5,000 per pound.

Several previous investigators have attempted the study of this coloring matter, but without definite results, except that color tests seemed to indicate some analogy to indigo-blue or indigo-red. In undertaking a new study of the matter Friedlaender obtained a supply of mollusks from various Mediterranean zoological stations. After breaking the shells, the glands, which show no color in their original condition, were taken out, their contents were spread upon filter paper and exposed to sunlight for the development of the color. This material was then treated with hot dilute sulphuric acid in order to remove more soluble matters, and then the coloring matter was extracted with a high-boiling solvent, such as quinoline or benzoic ether, from which it was easily obtained pure by crystallization. The yield was very small, amounting to only 1·5 g. from 12,000 specimens of *murex brandaris.*

Upon analysis the remarkable fact was found that it contained much bromine, and it was established without doubt that the substance was 6,6, diabrom indigo, a compound already known which can be synthesized in several ways, and which could be manufactured at a price a thousand times less than its cost in times of antiquity. But it is hardly to be expected that it will be used at the present time, for it has a rather dull, reddish-violet color, which makes no marked impression upon modern eyes, and besides the tint can be reproduced by several thio-indigo derivations. Friedlaender says that we have thus lost one of our

illusions ; but still he has observed that *murex trunculus* gives, besides this reddish-violet coloring matter, also a dark blue one, which results by oxidation, and not by the action of light, from a colorless body.

In spite of Friedlaender's verdict in regard to the royal purple, it still seems possible that the ancients may have been able to produce a really magnificent color by means of some lost method of combination or manipulation.—*Zeitschr. angew. Chem.*, xxii, 2321. H. L. W.

2. *The Purification of Water Supplies by the use of Hypochlorites.*—Dr. W. P. MASON has given an account of the use of bleaching powder or of sodium hypochlorite in the purification of water supplies. He says that those who have been opposed to this method must change their position on account of the results that have been obtained in France and England, as well as at the Chicago Stock Yards and with the municipal supply of Jersey City. In the latter case the dose of available chlorine used during the month of December, 1908, averaged approximately 0·03 grains per gallon, and has since been materially reduced. While using the above amount the daily counts of bacteria per c.c. were as follows :

	Raw Water	Treated Water
Maximum	1600	30
Minimum	240	0
Average	559	2·7

No part of this minute dose of hypochlorite reaches the consumer, and protection against pathogenic germs appears to be assured. It is not expected that the process will take the place of filtration, because it does not improve the physical appearance of a water, but as an adjunct to a filter plant there can be no question of its usefulness in times of emergency, and it can be depended on to render a somewhat polluted water safe for domestic purposes at a moderate price.—*Proc. Amer. Phil. Soc.*, xlviii, No. 191. H. L. W.

3. *Allen's Commercial Organic Analyses,* edited by HENRY LEFFMANN and W. A. DAVIS. Fourth edition, entirely rewritten. Philadelphia, 1909 (P. Blakiston's Son & Co.).—The first volume of a complete revision of Allen's great work will be welcomed by all commercial analysts. The revision is being undertaken by specialists in the various branches of the subject, an arrangement which will undoubtedly lead to a presentation of the most recent and best methods. The present volume contains an introduction dealing with general operations and the determination of physical properties of substances, and takes up the subjects of alcohols, malt and malt liquors, wines and potable spirits, yeasts, neutral alcoholic derivatives, sugars, starch and isomers, paper and paper-making materials, and acid derivatives of alcohols. The contributors to this volume are E. Frankland Armstrong, Julian L. Baker, William A. Davis, G. C. Jones, Henry Leffmann, Emil Schlichting and R. W. Sindall. Two of these contributors and several others who will assist in the prepa-

ration of subsequent volumes are Americans, so that the work will have an international character. The complete work will consist of eight volumes, which will be issued rapidly. H. L. W.

4. *Introduction to Physical Chemistry ;* by HARRY C. JONES. 12mo, pp. xv + 279. New York, 1910 (The Macmillan Co.).— This book is practically an abbreviated edition of the author's Introduction to Physical Chemistry and is designed for a shorter college course in physical chemistry. Much of the text and many figures are taken from the larger book. The six chapters in the book are on the atom, gases, liquids and solids, solutions, thermochemistry and photochemistry, electrochemistry, and chemical dynamics and equilibrium.

It will probably find considerable use in the colleges.

H. W. F.

5. *Change from Positive Reflection to Negative through Pressure.*—O. LUMMER and K. SORGE have repeated Lord Rayleigh's observations on this subject, moved, probably, to a consideration of the subject by the remark of Rayleigh, that in the study of surface conditions by means of light much can be learned of the constitution of matter. The authors of this paper show that the ellipticity at a reflecting surface can be appreciably changed by a mechanical change of the medium without influencing the reflecting surface.—*Ann. der Physik,* No. 2, 1910, pp. 325–342.

J. T.

6. *Study of Gaseous Suspensions.*—MAURICE DE BROGLIE refers to the Brownian movement in fluids and calls attention to analogous movements of suspended particles in air or gases. He describes an ultra microscopic arrangement which he uses to study smoke particles. He discusses the effect of an electric field, influence of weight, and the relations of the movements observed to Brownian movements. In smoke, he finds particles of which the radius lies between $\mu\mu$ and a hundredth of $\mu\mu$.— *Physik. Zeitschrift,* Jan. 15, 1910, pp. 33–39. J. T.

7. *Constitution of the Electric Spark.*—The work of Schuster and Hemsalech has been continued by T. ROYDS, under the advice and suggestion of Schuster and Rutherford. The method of observation consisted in focussing the spark upon a rapidly revolving photographic film. The velocities of metallic vapor caused by the spark between different terminals are given in a table. In general these velocities are within $10^3 \frac{m}{s}$. The author shows that the vaporization of the metallic electrode is simultaneous with the pilot or initial spark. Two simultaneous velocities were obtained in the case of calcium vapor.—*Phil. Mag.,* Feb., 1910, pp. 285–290. J. T.

8. *Cadmium Amalgams and the Weston Normal Cell.*—In a communication from the National Physical Laboratory, F. E. SMITH reviews the work of previous writers on this subject and submits his own measurements. There are many suggestions deduced from his work. Among them is the advice that the $12\frac{1}{2}$ per cent amalgam be replaced by a 10 per cent amalgam.—*Phil. Mag.,* Feb., 1910, pp. 250–276. J. T.

II. Geology and Natural History.

1. *Florida State Geological Survey;* E. H. Sellards, Geologist. Second Annual Report, 1908–9. Pp. 296, 19 pls., 5 figs., geologic and topographic map in pocket.—This includes the following : 1. A Preliminary Report on the Geology of Florida ; by George Charlton Matson and Frederick G. Clapp, prepared in coöperation between the United States Geological Survey and the Florida State Geological Survey under the direction of Thomas Waylant Vaughan. 2. Topography and Geology of Southern Florida ; by Samuel Sanford.—Scattered papers and reports dealing chiefly with the coast line have heretofore been the basis of our knowledge of Florida geology. We now have, however, a preliminary report on the geology of the whole state, together with a topographic and geologic map. In view of previous opinions, the reader of this report will be interested to learn that the geologic structure of Florida is diversified, not simple ; and that corals, instead of being the chief agent in the formation of the bed rock of the state, have really played a minor rôle : have always been limited to the extreme southeastern part of the peninsula. " There appears to be no reason to suppose that reefs have existed on the west coast or north of the north line of Palm Beach County on the east coast " (p. 40).

Florida is a region of low plains and deeply dissected uplands. The state as a whole has an elevation of less than 100 feet. The topographic map shows an area in the southern part of the state 150 miles long by 100 miles in width, with an altitude of less than 50 feet ; and one of the longest rivers in the state, the St. Johns, is nowhere more than 30 feet above the tide. On the other hand, detached areas along the Georgia-Alabama line reach 250 feet and " small areas may exceed 300 feet." The drainage is consequent and superimposed, and includes excellent illustrations of extended streams. The imperfectly drained areas contain thousands of lakes occupying either solution cavities or shallow basins due to unequal deposition of sands. Lakes of the former type predominate in the more elevated portion of the peninsula, and the rate of solution by ground water in this area is found by Sellards to equal the annual removal of 400 tons per square mile. The Everglades, 22.4 feet above tide, are found to be almost completely surrounded by a rim of rock ; and are believed by Mr. Sanford to be similar in origin to the Dismal Swamp of Virginia.

In structure Florida is " the southern extension of the coastal plain, and its history, in general, has been the same." An uplift similar to the Cincinnati arch has raised the lower Oligocene more than 100 feet above the sea.

The geological formations include Tertiary and Quaternary ; the oldest rocks belong to the Oligocene Period, and include the

Vicksburg and Appalachicola groups. Three of the four forma-
tions of the latter are believed to have been deposited contem-
poraneously. Two formations have been distinguished in the
Miocene, five in the Pliocene, including the Lafayette. The
various formations are discussed in detail, pp. 50–162. The
Pleistocene geology is unusually interesting here because of
abundant proof of several elevations and depressions of the penin-
sula, including movements going on at the present time. Modi-
fied drainage, sea cliffs and terraces are topographic features
abundantly represented.

The report of Samuel Sanford on the Topography and Geology
of Southern Florida (pp. 177–231) is the first attempt at a com-
plete geological description of this area. The studies include
the Everglades, the Coastal Plain, and the reefs and keys along
the line of the Florida East Coast Railway. Owing to the recent
deposition of the beds and their more recent elevation, the
topography of this area is in a stage of infancy. " Drainage is
defective, sloughs, shallow ponds and lakes abound. Most of the
interior is a swamp, there are no well-defined river systems nor
stream valleys, and some of the short rivers that flow from the
Everglades into the Atlantic are, where bed rock comes a few
feet above tide level, characterized by rapids in their upper
courses." The author agrees with Dall that " the present Florida
mainland is but the top of a vastly greater submarine plateau,
the southeastern and southern edges of which are near the pres-
ent shore line, the western edge many miles to the west." One
of the striking features of southern Florida is the absence of
rock outcrops over wide areas where the ledge is but a few feet
below the surface. Part of the extensive mantle of sand which
so effectually conceals the bed rock has been carried down the
Atlantic coast by waves and currents, and part of it comes from
the disintegration of arenaceous limestones and marls.

The State Geologist discusses the origin, distribution and com-
mercial importance of phosphates, diatomaceous earth, fullers'
earth, and other economic products.   H. E. G.

2. *Report of Topographic and Geologic Survey Commission
of Pennsylvania, 1906–1908.* Pp. 375, 21 plates and 21 figures,
Harrisburg, 1908.—The First Geological Survey of Pennsylvania
under the direction of H. D. Rogers was organized in 1836, and
issued reports in 1836, 1838, 1840, 1841, and 1842, with two vol-
umes of final reports in 1858. The Second Geological Survey,
organized in 1874 under the direction of J. P. Lesley, was con-
tinuously in operation from 1874 to 1887, issuing 77 volumes, 38
atlases, in addition to a " grand atlas." Three volumes of the
final report of this survey were issued in 1893–1895. In 1899 a
topographic and geologic survey was organized to work in coöper-
ation with the United States Geological Survey. Under these
auspices work was carried on under the general direction of M.
R. Campbell until 1894, when the general supervision was placed
in the hands of George H. Ashley. The results of the work have
been published from time to time by the United States Geologi-

cal Survey. Under present conditions, accuracy and complete-
ness in topographic and geologic work have reached a much
higher level than was possible under the conditions controlling
the earlier state surveys.

The present volume will doubtless be welcomed by the people
of Pennsylvania as well as by students of geology in general,
because it contains within a reasonable compass a discussion of
the salient features of the geology of the state. By means of
this General Review it is possible now to get a clear conception of
Pennsylvania geology, stratigraphic and physiographic, as well
as economic, and including recent discoveries, without reading
through a mass of detailed and technical description. The gen-
eral geologic report has been largely written by R. W. Stone, the
pre-Pennsylvanian stratigraphy by Charles Butts, the petroleum
and gas report by M. J. Munn.   H. E. G.

3. *Virginia Geological Survey;* THOMAS L. WATSON, Direc-
tor. Bulletin No. II–A ; The Cement Resources of Virginia,
West of the Blue Ridge, by RAY S. BASSLER, with an Introduc-
tory chapter on the Materials and Manufacture of Hydraulic
Cements, by EDWIN C. ECKEL. Pp. xii, 309, 30 plates, 30 figures.
Charlottesville, 1909.—The development of the cement industry
in Virginia justifies the publication of the present report, which,
however, is more than an economic paper, and includes a valuable
report (pp. 136–185), chiefly stratigraphic, on the geology of
western Virginia, a region which has heretofore been inadequately
studied.   H. E. G.

4. *Illinois State Geological Survey;* H. FOSTER BAIN, Direc-
tor. Bulletin 11 ; Physical Features of the Des Plaines Valley,
by JAMES WALTER GOLDTHWAIT. Pp. x, 103, 9 plates and 21
figures. Urbana, 1909.—Attention has previously been called to
the admirable series of Educational Bulletins dealing with the
geology of the state of Illinois, planned by the Illinois Geological
Survey. This present bulletin is fully up to the standard of the
others, and amply justifies the labor expended. Too little atten-
tion has been paid by state and national surveys to the needs of
teachers and general readers ; and it is hoped that this series,
dealing in a more or less untechnical way with interesting type
localities, will encourage other organizations to undertake a similar
work.   H. E. G.

5. *Geology and Water Resources of the Northern Portion of
the Black Hills and Adjoining Regions in South Dakota and
Wyoming ;* by N. H. DARTON. Professional Paper, U. S. G. S.,
No. 65, 1909. Pp. 105, 24 plates, 15 figures.—Several previous
papers and reports by Mr. Darton, dealing with the Black Hills
and the surrounding region, have presented the geology of this
interesting area in an exceptionally attractive manner. These
papers of Darton's taken in connection with the reports by
Professor Jaggar and Professor Irving, and the earlier report of
Newton and Jenney, constitute a body of geologic literature
available for few areas in the United States.

The present report includes part of the material previously published, as well as much additional matter ; and, taken in connection with the author's report on the southern Black Hills, will remain as the authoritative work on this area. This paper, including as it does the topography, general geology, stratigraphy, structure, geological history, as well as a discussion of the water resources, mineral resources, and climate, all parts of it well written and well illustrated, may serve as a type publication if the United States Survey desires to be directly helpful to teachers and students, and to the increasing body of readers who are interested in geography, physiography, and general geological description, rather than in details of paleontology, petrography and economic geology. H. E. G.

6. *Biological Survey of Michigan : An Ecological Survey of Isle Royale, Lake Superior ;* prepared under direction of CHARLES C. ADAMS. Pp. xiv and 422, 63 figures.—The following papers are included in Part I of this report : 1. Isle Royale as a Biotic Environment ; Dr. Charles C. Adams. 2. The Ecological Relations of the Invertebrate Fauna of Isle Royale, Michigan ; Dr. H. A. Gleason. 3. The Ecological Distribution of the Birds of Isle Royal, Lake Superior ; Otto McCreary. 4. The Fall Migration of Birds at Washington Harbor, Isle Royale, Lake Superior ; Max Minor Peet. 5. The Ecological Succession of Birds ; Dr. Charles C. Adams. 6. The Coleoptera of Isle Royale, Lake Superior, and their Relation to the North American Centers of Dispersal ; Dr. Charles C. Adams.

Part II contains the following annotated lists : 1. Notes on the Vegetation of Isle Royale, Michigan ; W. P. Holt. 2. Annotated List of Certain Isle Royale Invertebrates ; Dr. Charles C. Adams. 3. Annotated List of the Mollusca of Isle Royale, Michigan ; Bryant Walker. 4. Report on the Isle Royale Orthoptera of the 1905 Expedition to Isle Royale ; A. P. Morse. ·5. Neuropteroid Insects from Isle Royale, Michigan ; Dr. James G. Needham. 6. Diptera of the 1905 University Museum Expedition to Isle Royale ; Professor James S. Hine. 7. Annotated List of Isle Royale Hymenoptera ; E. S. Titus. 8. The Ants of Isle Royale, Michigan ; Dr. Wm. M. Wheeler. 9. The Cold-Blooded Vertebrates of Isle Royale ; Dr. A. G. Ruthven. 10. Annotated List of the Birds of Isle Royale ; M. M. Peet. 11. Notes on Isle Royale Mammals and their Ecological Relations ; Dr. Charles C. Adams. H. E. G.

7. *The University Geological Survey of Kansas*, ERASMUS HAWORTH, State Geologist. Vol. ix, Special Report on Oil and Gas. Pp. xiv, 586, with a geological map, 1 chart, 107 plates, and 8 figures. Topeka, 1908. Sent when applied for upon the receipt of 30 cents postage.—This large volume is devoted to a special report on the petroleum and natural gas of Kansas, and has been prepared by the state geologist and his assistants. The great economic development of these industries in the mid-continental field of Kansas and Oklahoma within the first few years (see also xxviii, 560) gives a peculiar interest to this volume. It

opens with a historical chapter in regard to the discovery of oil, particularly in Kansas, from 1860 down to the present time, the third or most important period beginning with 1890. Chapters follow on the history of field work, the stratigraphy, etc., while the subjects of the chemical composition of both gas and petroleum are taken up in much detail. J. W. Beede and A. F. Rogers (pp. 318–389) contribute an account of faunal studies from the Coal Measures, and E. H. Sellards chapters on fossil plants (pp. 386–480) and on fossil cockroaches (pp. 501–541).

8. *Das Antlitz der Erde;* von EDUARD SUESS. Third volume, second half; conclusion of the entire work. Pp. iv + 789, 55 text illustrations, three tables and five colored maps. Accompanied by an index of 153 pp. bound separately.—The publication of this final volume of "The Face of the Earth" marks the consummation of the life work of the distinguished leader of European geology, the completion of a labor so important and so vast that at the recent annual meeting of the Geological Society of America a resolution of congratulation and admiration signed individually by the entire body of geologists present was transmitted to its author.

In this work, the publication of which has extended over a generation, the entire geological literature of the past century of both the old and new worlds has been drawn upon for the materials of construction. The more important papers have been abstracted and numerous references will enable the future investigator to use these volumes as a starting point for research on any geological province or to acquaint himself with that degree of progress in the earth science which marked the nineteenth century. It must be thought of, however, as primarily a compilation, for Suess has done this work with a breadth of view which has made all subsequent generations of geologists his debtors and has used the materials to achieve ends of his own, bringing forth conclusions which the individual workers did not perceive.

The volume opens with a description of the regions folded at the close of the Paleozoic in the old and new worlds and goes on in later chapters to consider folded tracts of later date, faulted regions, and the island arcs of the Pacific. Later parts treat of the theories of origin of these structures and of igneous activity. A chapter is devoted to the Moon and a concluding chapter to the life of the earth.

In a brief notice of a voluminous work such as this no discussion can be given of the subject matter and conclusions, as space would only permit a partial view of a few arbitrarily selected topics. It may be noted, however, regarding the mode of treatment that the work is built upon an exhaustive study of areal, structural and paleontological geology. It sums up, therefore, and uses with great power the modes of research which were especially employed in the nineteenth century. The youngest member among the family of geological sciences, physiography,

has been widely applied as a mode of research only since the opening of the twentieth century and the light which it is throwing on the continental histories since the close of the Paleozoic has come too late to be incorporated into the body of this work. It is to be hoped that an English translation of this, as of the previous volumes, will soon appear in order that a wider and more intimate acquaintance of it among English readers may be acquired. J. B.

9. *Beiträge zur Flora der unteren Kreide Quedlinburgs, Teil II ; Die Gattung Nathorstiana P. Richter und Cylindrites spongioides Goeppert ;* by P. B. RICHTER. Pp. 11, with 62 figures and 6 plates. Leipzig, 1909 (Wilhelm Engelmann).—In this part are described in detail two new species of the new Lycopod genus *Nathorstiana* and *Cylindrites spongioides.* The latter is thought to be a strand plant, either a conifer or Pseudocycas. C. S.

10. *Cave Vertebrates of America : A Study in Degenerative Evolution ;* by CARL B. EIGENMANN. Pp. ix, 241, with 72 text figs., 29 plates and frontispiece. Carnegie Institution of Washington, Publication No. 104, July 9, 1909.—Dr. Eigenmann has enjoyed unusual privileges for the study of cave life and its degenerating influence, and the results of his years of study are embodied in this handsome quarto. Some of the more striking of the author's conclusions are as follows :

" The bleached condition of animals living in the dark, an individual environmental adaptation, is transmissible and finally becomes hereditarily fixed.

" Ornamental secondary sexual characters not being found in blind fishes are, when present, probably due to visual selection.

" Individual degeneration of the eye may begin in even earlier stages of development until nearly the entire development becomes affected, that is, functional adaptations are transmissible."

The cave environment is divided into three regions : (1) Twilight just within the cave bounded by the distance to which light penetrates from without; (2) Region of fluctuating temperatures ; (3) Inner cave region with absolute darkness, very slight temperature changes. The animals constituting the cave fauna are not all of one class, nor do those within one class belong to one family. They are very diverse in character and origin, but not all families of vertebrates are represented, as a certain predisposition in habit and structure is necessary.

Caves are populated by one of the four following processes : (1) By accidental carrying into caves; (2) Animals may step by step have colonized the caves, becoming adapted to the environment as successive generations gradually entered deeper and deeper recesses of the caves; (3) Animals which had elsewhere become adjusted to do without light may have gathered voluntarily in caves; (4) Animals may have developed along with the development of the caves.

The plant food of cave dwellers is from the nature of things

all imported. Eyes and color tend to degenerate ; but cave animals are marvelously sensitive to tactile sensations, especially to vibrations; and experiments go to prove that blind cave fishes are still sensitive to pencils of light over the entire body. In general the older caves have a more profoundly modified fauna than the newer, and cave animals tend to *converge* while epigean animals tend to *diverge*.   R. S. L.

11. *Die Säugetierontogenese in ihrer Bedeutung für die Phylogenie der Wirbeltiere ;* by A. A. W. HUBRECHT. Jena, 1909 (Gustav Fischer). Pp. 247, with 186 figures in the text.—In this important memoir Professor Hubrecht discusses the early ontogeny of mammals and its bearing upon the accepted phylogeny of the vertebrates. The paper sums up the later work not only of the author but of contemporary embryologists and arrives at some very interesting conclusions, several of which, however, are yet open to corroborative proof from other branches of biology.

Hubrecht regards the fœtal structures as of prime importance in the study of mammalian evolution, for the finer details of ontogeny give us a keen insight into the relationship of the various groups. The author proposes a new classification based upon this source of knowledge, which will not, however, be universally accepted. He divides the vertebrates into four super-classes : (1) Cephalochordata (Amphioxus) ;   (2) Cyclostomata ;   (3) Chondrophora (Elasmobranchii) ;   (4) Osteophora (all higher vertebrates).

He suggests that many of the Dipnoi, Ganoids, and Teleosts may have had terrestrial ancestors just as did the Cetacea ; that the mammals and Sauropsida may both trace their phylogeny back through amphibian-like Carboniferous animals and thence backward through aquatic ancestors to worm-like forms derived from the Cœlenterate stem. Based upon evidence derived from the placentation, Hubrecht concludes that Man, the Anthropoid apes and the insectivorous hedgehog are most primitive ; the human ontogeny showing the most archaic characteristics of all—an interesting argument in favor of the high antiquity of Man.
                                                         R. S. L.

12. *The Occurrence of Strepsicerine Antelopes in the Tertiary of Northwestern Nevada ;* by JOHN C. MERRIAM. University of California Publications, Vol. V, No. 22, pp. 319–330.—The expedition of 1909 to the Virgin Valley and Thousand Creek region of N. W. Nevada procured a wide range of mammalian forms of which a considerable per cent are new. Of these some of the most interesting are twisted-horned antelopes, known now only in Africa and throwing additional light upon past mammalian migrations. Two new genera, each with a new species, are described which are most nearly related to the strepsicerine or tragelaphine division of the antelope group, now confined to Africa, but represented by several typical twisted-horned types in Europe and Asia in later Tertiary time.   R. S. L.

13. *Recherches Géologiques et Pétrographiques sur l'Oural du Nord. Le Bassin de la Haute Wichéra* ; par L. Duparc. Mem. Soc. phys. et d'hist. nat. de Genève. 4°, vol. xxxvi, fasc I, 1909, pp. 207, pls. v.—The author states that in this work he has had the coöperation, especially in the field, of Prof. F. Pearce and Mdlle. Tikanowitch. It is the third volume on this region published by the author, the two preceding volumes being devoted to other parts of the northern Urals. The geological map shows that the bottom of the basin and the course of the river is determined along belts of Devonian rocks consisting of schists and dolomites, flanked on the one side by a range of Carboniferous limestones and quartzites, and on the other by mountains of pre-Devonian metamorphic schists of various types containing quartzite belts and injected masses of diabase. The various geologic features of this region, including studies of its structure, of terrace formations, of the petrology of its rocks with a number of chemical analyses, are given in considerable detail. Attention is also paid to the iron mines in a study of them and of the probable genesis of the ores. The whole forms a useful addition to our knowledge of the geological features of a little known region.　　　　　　　　　　　　　　　　　　　　　L. V. P.

14. *Laboratory Botany for the High School ;* by Willard N. Clute. Pp. xiv, 177. Boston, New York, etc., 1909 (Ginn & Company).—This little laboratory manual is divided into three parts. The first deals with the structure and life processes of angiosperms ; the second, with the structure and evolution of the plant kingdom ; while the third describes a series of experiments in plant physiology. The distinctive feature of the book is that the student is left largely to his own resources. Under each topic a long series of questions is asked, and these are to be answered independently through the study of appropriate material. The advantage of such a method is that the knowledge thus gained will be first-hand knowledge. The disadvantage is that much of it must of necessity be fragmentary and uncorrelated. Of course a well-trained teacher would be able to counteract this disadvantage by a formal and connected presentation of the more important topics, and in the hands of such a teacher the book should prove of distinct service.　　　A. W. E.

III. Miscellaneous Scientific Intelligence.

1. *The Norwegian Aurora Polaris Expedition 1902–1903.* Vol. I. On the Cause of Magnetic Storms and the Origin of Terrestrial Magnetism ; by Kr. Birkeland. First section. Pp. vi, 315, with 21 plates. Christiana, 1909.—The author of this work, between the years 1896–1903, carried out three expeditions to the polar regions, with the object of procuring material for the investigation of terrestrial magnetism and the aurora. The investigations are recorded in this work, the first section of volume I having the special title given above, while volume II

will treat of the aurora and some results of the meteorological observations made. The amount of material available will be obvious from the fact that in 1902 and 1903 magnetic register-ings were available from twenty-five observatories, scattered over the world, including the four Norwegian stations on Iceland, Spitsbergen, Novaja Semlja, and Finmark. Certain well-marked magnetic storms in 1882-3 have also been treated from the observations in the reports of the International Polar Expedition. The author in 1896 advanced the theory that magnetic disturb-ances on the earth, as well as the aurora borealis, are due to cor-puscular rays emitted by the sun ; and the observations recorded have been treated with a view to show their relation to this theory. He says : "The magnetic storms, for instance, have been studied in such a manner, that on the one hand we have formed from our observation-material a field of force which gives as complete a representation as possible of the perturbing forces existing on the earth at the times under consideration. On the other hand, by experimental investigations with a little magnetic terrella in a large discharge-tube, and by mathematical analysis, we have endeavoured to prove that a current of electric corpuscles from the sun would give rise to precipitation upon the earth, the magnetic effect of which agrees well with the magnetic field of force that was found by the observations on the earth."

He adds : " The disintegration theory, which has proved of the greatest value in the explanation of the radio-active phenomena, may possibly also afford sufficient explanation as to the origin of the sun's heat. The energy of the corpuscular precipitation that takes place in the polar regions during magnetic storms seems, indeed, to indicate a disintegration process in the sun of such magnitude, that it may possibly clear up this most important question in solar physics."

He believes that future results in this line will serve to solve the questions as to the origin of terrestrial magnetism and that of the sun's heat. Professor Störmer has carried on the mathe-matical investigations in connection with the author's theory, which are intended to make clear the movement of electric cor-puscles from sun to earth. These will be published in a special part of the present work.

The author considers it to be beyond doubt that the powerful magnetic storms in the northern regions are due to the action of electric currents above the earth near the auroral zone. The attempt has been made in the case of some of the storms to cal-culate the strength of horizontal currents that would cause them, supposing that they acted magnetically as galvanic currents. In the case of the greater storms, current strengths of from 500,000 to 1,000,000 amperes or even more have been obtained. He has calculated also that according as to whether the currents are due to cathode or to β-rays, the energy for 1,000,000 amperes would be $19 \cdot 6 \times 10^6$ or 535×10^6 horse-power. Further considerations lead to an estimate of 10^{13} horse-power for the energy of the rays

that would come in contact with the earth if the latter was non-magnetic.

2. *Carnegie Institution of Washington.*—In connection with the dedication of the administration building of the Carnegie Institution at Washington, Dec. 13, 1909, a pamphlet has been issued describing the plan and scope of the Institution, and showing in brief form what it has grown to be in the past eight years. There are ten departments enumerated, most of which have their own permanent homes where active research is being carried on ; these are illustrated by numerous views in this report.

The Eighth Year Book of the Institution (pp. vii, 259, with 16 plates), which has just appeared, gives a detailed account of its work during the year 1909. On the financial side it is interesting to note that about $700,000 of income were available, of which the sum of $467,500 was expended for the now well established larger projects, $50,000 for minor grants to individuals, $30,600 for research assistants and $104,600 for publication and administration. The entire amount expended by the Institution up to 1910 reaches the imposing total of $4,129,000.

The work of the Institution has expanded in a remarkable manner, particularly along the lines determined by the various special departments of research to which the resources are chiefly devoted. These include, as enumerated in former notices, the Solar Observatory in California ; the Geophysical Laboratory in Washington (the important results from which are contained in this Journal) ; the Marine Biological Laboratory at Tortugas, Florida, and that of Experimental Evolution at Cold Spring, N. Y.; the Desert Botanical Laboratory at Tucson, Arizona, and others. The non-magnetic yacht Carnegie started on her first trip in August last and at this date has just returned from a highly successful voyage of 8,000 miles. An interesting digest of the results accomplished in these and the other lines of research is given in the Year Book ; as a whole it gives a good idea of the efficiency of the entire organization under the charge of Dr. Woodward, and the vast amount of good work which is being accomplished.

As noted above, the administration of the Institution has now a permanent home in a handsome building at the corner of Sixteenth and P streets in Washington, dedicated in December last. The work of publication has gone on steadily through the year, nineteen volumes, aggregating about 5,000 pages, having been issued (see vol. xxvii, 347, xxviii, 564). The total number of publications is now 141, with some 35,000 printed pages.

3. *The Carnegie Foundation for the Advancement of Teaching. Fourth Annual Report of the President,* HENRY SMITH PRICHETT, *and the Treasurer,* THOMAS MORRISON CARNEGIE. Pp. 201; 576 Fifth Avenue, New York City.—At the end of September last the total funds of the Carnegie Foundation amounted to $11,108,000. The income for the year was $544,355, of which $343,870 was paid out for retiring allowances and about

$53,600 for expenses of administration, publication, etc. An unexpended balance of $147,000 remained, which is included in total amount of the fund as stated above. During the year 115 pensions aggregating $177,000 were granted, bringing the number of pensions now being paid up to 318, involving a cost of $466,000; this statement alone shows how widely the benefits of this great contribution to the cause of the higher education are being distributed. There are now 67 institutions in the accepted list, including five state institutions, one of these at Toronto, Canada.

An important change has been made the past year in the working of the system, the service pension, which allowed an individual to retire at any age after twenty-five years of professional service, having been withdrawn except in the case of teachers who from disability are unable to continue active work. On the other hand, the age pension, which as previously allows retirement at an age of sixty-five years, is extended to all who have served twenty-five years, including their work as instructors. The reasons which have led to these changes are clearly stated by the President. A variety of other problems are also discussed by him: these are in part administrative, dealing with college finances and financial reports, advertising, the function of the trustee, and other related points. Other matters treated of are educational and have to do with the standards of entrance examinations, and of college and university instruction in general. The Foundation aspires to be a powerful force in raising and unifying college requirements and standards; in this direction it can accomplish great good, but constructive criticism from without, in the case of an established institution, involves many delicate questions which require careful handling that good results may be assured.

4. *Relief Maps.*—The geological department of the University of Wisconsin has prepared a geological relief map, or model, of the state of Illinois, copies of which may be purchased from the Board of Regents at Madison for $100. The map framed is 6 feet 7 inches × 3 feet 9 inches, and is on a horizontal scale of five miles to one inch and a vertical scale of 1320 feet to one inch. A model of the Malaspina glacier, Alaska, including the adjacent region near Mt. St. Elias and Yakutat Bay, may also be obtained for $125. It is about 7 feet × 4⅔ feet, and is on a scale (horizontal and vertical) of 1 : 80,000 or one inch to one and one-quarter mile.

5. *Report of the Librarian of Congress and Report of the Superintendent of the Library Building and Grounds* for the fiscal year ending June 30, 1909. Pp. 220, with 6 illustrations. Washington, 1909.—The Library of Congress is so universally recognized now as the standard of work of that kind in the country that the report of Mr. Putnam has great interest for those especially concerned. It may be noted that the appropriation for 1910 amounts to $855,000 as against an expenditure of $685,560 in 1909. The Library on June 30th, 1909, contained 1,703,000

books, a gain of nearly 168,000 for the year. The most important accession of the year was a gift from the Chinese Government of a set of the great Chinese Encyclopædia, comprising over 5,000 volumes; this was brought to Washington by a special ambassador. Another important gift is that of one hundred printed volumes from the library of George Bancroft presented by Mrs. J. C. Bancroft Davis. The Library has also issued the following :

Want List of Publications, 1909, pp. 30.

Publications issued since 1897. Pp. 48. January, 1910.

Select List of References in Sugar, chiefly in its economic aspects ; compiled under the direction of HERMANN H. B. MEYER. Pp. 238.

4. *Harvard College Observatory:* EDWARD C. PICKERING, Director.—Recent publications are noted in the following list (continued from vol. xxviii, p. 565).

ANNALS. Vol. LII, Part II. A Discussion of the Eclipses of Jupiter's Satellites, 1903–1893 ; by RALPH ALLEN SAMPSON. Pp. 153–343, with 4 plates.

Vol. LV, Part II. Maxima and Minima of Variable Stars of Long Period ; by ANNIE J. CANNON, under the direction of EDWARD C. PICKERING. Pp. 99–291.

Vol. LIX, No. V. Photographic Magnitudes of 76 Stars ; by EDWARD S. KING. Pp. 128–155.

Vol. LXIX. Part I. Photometric Observations made with the Fifteen-inch East Equatorial during the Years 1892 to 1902 ; by OLIVER C. WENDELL. Pp. iii, 97.

Vol. LXX. Durchmusterung Zones observed with the Twelve-inch Meridian Photometer ; by EDWARD C. PICKERING. Pp. vi, 235.

CIRCULARS. No. 149. Group of Red Stars in the Constellation Sagittarius. Pp. 3.

No. 150. A Standard Scale of Photographic Magnitudes. Pp. 7.

No. 151. 20 New Variable Stars in Harvard Map, No. 49. Pp. 4.

No. 152. New Variable Stars in Harvard Map, Nos. 2, 5, 32, 44, and 53. Pp. 3.

OBITUARY.

M. SERGE NIKITIN, geologist-in-chief of Comité Géologique of Russia, died on the 18th of November, 1909.

Dr. SHELFORD BIDWELL, the English physicist, died on December 18 at the age of seventy-one years.

Established by **BENJAMIN SILLIMAN** in 1818.

THE

AMERICAN

JOURNAL OF SCIENCE.

Editor: EDWARD S. DANA.

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FOURTH SERIES

VOL. XXIX—[WHOLE NUMBER, CLXXIX.]

No. 172—APRIL, 1910.

NEW HAVEN, CONNECTICUT.

1910.

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

NEW ARRIVALS

BRAZIL. I have just received from this locality an excellent shipment which includes the following specimens : An exceptionally large Tourmaline, green and pink, showing good color and form with its crystal attached to a quartz crystal ; deep green Tourmaline CRYSTALS, gem quality with very steep rhombohedral terminations ; a fine lot of EUCLASE CRYSTALS showing sharp crystal faces and good form ; a number of the new gem PHENACITE CRYSTALS and GROUPS which show better quality for this mineral than has ever before been found, and some excellent AMETHYSTS, deep in color, in good crystal form.

SOUTH CALIFORNIA. From here a new lot of Tourmalines, green and brilliant pink in color ; some showing both colors together, others in groups ; a fine lot of beautiful TOURMALINE SECTIONS ; and fine TOPAZ CRYSTALS from Ramona, clear, sharp and symmetrical.

HADDAM, CONN. From an old collection which I secured complete I have a fine lot of Tourmalines showing beauty in color and form not to be found elsewhere.

NEW MEXICO. From this place a lot of beautiful BLUE TURQUOISE in the matrix.

Besides these additions I have still on hand a number of AWARUITES, as announced and described in the February issue.

I am still receiving small shipments of Franklin Furnace Minerals, consisting of excellent Rhodonite, Willemite, Franklinite, Zincite specimens, etc.

ICELAND. Some very fine specimens of Iceland Zeolites, including Stilbite, Heulandite, Ptilolite, Quartz geodes, etc., are still in my possession.

AUSTRALIAN MINERALS. I have received a small lot of these which included : Atacamite, Cerussite and precious Opals, both cut and in the rough ; also a few Tasmania Crocoites ; one very fine, with large crystals.

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Art. XXII.—*Studies on the General Circulation of the Earth's Atmosphere;* by Frank H. Bigelow.

A Discussion of the Departures and the Residuals of the Temperature and Precipitation in Climatology.

Meteorological and climatological observatories, at numerous stations in all parts of the world, are turning out an enormous mass of raw material every year, which is of only moderate value unless it can be intelligently and thoroughly discussed. This material consists of daily observations which, when collected together in tables, produce the daily, monthly and annual means, respectively, by the usual processes of summation for the several time-terms. When these time-terms or periods are repeated many times, a normal mean can be computed as a reference value. The variations of each time-term on the normal may be called its *departure;* the variation of a time-term on its *consecutive mean* may be called its *residual.* To illustrate these terms, take the following examples derived from Bulletin S, U. S. Weather Bureau, as given in table 1, 1909. The annual means from 1873 to 1905 for five stations are called t_1, t_2, t_3, t_4, t_5, and this notation can be extended for n stations to t_n. When the original observations are reduced to a *strictly homogeneous* series by eliminating the errors of observing and computing, the mean of a long record, as of thirty-three years, is the *normal*, t_0. The differences t_1-t_0, t_2-t_0, ... t_r-t_0, for the several years, r in number, give the *departures*, v_1 having r values for the first station, v_2 having r values for the second station, and v_n having r values for the nth station. There are rn departures for n stations and r time-terms. Since it is evident that in restricted areas, as the Lake Region of the United States, the variations

Figs. 1-3.
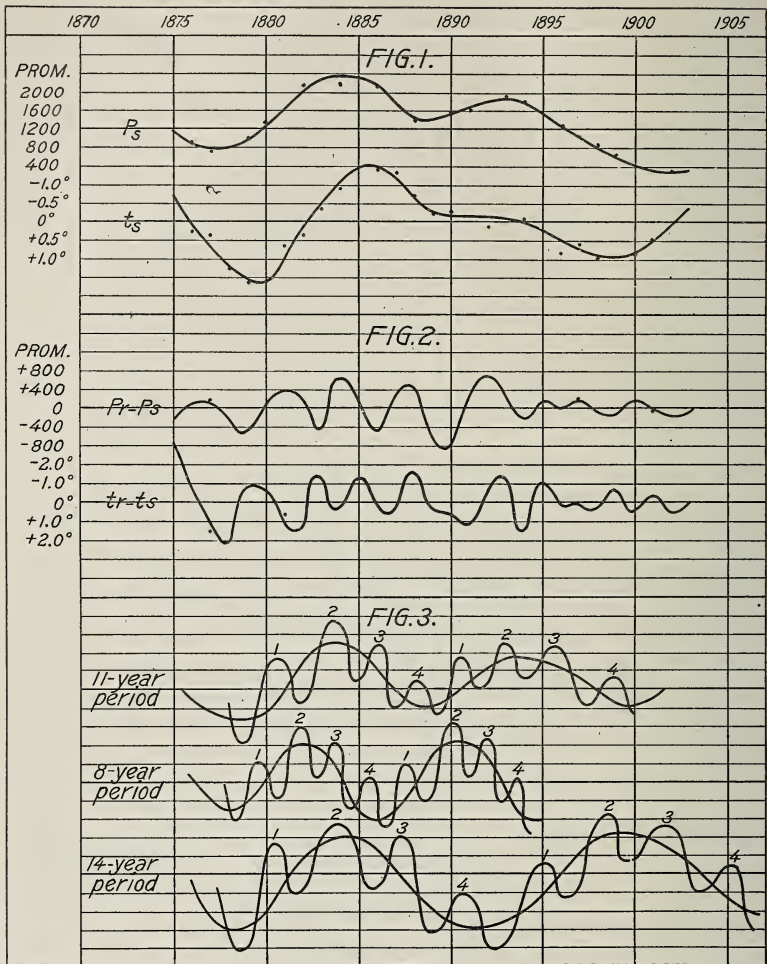
FIG. 1. Long period of prominences and temperatures.
FIG. 2. Short period for prominences and temperatures.
FIG. 3. Summation of variable periods in a single definite period.

in the temperature system, month by month, year by year, are similar, it is proper to concentrate the departures by taking the mean, τ, for several stations, 5 in this case, or n in general. The mean departures, τ_r, for r years, make good material for the discussion of problems concerned with the general and

TABLE I.—ILLUSTRATIONS OF TIME-TERMS, DEPARTURES, MEAN DEPARTURE, CONSECUTIVE DEPARTURE AND RESIDUALS.

Stations n=5	Marquette, Mich.	Milwaukee, Wis.	Chicago, Ill.	Alpena, Mich.	Detroit, Mich.	Departures for the term-times r=33 in number					Mean departure	Consecutive means Long period	Prominences Long period	Temperature Short period	Prominences Short period
Ye'r	t_1	t_2	t_3	t_4	t_5	v_1	v_2	v_3	v_4	v_5	τ_r	τ_s	P_s	$\tau_r-\tau_s$	P_r-P_s
1873	38·5	44·1	47·4	39·8	46·5	−2·0	−1·2	−1·1	−1·9	−1·7	−1·6	----	----	----	----
74	40·5	46·1	50·6	41·4	48·6	0·0	+0·8	+2·1	−0·3	+0·4	+0·6	----	----	----	----
75	36·4	40·9	45·6	37·6	44·4	−4·1	−4·4	−2·9	−4·1	−3·8	−3·9	−0·7	1188	−3·2	−332
76	40·1	44·1	49·2	41·0	47·5	−0·4	−1·2	+0·7	−0·7	−0·7	−0·5	+0·3	865	−0·8	+ 11
77	43·8	46·1	50·5	43·5	49·3	+3·3	+0·8	+2·0	+1·8	+1·1	+1·8	+0·3	695	+1·5	+ 47
78	45·8	48·7	51·7	45·2	49·9	+5·3	+3·4	+3·2	+3·5	+1·7	+3·4	+1·3	791	+2·1	−353
79	42·0	46·4	50·1	41·5	48·2	+1·5	+1·1	+1·6	−0·2	0·0	+0·8	+1·7	1015	−0·9	−454
1880	41·3	46·9	50·8	42·4	48·9	+0·8	+1·6	+2·3	+0·7	+0·7	+1·2	+1·7	1332	−0·5	+ 6
81	40·3	46·6	49·6	42·2	51·5	−0·2	+1·3	+1·1	+0·5	+3·3	+1·2	+0·6	1604	+0·6	+394
82	41·6	47·4	49·8	42·8	51·5	+1·1	+2·1	+1·3	+1·1	+3·3	+1·8	+0·4	2063	+1·4	+264
· 83	37·5	43·6	46·5	38·9	48·0	−3·0	−1·7	−2·0	−2·8	−0·2	−1·9	−0·4	2252	−1·5	−456
84	38·4	44·1	48·4	40·6	50·0	−2·1	−1·2	−0·1	−1·1	+1·8	−0·5	−0·9	2170	+0·4	+686
85	37·5	41·6	46·7	38·0	47·2	−2·9	−3·7	−1·8	−3·7	−1·0	−2·6	−1·4	2280	−1·2	+ 4
86	39·9	40·9	49·2	40·7	49·2	−0·6	−4·4	+0·7	−1·0	+1·0	−1·3	−1·4	2098	+0·1	−513
87	39·1	44·8	47·9	40·8	48·7	−1·4	−0·5	−0·6	−0·9	+0·5	−0·6	−1·3	1671	+0·7	+206
88	37·4	43·2	46·8	39·8	46·0	−3·1	−2·1	−1·7	−1·9	−2·2	−2·2	−0·7	1352	−1·5	+535
89	41·0	45·9	48·4	42·3	47·8	+0·5	+0·6	−0·1	+0·6	−0·4	+0·2	−0·2	1402	+0·4	−678
1890	40·7	46·2	48·8	42·2	48·3	+0·2	+0·9	+0·3	+0·5	+0·1	+0·4	−0·2	1521	+0·6	−836
91	42·1	46·6	48·4	43·2	48·4	+1·6	+1·3	−0·1	+1·5	+0·2	+1·2	−0·1	1592	+1·3	+244
92	40·5	44·4	46·8	41·7	47·4	0·0	−0·9	−1·7	0·0	−0·8	−0·7	+0·2	1740	−0·9	+732
93	38·9	43·9	46·5	41·0	46·8	−1·6	−1·4	−2·0	−0·7	−1·4	−1·4	0·0	1936	−1·4	+310
94	42·4	47·4	49·8	43·6	49·2	+1·9	+2·1	+1·3	+1·9	+1·0	+1·6	0·0	1806	+1·6	−339
95	40·3	44·8	47·5	41·4	46·7	−0·2	−0·5	−1·0	−0·3	−1·5	−0·7	+0·3	1534	−1·0	+106
96	41·6	46·8	49·8	42·9	48·4	+1·1	+1·5	+1·3	+1·2	+0·2	+1·1	+0·9	1230	+0·2	− 19
97	41·2	46·6	48·8	43·1	48·1	+0·7	+1·3	+0·3	+1·4	−0·1	+0·7	+0·6	1037	+0·1	+ 76
98	42·2	47·0	49·1	44·1	49·6	+1·7	+1·7	+0·6	+2·4	+1·4	+1·6	+1·0	817	+0·6	− 96
99	40·2	46·3	48·8	42·0	48·3	−0·3	+1·0	+0·3	+0·3	+0·1	+0·3	+0·9	604	−0·6	−106
1900	42·6	47·2	48·9	43·8	49·1	+1·2	+1·9	+0·4	+2·1	+0·9	+1·5	+0·8	398	+0·7	+145
01	41·4	46·0	47·8	42·4	47·5	+0·9	+0·7	−0·7	+0·7	−0·7	+0·2	+0·5	295	−0·3	−150
02	42·2	46·3	48·6	42·8	48·2	+1·7	+1·0	+0·1	+1·1	0·0	+0·8	+0·1	305	+0·7	−222
03	41·0	45·2	47·4	42·4	47·6	+0·5	−0·1	−1·1	+0·7	−0·6	−0·1	−0·3	300	+0·2	− 96
04	38·6	44·0	46·2	39·6	45·6	−1·9	−1·3	−2·3	−2·1	−2·6	−2·0	----	----	----	----
05	40·0	45·3	48·0	41·6	47·5	−0·5	0·0	−0·5	−0·1	−0·7	−0·4	----	----	----	----
t_0	40·5	45·3	48·5	41·7	48·2										

	Residuals		u_1	u_2	u_3	u_4	u_5
1873			−0·4	+0·4	+0·5	−0·3	−0·1
74	$u_1 = v_1 - \tau$		−0·6	+0·2	+1·5	−0·9	−0·2
75	$u_2 = v_2 - \tau$		−0·2	−0·5	+1·0	−0·2	+0·1
76	$u_3 = v_3 - \tau$		+0·1	−0·5	+1·2	−0·2	−0·2
77	$u_4 = v_4 - \tau$		+1·5	−1·0	+0·2	0·0	−0·7
78	$u_5 = v_5 - \tau$		+1·9	0·0	−0·2	+0·1	−1·7
79			+0·7	+0·3	+0·8	−1·0	−0·8
1880			−0·4	+0·4	+1·1	−0·5	−0·5
81			−1·4	+0·1	−0·1	−0·7	+2·1
82			−0·7	+0·3	−0·5	−0·7	+1·5

cosmical causes, such as the movement of the sun in declination, from 23° north latitude to 23° south latitude, due to the annual motion of the earth about the sun, the rotation of the sun on its axis, the aperiodic fluctuations of the solar radiation due to its thermodynamic internal actions, which affect the temperatures of the earth in small regions or as a whole. These mean departures, τ_r, usually consist of long and short fluctuations, and it is necessary to separate them in preliminary studies, in order to obtain some idea of the kind of action underlying the variations, with the purpose of finding out the laws representing the physical processes involved. The most convenient way is to take *consecutive means* for a selected number, τ_s, of the available r time-terms. In the example the consecutive years are 5 in number, and the 5-year means τ_s derived from $\tau \ldots \ldots \tau_5$ in succession are placed in the next column, that for 1873–1877 against 1875, that for 1874–1878 against 1876, the last being 1900–1905 against 1903. The τ_s consecutive departures represent the *long period term*, which is found in the rapidly changing system of departures v_{rn}. The *short-period term* is found by subtracting each τ_s from τ_r in succession, so that the *residuals*, $\tau_r{-}\tau_s$, are short period variations in the system of departures. Examples of the use of this method can be found in the following papers : Bulletin R, The Daily Normal Temperature and Precipitation of the United States ; Abstract of data, No. 3, The Annual Precipitation of the United States; this Journal, vol. xxv, p. 413, May 1908, The Relation between the Meteorological Elements of the United States and Solar Radiation. In the last paper the data of the solar prominence frequency numbers and the European horizontal magnetic force are treated in the same way, and the data of the solar prominences here used are extracted from it. The long-period consecutive means P_s, for 5-year intervals, and the short-period residuals, $P_r{-}P_s$, are placed in Table 1; they are plotted together with the corresponding temperature variations in fig. 1. An inspection of these diagrams brings out clearly several features of the problems of *departures* and *residuals*, which must be carefully considered in discussing the physical causes that produce them. It is apparent that the long-period curves have a similar synchronism, but that the temperatures *seem to lag for about two years* behind the prominences during the interval 1877 to 1888, while the lag has apparently disappeared after 1888. In the short-period the same lag occurs in the first half of the run, the crests being displaced in the temperatures about two years to the right, while in the second part of the curve the crests synchronize or become minor and irregular

together. Both sets of curves are inverted so that an *increase in the solar prominence frequency* is followed by a *decrease in the annual temperatures* of the Lake Regions of the United States.

It is not our purpose to discuss these problems here other than as illustrating certain principles in the discussion of departures and residuals in solar and meteorological data derived from observations. Similar data, as stated, are being collected in every branch of physics pertaining to the atmospheres of the sun and the earth. In stellar and planetary astronomy the problems of variations and departures, called perturbations, are comparatively easy, because the effects of the laws of gravitation are studied in rigid masses that can be reduced to ideal points. In astrophysics and meteorology these problems become enormously difficult, because the masses are gases flowing in complex paths that cannot be traced directly, as one follows a comet or a planet in the heavens, but only indirectly in the accumulated effects of a general circulation, and its local disturbances, that is in the barometric pressures, the temperatures, the densities, and the velocities of the atmosphere, at the numerous meteorological stations, these being located only in the lowest stratum of the moving fluid. The problem is so exceedingly difficult in itself that we may fairly be permitted to employ such means of discussion as are obviously suitable in order to avoid an inevitable failure in reaching a valuable result. The problems of solar and terrestrial synchronism can be discussed by two general methods, (1) a strictly rigid mathematical analysis, and (2) a statistical method combined with an interpretation guided by graphic traces. The former is preferred by some as applying definite principles, and allowing no chance for accommodation by a biassed judgment; the latter is preferred by many as the only method for a first approximation to a clear understanding of relations too complicated to be unravelled by any mathematics now in existence. Some criticise the former method as allowing no room for the practical judgment, and the latter method is criticised by others as allowing too much room for the judgment, especially on the part of those who seek a special result. The truth seems to be that the former method is allowable for the adjustment of the constants and terms of an equation *wherein the physical processes are already approximately understood.* The latter method is necessary and allowable in those preliminary researches which seek to discover what the law in question is, rather than in the refinement of it. The first method always leads to zero-results in dealing with solar and terrestrial phenomena. The latter offers some hope of

success in the present state of the development of this branch of science. We mean to include under the former method of rigid analysis, (1) the usual application of the theory of least squares for the detection of an unknown period, by the criterion of the sum of the squares of the departures being a minimum; (2) Professor Schuster's Harmonic Analysis and Periodogram for the detection of hidden periodicities, Terr. Mag. 1898; (3) the Fourier series in various forms of the harmonic analysis; (4) Professor Newcomb's criterion for fluctuations without any discernible period, Am. Phil. Soc., vol. xxi, part v, 1908.

Periodic and aperiodic synchronism.

There is one general principle underlying each of these methods of analysis, namely, that they seek a *definite period*, and assume as the premise of argument that synchronism between solar and terrestrial variations depends upon the existence and proof of such a period. It has, however, not been established that the cycle of the solar thermodynamic processes is periodic, in anything like the same sense that the annual orbital motion of the earth about the sun produces one true period in the processes within the earth's atmosphere, while the rotation of the earth on its axis produces another true periodic cycle of variations. On the contrary, the observed solar processes are so irregular as to be distinctly aperiodic. The so-called 11-year period varies between 8 years and 14 years in length in an irregular succession; the synodic rotation of the sun on its axis varies in latitude and altitude above the photosphere, from 26·7 days at the equator to 31·0 days near the poles for the level of the photosphere, but from 26·0 days at the equator to something like 29 days for the upper levels of the chromosphere. There are numerous irregularities noted in the irruption of the prominences in different longitudes so that they appear earlier in the middle latitudes of the sun than in the equatorial and the polar zones. Furthermore, it is found that in the analysis of the sun spot numbers, the prominence frequencies, and the magnetic field intensities, there is usually superposed upon the long period, ranging from 8 to 14 years, four minor crests, though only three of them are fully developed in some periods. If, for example, we assume a long period of variable length, having three or four minor variations within each of them, and attempt to sum them together on any assumed definite period, the result will be similar to that displayed in fig. 3. If the 11-year period with four crests be summed with an 8-year

period and a 14-year period, it is evident that the summation will destroy all evidences of periodicity and synchronism in the minor fluctuations. The long periods may survive with a feeble amplitude, while the short periods will certainly vanish. It is a misnomer to speak of these irregular oscillations as periods, and it is a non sequitur of analysis to assume that synchronism depends upon periodicity. If the irregularities in the variations of the solar and the terrestrial phenomena match each other in the time-sequences, this is a better proof of synchronism in physical causes and effects than could be obtained by employing a definite period having wide amplitudes of oscillation.

Inversion effects.

Besides the impropriety of forcing the observed departures of different phenomena into mean periods which do not exist in nature, there is a failure to recognize the fact that the same external or general cause, as an increase in the solar radiation energy, may produce inverted effects within the earth's atmosphere when different localities are compared together. Since the total weight of the earth's atmosphere remains fixed, it is obvious that the *pressures* of the atmosphere can be distributed in diverse manners only by balancing an excess in one region by a defect in another region. It has been found that the pressures of the atmosphere of the earth as a whole vary in such a manner that the years of annual excess in the eastern hemisphere are compensated by simultaneous deficiencies in the western hemisphere, the variations following the sequence of the solar prominences. Since the sum of the moments of inertia for the whole earth's atmosphere must be equal, in order to maintain the period of the earth's rotation on its axis a constant, it follows that the *circulation* of the atmosphere adjusts itself automatically under the action of the force of gravitation to certain velocities appropriate to the latitude away from the equator, and the height above the earth's surface. This complex process is only partially understood as yet, but it is evident that along with the readjustment of the circulation there is a redistribution of the terrestrial temperatures in latitude and in longitude. Thus, it has been found that the year of excess of temperature in the tropical zone is accompanied by a defect of temperature in the temperate zones, this being due to the return-cold or polar currents bringing down air from the higher levels to the surface in temperate zones, to compensate for the increase of the upward circulation in the Tropics as caused by the increase in the solar radiation. This general principle has many exceptions in the temperate

zone, due to the relative action of the continents and the oceans upon the general circulation in the surface levels where the observations are generally made. Again, it is not possible to treat a continent, or even a portion of a continent, as a unit. Thus, there is usually a temperature oscillation between the Pacific States and the Central and the Eastern States in North America, one being high while the other is low. Sometimes the interior stations of the United States show an excess of temperature, while all the states bordering on the Atlantic Ocean, the Gulf of Mexico and the Pacific Ocean have a simultaneous defect. The complications of the circulation are excessive and difficult to classify in a simple system, but it is important to emphasize the fact that stations from all parts of the world cannot be massed together for short-period variations, and even for long-period oscillations a discriminating knowledge and judgment is demanded. The selection of stations for any least square or harmonic analysis should have as much regard for the fact of inversion-effects, proceeding from the same external general cause, as for the other fact that periodicity is not necessary for synchronism in physical processes.

Homogeneous direct observations.

The means, departures, consecutive means, and the residuals, depend upon *original observations which must be homogeneous* to produce valid variations of any sort. In the temperatures, the observations are made at a few selected hours; in the precipitation they are made occasionally, at the end of the irregular rain and snow intervals; in the solar prominences they are made from a few stations as sights of the sun are permitted by local cloudiness; and similarly with other phenomena. In the United States the daily temperatures depend upon observations made at 7 A. M., 3 P. M., 11 P. M., Washington meridian time, 1871–88; at 8 A. M., 8 P. M., 75th meridian time, or maximum and minimum temperatures since July, 1888. Previous to the publication of Bulletin S, 1909, there was no series of homogeneous temperatures in the United States available for discussion. The hours of observation differ widely in other countries, and in general the entire subject of temperature variations for the world is very chaotic and unsatisfactory. The practical difficulty of securing 24 hourly observations every day, except by self-registering instruments, is so great that different combinations of selected hours have been used as substitutes, to the great detriment of scientific meteorology. Since the selected hours of observation are on Washington or 75th meridian mean time, it follows that the

local hours of observation change by the difference of longitude between the standard meridian and the local meridian, so that 8 A. M., 8 P. M. becomes 7 A. M., 7 P. M. on the 90th meridian, 6 A. M., 6 P. M. on the 105th meridian, 5 A. M., 5 P. M. on the 120th meridian. If the mean of 8 A. M. and 8 P. M. on the 75th meridian gives the same mean as the mean of 24 hourly observations, it will not do so on other meridians at some distance from it, because the temperatures change with the local hours. The mean of the maximum and the minimum temperatures, taken with the standard thermometers, is the best substitute for 24 hourly readings, considering all the irregularities produced by local conditions, though a correction is required for accuracy. It is obvious that these selected hourly readings having been used to compute the daily, monthly and annual means, from which the normals, departures, and residuals are derived, introduce systematic errors in the variations, which render them unfit for discussion by any graphic method or harmonic analysis. If the published reports in meteorological libraries are used without any reconstruction such as that indicated, it is evident that conclusions derived from them cannot carry much weight in any problem of solar and terrestrial synchronism.

Grouping of Stations into districts and size of means.

A preliminary examination of the pressure and temperature departures for the whole earth, 1873–1901, as published in the Monthly Weather Review, November 1903, indicates the following conclusions : (1) inversion of pressure variations between the eastern and western hemispheres ; (2) inversion of temperature variations between the tropics and the polar temperate zones ; (3) very small survival of the long, or 11-year, period, for the entire earth ; (4) comparatively large departures for the short, or 3-year, period ; (5) the inversion of temperature from the tropics to the poles producing a vanishing or irregular variation along the high pressure belt near latitude 35° ; (6) an increase of amplitude in the direct temperature type towards the equator, and an increase in the amplitude of the inverse type towards the pole from latitude 35° ; (7) a tendency to invert between the ocean and continent ; (8) that the 11-year period amplitude does not diminish from the equator to the pole by the function of the cosine of the latitude ; (9) that it is not proper to combine tropical and temperate zone stations in the same summation without regard to inversion ; (10) that it is not proper to combine several periods of unequal length in one summation without reducing the phases for the short period to an assumed standard period, as 11-years.

To illustrate a few of these points, take the stations in the United States, Washington, Key West, Galveston, St. Louis, Salt Lake City, Phœnix, San Diego, and sum the departures as follows in four groups, in Table 2:

Eastern Districts, Wash., K. W., Gal., S. L. and take mean τ_1
Western Districts, Salt Lake, Ph., S. D.   "   "   " τ_2
Inland or Northern, Wash., S. L., S. L. C., Ph. "   "   " τ_3
Coast or Southern, K. W., Gal., S. D.   "   "   " τ_4

If now we combine τ_1 and τ_2 in a general sum, taking the sum of the positive values of τ_1, and setting against τ_2 the algebraic sum as it comes, in order to see whether there is inversion or not within the United States, we find the following results:

When
$$\tau_1 = +10\cdot7, \; \tau_2 = -4\cdot2$$
$$\tau_1 = -10\cdot1, \; \tau_2 = +1\cdot9$$

showing that there is a tendency to inversion between eastern and western districts.   Similarly,

when
$$\tau_3 = +11\cdot0, \; \tau_4 = \quad 0\cdot0$$
$$\tau_3 = -10\cdot4, \; \tau_4 = -0\cdot9$$

showing that when the inland or northern districts vary the tendency is for the coast and southern districts to fluctuate accidentally.   The smallest variations in the United States are on the Southern Rocky Mountain plateau, and the largest in the Lake Region.   Similar studies should be made of residuals before attempting to combine them, because the same external and general cause produces inverted effects through the action of the complex circulation of the atmosphere, as will be explained in other papers.

The size of the annual departures demands a statement as regards their value in practical meteorology.   On the face of it, the annual variations on the normals are small, and they show that there is no secular progressive change in the conditions of the climate.   An examination of the daily and monthly means from which the annual means are divided shows that the years divide into two classes, (1) those of *wide* oscillations and those of *narrow* oscillations.   When the years of wide swing occur it implies that the cold polar currents and the warm tropical currents which meet in the United States are each respectively more pronounced, colder and warmer in succession, than in the quiet years.   This intensification of warm and cold currents is due to an increase in external solar radiation, which produces a stronger general and a more irregular local circulation.   Now the mean of these wide oscillations of the several months in a year, amounting in the winter in the Lake Region to as much as plus 18° F. to minus 18° F., will be about the

TABLE II.—GROUPING OF THE DEPARTURES IN DIFFERENT DISTRICTS.

Year	Wash.	K. W.	Gal.	S. L.	S. L. C.	Ph.	S. D.	τ_1	τ_2	τ_3	τ_4
1873	+0·4	+0·3	−0·7	−1·6	····	····	−0·1	−0·4	−0·1	−0·6	−0·2
74	+1·6	+1·1	+0·5	+1·1	··	····	−1·2	+1·1	−1·2	+1·4	+0·1
75	−2·2	+1·4	−0·2	−2·4	+0·9	····	+0·9	−0·9	+0·9	−1·2	+0·7
76	−0·1	+0·3	0·0	−0·2	−0·4	····	+0·2	0·0	−0·1	−0·2	+0·2
77	+1·1	+0·3	−1·0	+0·9	−0·1	+0·5	+1·3	+0·3	+0·6	+0·6	+0·2
78	+1·6	+0·4	0·0	+1·8	+0·4	−0·5	−0·2	+1·0	−0·1	+0·8	+0·1
79	+0·7	+0·4	+0·8	+0·1	+1·4	+1·2	−0·7	+0·5	+0·6	+0·9	+0·2
1880	+1·3	+2·0	−0·2	−0·5	−3·0	−0·3	−2·3	+0·7	−1·9	−0·6	−0·2
81	+1·5	+1·4	+0·1	+0·4	+0·3	−2·0	−0·3	+1·1	−0·7	0·0	+0·4
82	+0·4	+1·5	+1·5	0·0	−2·3	+0·3	−0·9	+1·1	−1·0	−0·4	+0·7
83	−0·4	+1·7	+0·6	−2·0	−0·8	−0·6	+0·4	0·0	−0·3	−1·0	+0·9
84	+0·6	+0·9	+0·3	−0·3	−0·7	−2·3	−0·1	+0·4	−1·0	−0·7	+0·4
85	−1·5	−0·2	−0·2	−1·0	+0·8	−0·4	+1·4	−0·7	+0·6	+0·5	+0·3
86	−1·0	−0·8	−1·9	−2·5	0·0	−0·1	−0·3	−1·6	−0·1	−0·9	−1·0
87	+0·4	−0·6	+0·4	+1·9	+1·2	····	−0·2	+0·5	+0·5	+0·9	−0·1
88	−1·2	+0·3	−0·1	−1·6	+1·8	····	+0·8	+0·7	+1·3	−0·3	+0·3
89	0·0	+0·2	−0·2	−0·1	+1·7	····	+1·2	0·0	+1·5	+0·4	+0·4
1890	+1·1	+0·2	+1·8	+1·0	+0·6	····	+1·1	+1·0	+0·9	+0·9	+1·0
91	+0·1	−0·4	+0·5	+0·1	−0·6	····	+0·8	+0·1	+0·1	−0·1	+0·3
92	−0·8	−1·0	−0·3	−0·8	−0·2	····	−0·4	−0·7	−0·3	−0·6	−0·6
93	−1·2	0·0	+0·7	−0·6	−1·1	····	−0·2	−0·3	−0 7	−1·0	+0·2
94	+1·2	−0·3	+0·4	+1·3	−1·1	····	−2·9	+0·7	−2·0	+0·5	−0·9
95	−0·9	−0·8	−1·8	−1·0	−1·3	···	−0·6	−1·1	−1·0	−1·1	−1·1
96	+0·4	−0·3	+0·7	+1·6	+0·1	+0·8	+0·8	+0·6	+0·4	+0·7	+0·4
97	0·0	+0·3	+0·6	+1·1	−0·5	−0·8	−0·3	+0·5	−0·5	−0·1	+0·2
98	+1·1	−0·6	−0·4	+0·9	−1·5	+0·5	−0·6	+0·3	−0·5	+0·3	−0·5
99	−0·5	−0·2	−0·6	+0·4	−0·6	+0·3	−1·0	−0·2	−0·4	−0·1	−0·6
1900	+1·6	−1·0	+0·4	+1·9	+2·1	+1·3	+0·9	+0·7	+1·4	+1·7	+0·1
01	−0·8	−2·1	+1·3	+1·2	+1·6	+1·1	+0·1	−0·5	+0·9	+0·8	−0·8
02	+0·2	−0·6	+0·2	+0·6	+0·8	+0·7	−1·0	+0·1	+0·2	+0·6	−0·5
03	−0·6	−0·8	−1·5	−0·2	−1·2	+0·2	−0·1	−0·8	−0·4	−0·5	−0·8
04	−2·6	−1·1	0·0	−1·8	+0·3	+1·2	+1·2	−1·4	+0·9	−0·7	0·0
05	−0·9	−0·6	−0·7	−0·9	+0·2	+0·4	+0·4	−0·8	+0·3	−0·3	−0·3
Combinations of Stations								+10·7	−4·2	+11·0	0·0
								−10·1	+1·9	−10·4	−0·9

τ_1	Wash., K. W., Gal., S. L.	Eastern Districts	
τ_2	S. L. C., Ph., S. D.	Western Districts	
τ_3	Wash., S. L., S. L. C., Ph.	Inland Districts	
τ_4	K. W., Gal., S. D.	Coast Districts	

same as when the monthly oscillations are only 6° F. or 5° F., when the twelve months are summed together. In so long an interval as 365 days, the oscillations due to the passage of cyclones and anticyclones, whether they are strong or weak in type, nearly balanced each other about the normal value. If there is a small annual excess it means that many colder waves have passed over the United States, and if there is a small annual deficiency, that more warm waves have passed over the country. The annual departure is a guide to the interpretation of the kind of weather conditions that have prevailed, and

its practical value is far greater than its apparent numerical size, when rightly interpreted. The departures of temperature and precipitation, monthly and annual, must be interpreted by the true significance of their component parts in a typical oscillation. The 11-year variation may be very small, but it is made up of numerous wide oscillations of short duration, and the mean departure is a key to their inner meaning.

Professor Newcomb's Criterion of the Mean Departure.

Before leaving the discussion of the temperature departures and residuals, it will be proper to summarize Professor Newcomb's criterion for the computation of a world-departure, that is, a variation common to the entire earth, and due to an external cause as the change in the intensity of solar radiation. One may conceive the earth as hung in space and affected as a whole by the intensity of the radiant heat energy that falls upon it. If this outside energy produces a simultaneous rise in the temperature of the atmosphere at the surface of the earth, it should be possible to compute the amount by combining stations in different parts of the world for the same interval of time. If this effect were a simple response to the outside cause, it would be an easy problem, but since it is complex it becomes an exceedingly difficult question how to discuss the observed departures and residuals. Supposing that the observations at each station to have been made *homogeneous*, it is evident that they can be combined in one summation only upon the following conditions : (1) The series of fluctuations depending upon solar action must be reduced to the *same period*, or else by taking the same phase at different intervals of time from the epoch, the summation will destroy the residuals by mere dislocation. (2) Since the same outside cause produces *inverted* effects in different parts of the atmosphere, an inversion of departures and residuals must be admitted. (3) The magnitude of the departures depends upon the place in the general circulation to such an extent that the local effect of oceans and continents must be considered in the method of collecting the data. Since the same outside cause produces opposite effects, in consequence of the general and local circulation, unless discrimination is made in the grouping of the data, a non sequitur in the argument follows. If the existing departures are summed together indiscriminately, making no allowance for periodic oscillations of *irregular lengths*, for *inversion effects* between the tropics and the temperate zones, for the local influence of land and water masses upon the *absorption of solar heat, and the radiation of the heat at terrestrial temperatures*, the surviving sum of the departures and residuals

will be so nearly zero as to be regarded elusive and unimportant.

It may be remarked, in passing, that Professor Newcomb's paper does not sufficiently recognize these principles to do justice to his criterion. Since this method may properly be applied to many problems in meteorology, it should be fully understood, and the following statement of it is made, slightly changing the original notation. Let,

n = the number of stations in each time-term.
r = the number of time-terms (11-years, 3-years, year, etc.).
v_{nr} = the departures from a long-record normal.
τ_r = the mean departure in each term-time.
τ_0 = the world-departure, or regional-departure.
$u_{nr} = v_{nr} - \tau_r$ = the residuals.
$v'_{nr} = v_{ur} - \tau_0$ = the purely accidental local departures.
$e = \tau_r - \tau_0$ = the mean accidental local regional departure.

$$e^2 = \frac{\Sigma_n v'^2}{n^2} = \frac{\epsilon^2}{n} = \text{the square of the mean } v'.$$

$$\epsilon^2 = \frac{\Sigma_n v'^2}{n} = ne^2 = \text{the mean square of } v'.$$

Hence, $v = \tau_0 + v'$, and $\tau = \tau_0 + e$.

The original equation is by definition.

$$v_1 + v_2 + v_3 + \ \cdots\ + v_n = \Sigma_n v = n\tau. \tag{1}$$

Square this equation term by term, form the squares and the products, and take the sums, calling vv the successive pairs,

$$\Sigma_n^2 v^2 + 2\ \Sigma v v_1 = n^2 \Sigma \tau^2. \tag{2}$$

If the variations v_1, v_2, v_3, etc. are *purely accidental*, there will be as many positive as negative values of vv_1, and the sum of the products will be zero,

$$2\ \Sigma v v_1 = 0. \tag{3}$$

Hence, if the departures are purely accidental,

$$n^2 \Sigma \tau^2 - \Sigma_n v^2 = 0 = \Delta = \text{Criterion.} \tag{4}$$

If $\Delta = 0$ the value of the regional departure is zero; if Δ is a *positive* quantity, there is a true regional-departure or a true world-departure; if Δ is a *negative* quantity, one regional-departure is hotter or colder at the expense of another regional-departure. Substitute $\tau_0 + v'$ for v, and $\tau_0 + e$ for τ in (4), in order to separate the purely accidental parts of the local and regional departures.

$$\Delta = n^2 \Sigma (\tau_0 + e)^2 - \Sigma_n (\tau_0 + v^1)^2. \quad \text{Expand,} \tag{5}$$
$$\Delta = n^2 \Sigma (\tau_0^2 + 2\tau_0 e + e^2) - \Sigma_n (\tau_0^2 + 2\tau_0 v' + v'^2). \tag{6}$$

The terms $\Sigma 2\tau_0 e$ and $\Sigma 2\tau_0 v'$ are each equal to zero, and since $ne^2 = \Sigma_n v'^2$ by definition,

$$\Delta = n^2 \tau_0^2 - n\tau_0^2 = n^2 \Sigma \tau^2 - \Sigma_n v^2 = 0, \text{ for accidental } v_n. \quad (7)$$

$$\Delta = n(n-1)\tau_0^2 = n^2 \Sigma \tau^2 - \Sigma_n v^2, \text{ for } n \text{ stations.} \quad (8)$$

Similarly,

$$\Delta_r = rn(n-1)\tau_0^2 = n^2 \Sigma_r \tau^2 - \Sigma_{nr} v^2 = 0, \text{ for } r \text{ series.} \quad (9)$$

This is Newcomb's Criterion for accidental departures for a large regional or world departure τ_0. (1) Take the mean of the departures v_n for the τ; square them and take the sum multiplied by n^2; (2) square all the v in the n-stations and r-time-terms and take the sum; (3) divide the difference by $rn(n-1)$ to find τ_0, the mean regional departure. These should be completed by *consecutive series* in succession, as 1872–76 for τ_0 at 1874, 1873–77 for τ_0 at 1875, and so on, thus eliminating all periods shorter than r time-terms, 5 years in this case.

The probable error of the world or regional departure from the normal is found as follows: The probable error is, by the theory of least squares,

$$u^2 = v^2 - \tau^2. \quad (10)$$

Substitute $v = \tau_0 + v'$ and $\tau = \tau_0 + e$,

$$u^2 = v'^2 - e^2 - 2\tau_0(v' + e). \quad (11)$$

In the summation the product $\Sigma 2\tau_0(v' + e) = 0$

$$\Sigma_n u^2 = \Sigma_n v'^2 - ne^2. \quad (12)$$

Substitute $\Sigma_n v'^2 = n\epsilon^2$ and $ne^2 = \epsilon^2$,

$$\Sigma_n u^2 = n\epsilon^2 - \epsilon^2 = (n-1)\epsilon^2 = \Sigma_n v^2 - n\tau^2. \quad (13)$$

Similarly for a series of r time-terms,

$$r(n-1)\epsilon_r^2 = \Sigma_{nr} v^2 - n\Sigma_r \tau^2, \quad (14)$$

from which the value of ϵ or ϵ_r are found.

These mathematical principles are valuable in some cases of pure homogeneous data, simple definite period, no inversion effects and no complex absorption and radiation effects of land and water masses, but they must be applied with discrimination and knowledge of facts in order not to lead to a vanishing summation, and a non sequitur conclusion as to the meaning of the fluctuating departures and residuals in the observations. It is proper that meteorologists should approach these summations cautiously. At present they are engaged in making their records of observations homogeneous, and in studying the general principles of inversion, radiation and absorption, under the dominating influences of circulation.

The Departures and Residuals of the Precipitation.

Unfortunately it is more difficult to know how to discuss the departures and residuals of the precipitation, because of the greater irregularity in this element due to transportation of
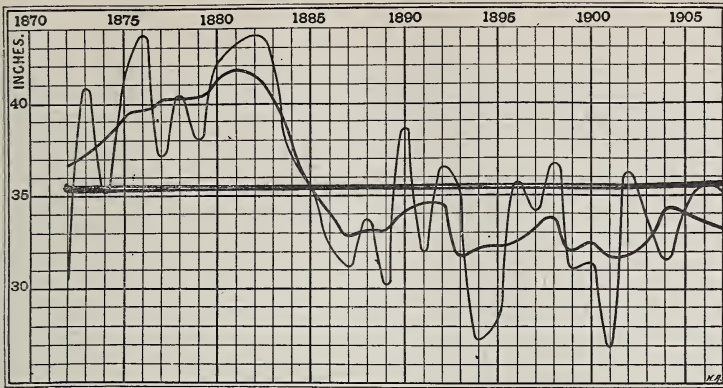
SEC. 1.—Annual precipitation in the Lake Region and the central valleys. Heavy lines for the means of successive five-year groups.
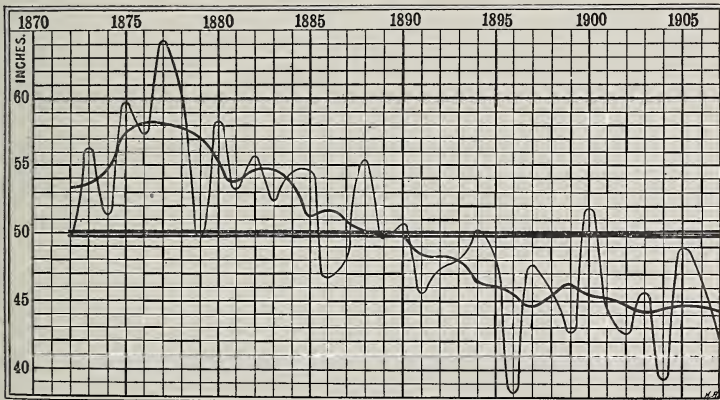
SEC. 2.—Annual precipitation in the east Gulf States. Heavy lines for the means of the successive five-year groups.
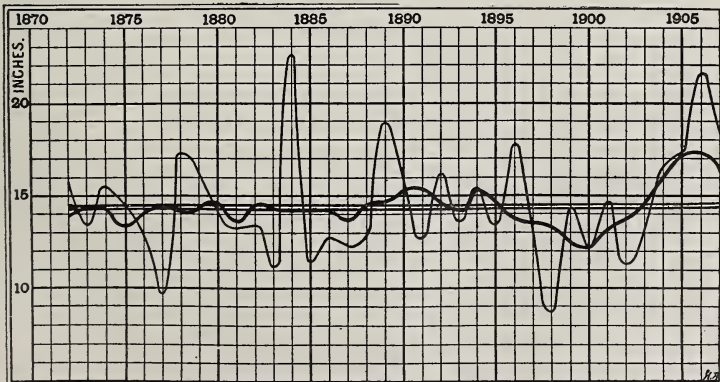
SEC. 3.—Annual precipitation in the South Pacific States and southern Rocky Mountain Plateau. Heavy lines for the means of successive five-year groups.

aqueous vapor in the great currents of the circulation. It has been customary to take the mean of a series of years or months for the normal, and the difference between this normal and the individual values for the departures. Fig. 4 shows the general case that is to be considered, the data being taken from Abstract 3 of the Climatological Division. The normal of precipitation for the Lake Region and Central valleys, 1872–1907, is 35·55; for the east Gulf States it is 50·04; for the south Pacific States and southern Rocky Mountain Plateau it is 14·55 inches per year. If the normal line on fig. 4 lies between the two close parallel lines, the *departures* are measured from this normal to the crests of the annual line; the *residuals* would be measured from the consecutive mean line to the crests. When the normal and the consecutive mean line are practically coincident as in the section 3, the departures and the residuals agree together, and no question arises. When, as in sections 1 and 2, the normal line and the consecutive mean line do not agree, then the residuals are different from the departures. In such a case as the east Gulf States for 1872–1889 the entire system is *above* the normal, and for 1890–1907 it is entirely *below* the normal. It does not seem proper to confuse residuals with departures for practical purposes, because a series of departures all largely positive for a set of years, and all largely negative for a following set of years, does not give a good idea of the course of the phenomena in the current years that are within the memory of man.

It is not easy to see how the line of consecutive five-year means can be extended forward with such accuracy as to make it suitable for a computation of the residuals of the current month and year in which the Climatological data are to be published. It is proper to submit this question to public discussion, and an expression of opinion is solicited from engineers regarding the desirability of substituting *approximate residuals* for the wide departures at present in use. The question is not concerning the causes of the change in the normal precipitation in different series of years, such as change in the general circulation, change in the exposure of the rain gauges due to the growth of cities, nor of the effect of deforestation and cultivation of the soil upon climate. It only concerns the treatment of the records of precipitation as they are actually made. It is obvious that the departures of precipitation differ materially in principle from the departures of temperature as published in the Monthly Weather Review, and its readers should at least be aware of the problems concerning their discussion. If the printed departures stand as raw material without fixed principles of interpretation, it is evident that differences of opinion will arise regarding practical results which are due solely to different ways of interpreting the facts of observation.

Art. XXIII.—*On Mixed Crystals of Silver Sulphate and Dichromate;* by R. G. Van Name and Rowland S. Bosworth.

In 1891 Retgers[*] described an attempt to form mixed crystals of silver chromate and sulphate by allowing an ammoniacal solution of the two salts to evaporate. The two silver salts were found to crystallize separately and no mixed crystals were obtained. The failure of this experiment makes it seem doubtful whether the sulphate and normal chromate of silver possess, to any appreciable extent, the property of forming mixed crystals together, especially since Retgers was unable to obtain mixed crystals of the corresponding sodium salts.

We have found, however, that if the solution be sufficiently acid, and the ratio of chromate to sulphate within certain narrow limits, well developed crystals are formed, of colors ranging from pale yellow through shades of orange and vermillion to a deep scarlet, according to the value of the ratio just mentioned. Analysis of these crystals shows that they consist of silver dichromate and normal silver sulphate in varying proportions. As these mixed crystals have not, so far as we know, been described heretofore, it has seemed desirable to carry out the following brief investigation of their properties.

A series of crystallizations was made at 25° starting with solutions of the same total acidity, about one fourth normal, but containing different proportions of the two acids. The change in concentration caused by the crystallization was kept as low as practicable by using in each experiment a large volume of solution, two liters, and so choosing the conditions that equilibrium was reached when only a small weight of crystals, usually less than three grams, had been formed. As will appear later, mixed crystals were only obtained when the molecular ratio of SO_4 to Cr_2O_7 in the solution was above 99 to 1. An increase in the proportion of Cr_2O_7 gave only pure crystals of silver dichromate, so that the investigation of solutions containing high proportions of dichromate was unnecessary. It was therefore possible to obtain a sufficient range of concentration of dichromate for all needed experiments by merely dissolving various amounts of silver chromate in the same volume of the standard sulphuric acid solution, previously warmed. When a higher concentration of silver was required silver sulphate was also added.

The different sulphuric acid solutions were adjusted to

exactly the same strength by comparison with the same sodium hydroxide solution. Silver sulphate was prepared from the purchased salt by dissolving in sulphuric acid, precipitating by diluting with water, and washing on the filter until the filtrate showed no acidity. Silver chromate was prepared by evaporating an ammoniacal solution of the ordinary precipitated product, a method which gives the salt in a finely crystalline state, in which it is very easily washed.

The method in detail was as follows: Two liters of the standard sulphuric acid solution were warmed to about 50° and the desired amounts of silver sulphate and chromate dissolved as described above. This solution was filtered while still warm into a large beaker, cooled to nearly 25°, and placed in the thermostat. A rotary stirrer kept the liquid in constant motion during its crystallization. After 24 hours, samples of the liquid were taken for analysis, and the crystals collected, washed, and dried at 130°. The crystals were small, and when examined under the microscope were found to be well developed and apparently free from inclusions of liquid.

In analyzing the solution Ag, SO_4, and Cr_2O_7 were determined in separate portions of 25^{cc} each, the first two by weighing as AgCl and $BaSO_4$ respectively, the last volumetrically by titrating the iodine set free from KI. The same methods were used in analyzing the crystals. The results are given in the accompanying table.

Owing to the small differences in composition between the different solutions analyzed, and to the high ratio of SO_4 to Cr_2O_7, experimental errors have a very disturbing effect, as is evident on comparing the values obtained, given in the first four columns of the table.* The next four columns contain the molecular ratios of SO_4 to Cr_2O_7 in the solution and crystals respectively. The ninth column gives the total acidity in equivalents per liter, calculated by subtracting the equivalent concentration of the silver from the sum of those of SO_4 and Cr_2O_7. The observed slight variations in the total acidity were probably caused in part by difference in the amount of evaporation which took place during the experiment, and in part by loss of chromic acid through the crystallization of dichromate.

In experiment I no chromate was present. Experiments II and III gave mixed crystals containing different proportions of dichromate and of different color, vermillion in II and deep

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* Thus in experiment IV the proportion of dichromate in the solution must in reality have been larger than in experiment II, although the analysis, probably owing to a summation of errors, indicated the reverse. The large effect of certain errors is well illustrated by the fact that a difference of less than 0.2^{cc} in the amount of thiosulphate used in experiment IV would have eliminated this inconsistency.

Formation of Mixed Crystals of Ag_2SO_4 and $Ag_2Cr_2O_7$ at 25°.

	Analysis of 25cc of solution				Molecular ratio				Acidity equiv. per liter	Solid phase
	Ag.	SO$_4$	Na$_2$S$_2$O$_3$ Cr$_2$O$_7$		Solution		Crystals			
	grm.	grm.	cc.	grm.	SO$_4$	Cr$_2$O$_7$	SO$_4$	Cr$_2$O$_7$		
I	0·1621	0·3690			100·0	0·0	100·0	0·0	0·2476	Ag$_2$SO$_4$
II	0·1645	0·3693	2·41	0·0074	99·10	0·90	98·8	1·2	0·2496	Mixed crystals
III	0·1621	0·3666	2·41	0·0074	99·09	0·91	95·9	4·1	0·2484	Mixed crystals (trace of Ag$_2$Cr$_2$O$_7$)
IV	0·1612	0·3666	2·23	0·0068	99·2	0·8	84·5	15·5	0·2482	Mixed crystals + Ag$_2$Cr$_2$O$_7$
V	0·1630	0·3617	2·46	0·0076	99·0	1·0	0·0	100 0	0·2440	Ag$_2$Cr$_2$O$_7$
VI	0·1381	0·3476	3·00	0·0093	98·8	1·2	0·0	100 0	0·2420	Ag$_2$Cr$_2$O$_7$
VII	0 ·0583		7·13	0·0230	96·7*	3·4*	0·0	100·0		Ag$_2$Cr$_2$O$_7$

* Calculated from the average acidity.

scarlet in III. With the scarlet crystals produced in experiment III was mingled a minute quantity of much darker crystals. These were again obtained in experiment IV in large amount, together with mixed crystals of the same scarlet color as before. The three remaining experiments gave crystals in which no sulphate could be detected, and which, on complete analysis, were found to be pure silver dichromate. The color of these crystals, deep wine red by transmitted light, metallic gray by reflected light, was the same as that of the darker crystals obtained in experiments III and IV. With much labor about 15 milligrams of the latter crystals were separated under the microscope from the scarlet crystals with which they were mingled, and were carefully tested for sulphate without result, thus showing that they too consisted of pure silver dichromate.

The mixed crystals, as proved by the usual goniometric and optical tests, were orthorhombic, having the same pyramidal habit and nearly the same crystal angles as those given by

Mitscherlich* for silver sulphate. The silver dichromate was found to be triclinic, as stated by Tschermacher† and Schabus.‡

From the above results it is clear that silver sulphate is "insoluble" in the ordinary triclinic silver dichromate and that the formation of mixed crystals is due to a rather limited solubility of silver dichromate in orthorhombic silver sulphate. The extent of this solubility at 25°, i. e. the composition of the saturated mixed crystals, must be very near the value given by the analysis of the crystals in experiment III, since the pure silver dichromate mingled with the mixed crystals was present in too small a quantity to seriously affect the result, and would, moreover, tend to compensate for the error introduced by the gradual change in the composition of the solution during the crystallization. As a check upon this result an analysis was made of another sample of approximately saturated mixed crystals prepared in a different experiment. The value obtained was 4·4 molecular per cent of dichromate, against 4·1 per cent in experiment III. On account of the small amount of material available for this last analysis, the result is probably less accurate than that obtained in experiment III.

To determine the effect of an increase in acidity a series of crystallizations was made at 25° from solutions whose total acidity was approximately twice equivalent normal, prepared by mixing standard solutions of the two acids in a known ratio. The crystals were not analyzed as the two kinds could readily be distinguished by their color. An initial ratio of 1·2 equivalents of Cr_2O_7 to 98·8 of SO_4 gave both dichromate and mixed crystals, a ratio of 1·1 to 98·9, mixed crystals only. The composition of the solution which is in equilibrium with both kinds of crystals must evidently lie between these limits.

The above facts may be briefly summarized as follows :
The mixed crystals formed at 25° resemble the orthorhombic silver sulphate in crystal form and habit, and contain a maximum of about 4 molecules of dichromate to 96 of sulphate. The solution which is in equilibrium with these saturated mixed crystals, and at the same time with pure silver dichromate, has a composition, expressed in molecular per cent of Cr_2O_7 (equivalents of Cr_2O_7 per 100 equivalents of the mixture of Cr_2O_7 and SO_4), lying between the limits 0·90 and 0·95 when the total acidity of the solution is one fourth normal, and between 1·1 and 1·2 when the acidity is twice normal.

The authors wish to express their thanks to Professor Edward S. Dana for his kind assistance in the crystallographic and optical tests.

* Pogg. Ann., xii, 137, 1828.   † Phil. Mag., [2], i, 345, 1827.
‡ "Bestimmung der Krystallgestalten in chemischen Laboratorien erzeugter Producte," Wien, 1855, page 185.

ART. XXIV.—*Osteology and Affinities of the Genus Stenomylus ;* by FREDERIC B. LOOMIS.

DURING the summer of 1907 the Amherst College field party while prospecting in the sandstones of the Lower Harrison levels some five miles to the southeast of the Agate Spring postoffice, Sioux Co., Nebraska, found fragments of a Stenomylus smaller than the *S. gracilis* then known. During that season a few badly shattered remains were collected, after which work was continued in other sections of the field. On returning the next season, however, the same levels were further excavated, on which it developed that there was a veritable quarry of these skeletons at this locality ; for no less than eighteen skulls, together with enough disarticulated bones to represent the complete skeletons, were collected from one pocket, and in an adjacent portion of the hill three complete skeletons were found. Following this the Yale University party collected three skeletons, the American Museum party five or six skeletons, and the Carnegie Museum party five or six. During the season of 1909 the Carnegie Museum again collected in this quarry, obtaining a large number of skeletons. Thus already not less than forty skeletons, and I should estimate many more, have been taken out, and as the specimens are found along over 150 feet of the face of the hill, I see no reason why as many more complete skeletons should not be obtained from the same source. With this wonderful and well-distributed material there is every reason that a complete description should be made both for identification, osteological study, and comparison.

The quarry.—The Stenomylus quarry is located some five miles due southeast of Agate Spring postoffice, and about one and a half miles up the "draw" south of the upper Harris place, and about the same distance a little east of south from the famous Agate Springs quarry of the Carnegie Museum. The horizon is in the Lower Harrison beds about 75 feet from their upper boundary. The matrix is a fine, homogeneous, well-bedded, soft sandstone, which differs materially from the much coarser and more irregularly bedded sandstone typical of these beds. These fine sands are about 100 feet in thickness and seem to have a limited extension, being traced only about three-fourths of a mile to the south and thinning out very soon in the other directions. To the east the Upper Harrison beds directly overlie these fine sandstones. The Stenomylus remains occur in two levels ; the one about four feet above the other, and both some 70 feet below the top. In the lower of the two

levels the skeletons are pretty much disassociated, while in the upper level, when a specimen is found, it is usually a more or less complete skeleton. Above these levels there is nothing approaching a bone bed, but occasionally Stenomylus remains are, however, found throughout the whole thickness of the fine sandstones. The even sorting and bedding of these sands indicate deposition in comparatively quiet water; and as the Lower Harrison beds seem to be flood-plain deposits, it would appear that these finer sandstones were laid down in some more sheltered area behind a barrier, which barrier must have been of considerable extent and height to account for the deposition of about 100 feet of uniform material. The Stenomylus remains presumably floated to their final resting place, and each of the two bone-bearing levels represents the destruction of scores of individuals. The simplest reconstruction of conditions would picture a herd of the unfortunate creatures during the distress of a great flood taking refuge on the highest available point of land; which, however, proved too low, and after surrounding them the rising waters drowned and carried off the whole herd, males and females, young and old. The carcasses then floated down stream and were accumulated in the backwater, where they were then buried in the accumulating sands. This was apparently a relatively rapid accumulation, for the carcasses, especially in the upper level, are not pulled to pieces by carnivores. The position of the head in the type (fig. 1) is characteristic of a good many of the skeletons, and I believe is common among drowned animals. Presumably the same point of land in two seasons proved to be a fatal trap for herds of these delicate creatures, and afterward it was only occasionally that an individual carcass was washed into the area where these sands were accumulating. Remains of other animals are very scarce in these sandstones, but a few isolated bones, the Diceratherium, and the major part of a skeleton of *Daphœnodon superbus* Peterson, and a few bird bones do occur with the Stenomylus bones, and confirm the stratigraphic determination of Lower Harrison.

Plan.—In considering the material it seems best to give a detailed osteological description of this species, followed by the distinctive comparisons of the three known species, and finally to consider the affinities and phylogenetic position of the genus.

Stenomylus hitchcocki sp. nov.

Type.—The type is a complete skeleton, all the bones articulated and in place, No. 2059 of the Amherst College collection. With this are used six skulls and a dozen upper and lower jaws, together with some four disarticulated skeletons and iso-

FIG. 1.
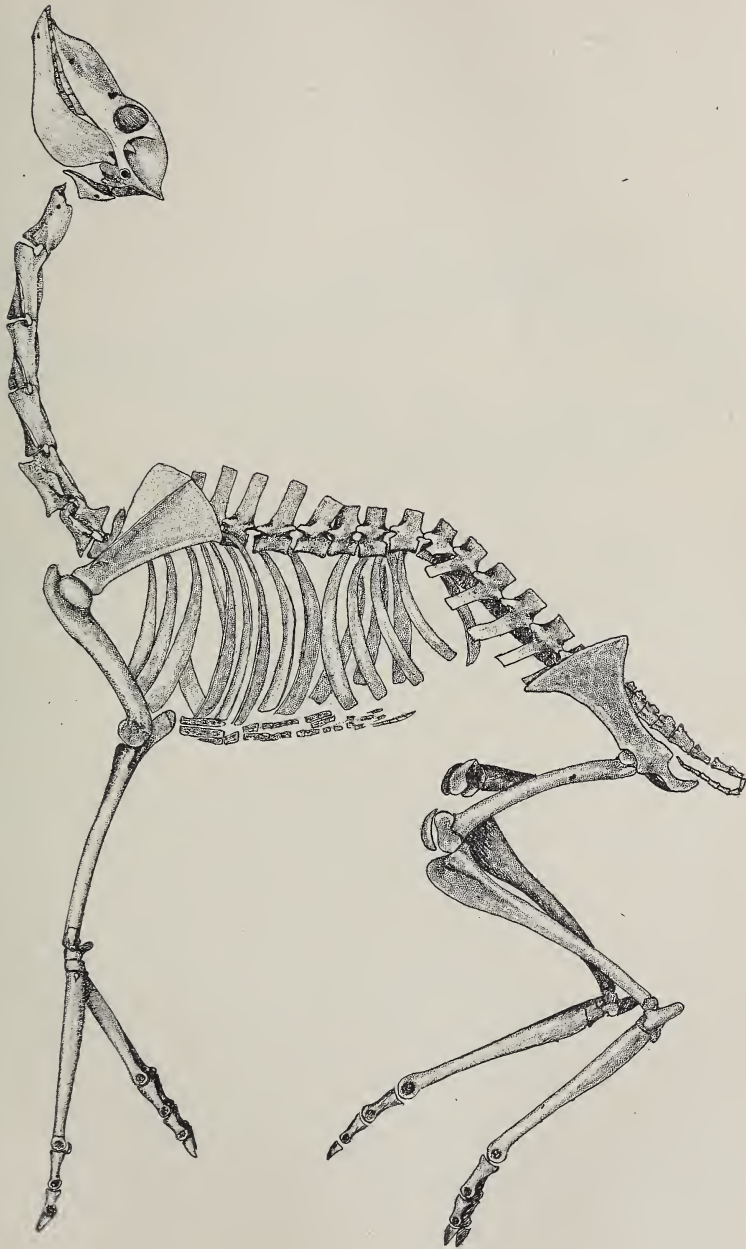
FIG. 1. *Stenomylus hitchcocki,* type specimen as seen lying in the original matrix. ×1/6.

lated bones, and the four complete skeletons of the American
Museum. In the series are individuals which are interpreted
as male and female, and a number of young having but their
milk dentition. The species is named after Dr. Edward
Hitchcock, whose work in comparative anatomy and paleon-
tology was the stimulus for the expedition and the work of the
writer. The individual used for the type is one which
has just reached maturity as shown by having all the molars
worn, but that is all, for the epiphyses of several of the
limb bones are still free from their shafts. The position of the
type specimen is that of an animal which has just laid down
with legs outstretched and head thrown back, or probably
better, of an animal which has been drowned, but is natural
enough so that we can readily get measurements of the whole
animal.

Height at the shoulders	684^{mm}	(27 in.)
Length of head	175^{mm}	(7 in.)
Length of neck	380^{mm}	(13½ in.)
Length of body	433^{mm}	(17 in.)
Length of tail	155^{mm}	(6¼ in.)

This individual is slightly smaller and lighter in build than
some of the others, and I have interpreted it as a female. In
comparing the measurements with those of other Tylopoda it
will be apparent that the body is unusually short; the limbs,
therefore, appear long, though when compared with the
length of the humerus, they are but little longer relatively
than those of Pöebrotherium. The neck in conjunction with
the increase of limb is also a little longer than that of the Oli-
gocene tylopod.

Skull.—The relatively small skull has a wide cranium but a
narrow compressed muzzle. The basicranial axis is only
slightly bent. In conformity to the lateral compression of the
muzzle the nasals are slender splints which diverge when they
reach the wedge-shaped anterior end of the frontals. These
latter bones are very wide, overhanging the orbits which stand
out from either side of the skull. The two parietals are fused
medianly and make a bone of considerable extent, on the pos-
terior half of which is situated a low sagittal crest, which unites
with the strong lambdoidal crest. This latter crest is high and
projects strongly backward, overhanging the occiput. The
premaxillæ rise rapidly on the high muzzle, expanding some-
what at the upper end. It is the maxilla which makes up the
greater part of the side of the snout and in this bone are two
deep pits on either side, the first a preorbital pit, a little in
front of the orbit and high up on the muzzle; the second a
subnasal pit, considerably in front of the former and much
lower on the muzzle. The preorbital pit, situated some 20^{mm}

in front of the orbit, is an oval depression some 25^{mm} long by 12^{mm} high, and so deep that between the two sides there is but 9^{mm}, which must nearly close the olfactory space within the muzzle. In like manner the subnasal pit is well down on the side of the snout, and extends from over premolar 1 to over premolar 4, being about the same size as is the preorbital pit. In the latter case the depth of the pits is, however, such that

FIG. 2.
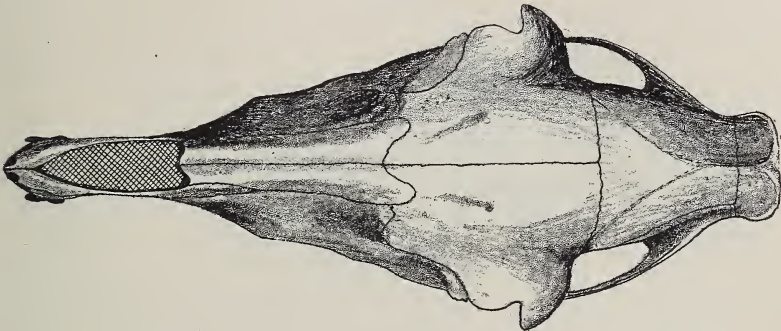
FIG. 2. *Stenomylus hitchcocki*, skull seen from above. × 1/2.

there is but six millimeters between the two sides of the skull opposite the bottom of the pits, so they must practically close the internal olfactory passage in that vicinity. Similar, though less developed, pits occur in other primitive genera among the Tylopoda : and the preorbital pit is also characteristic of several species of horses of the Oligocene genus, Mesohippus. The pits were probably occupied by glandular structures, but pits of such extent are not known to the writer among recent genera. The pit occupied by odor-secreting glands among certain artiodactyls may be cited as a counterpart, but it is hard to believe that odor glands in any species became as large as those pits would indicate.

As is usual for members of the tylopod phylum, there is an orbital vacuity of some extent at the juncture of the maxilla, nasal and lacrymal bones. The lacrymal bone itself is relatively large, extending considerably in front of the orbit. The margin of the orbit is sharply outlined and smooth except that on the lacrymal there are two deep and characteristic notches. The lacrymal foramen is well within the border of the orbit. The jugal bone bounds the front and lower part of the orbit, meeting in the rear the broad postorbital process of the frontal. The squamosum is of moderate dimensions, and carries a slender zygomatic process. On the lower surface the glenoid articular surface can scarcely be described as a cavity, making

as it does rather a wide convex rectangular area which must have allowed very free movement to the lower jaw, both laterally and vertically. The postglenoid facet is practically vertical and closely appressed to the bulla, the two facets (glenoid and postglenoid) being separated by a gap, as is the case in modern camels. The tympanic bone is fused to the squamosum, the external auditory meatus being a closed slightly pro-

Fig. 3.
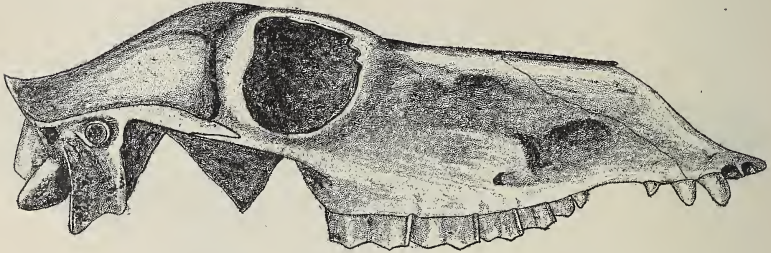
Fig. 3. *Stenomylus hitchcocki*, side view of the skull. × 1/ 2.

jecting ring; while the greatly inflated bulla is filled with cancellous bone, as is the case in Tylopoda generally. The bulla is also fused to the paroccipital process for most of its length. The occipital bones are all fused, and the occiput is narrow and small. The two condyles are sessile, and do not project behind the plane of the occiput. Below, their facets do not quite meet, being separated by a narrow groove of about a millimeter, the groove being, however, much wider in youthful specimens. The pterygoids unite with the palatines to make deep plates projecting below the base of the skull. The posterior nares open between the palatines so far forward as to make a very short hard palate. The front of the naral opening is opposite the front of the second molar, which in general is very far forward for this opening. However, in the Tylopoda generally it is characteristic to have the posterior nares open well forward: so that this genus simply shows a somewhat higher specialization in this feature. I feel that the compression of the muzzle by the preorbital and subnasal pits tends to cause the posterior opening of the respiratory passage to emerge into the mouth as far forward as possible.

The mandible is decidedly deep for so slender a creature, but the reason for this is readily seen in the extreme hypsodont condition of the teeth, which in a recently mature individual extend nearly to the bottom of the jaw. The symphysis

is of moderate length and spout-like in form. The angle of the mandible is not produced into the upward hook-like process so common among the tylopods but shows simply a slight projection (see fig. 6) at that point. The coronoid process is short and slender, being slightly recurved. The articular condyle is broad and slightly concave, the postglenoid facet being large and resembling that of the llama.

The following measurements give the proportions of the skull:

Specimen	Length incisor to occ. condyle	Length premolar 2-molar 3	Orbit weight by width	Width across orbits	Width across molars 2	Age	Sex
S. hitchcocki type	166	60.5	27 × 26·5			barely mature	♀
S. hitchcocki 2019	179	58	24 × 28	67	37	old	♀
S. hitchcocki 1090	191	67	28 × 29	68		mature	♂
S. hitchcocki 2009		33 ρ^{2-4}				milk	
S. crassipes	211	78				mature	
S. gracilis		80	27 × 26	95	57	mature	

Age.—The series of adult skulls fall into two classes irrespective of the amount of wear of the teeth, namely smaller, lighter ones, which I should interpret as female; and larger, heavier ones, which would be males. Aside from these characters of relative proportion I have found no distinctive sex characters. As all the associated skeletons must have been accumulated at one time, and births presumably took place in the spring, such individuals as show differences in age must have been a year apart. On this basis, the youngest, which have the entire milk dentition and the first molar just showing, would be one year old; while the next set, in which the third molar is just up, would be two years old, at which time they have reached nearly full size, as shown by such a specimen as the type. How long they lived would be difficult to estimate, but every indication points to very rapid wear of the teeth; so that five or six years seem to me to represent the probable length of life of the older individuals studied.

Dentition.—The dental formula is i.$\frac{3}{3}$c.$\frac{1}{1}$p.$\frac{4}{4}$m.$\frac{3}{3}$ = $\frac{22}{22}$ = 44, which is the full and primitive set. The upper incisors are simple chisel-shaped teeth, entirely unreduced and crowded into a full series. The upper canine is laterally compressed, making it into a subincisiform tooth, which stands a little apart from the incisors, however. Behind the canine there is

a moderate diastema which precedes the reduced two-rooted first premolar, while behind this tooth a much greater diastema occurs, separating it widely from the second premolar, which, like its predecessor, is reduced and two-rooted. The third premolar follows without any diastema, and is a narrow elongated tooth, but with none of the specializations of the teeth which follow it. The fourth premolar has acquired the selenodont character, though but single-lobed, its inner and outer cusps having developed into high crescentric ridges, with a deep pit between. The three molars are all extremely hypsodont,

FIG. 4.

FIG. 4.   *Stenomylus hitchcocki*, upper dentition and palate.   × 1/2.

which is one of the most marked features of the genus. Each tooth is very simple, consisting of two lobes, each with a deep pit in it. There is no cement in the valleys. Each tooth is nearly flat on the outer side, there being but a slight convexity outside the paracone and metacone, and no column except that the anterior border of each molar is developed into a parastyle. The widest portion of the series is at the second lobe of the first molar. The crown of each molar is greatly developed in height, as is seen in the section of a second molar (fig. 5), the top being slightly narrower than the base, so that as they wear the teeth appear relatively wider. A slightly worn second upper molar of *S. hitchcocki* has a crown 23^{mm} high which contained a pit 19^{mm} deep, these pits in the upper molars being materially deeper than in the lower molars. The successive molars seem to come up slowly or else the wear is very rapid, for when molar 3 is but slightly worn the first molar is down to the bottom of the pit. In addition to the considerable height of the crown the upper part of the pulp cavity fills in with dentine, so that some time after the bottom of the pit is reached the tooth still has a solid center, in the middle of which is a small discolored "mark." Inasmuch as the wear seems to continue considerably below the base of

FIG. 5.

FIG. 5.   *Stenomylus hitchcocki*, section of upper second molar, to show depth of pit. × 1/1.

the pit, the tooth in addition to its great height must increase still more by growth at the base during life.

The lower dentition.—The lower incisors are flattened and expanded at the top so that each successive incisor slightly overlaps the preceding one. The laterally compressed canine is grouped with the incisors and has assumed the incisiform character completely. Even the first premolar is semi-incisiform and stands close behind the canine, being thus in the incisor group. Behind this there is a considerable gap in front of the second premolar, which, though two-rooted, is considerably reduced. Behind this in turn occurs a wide diastema followed by the small but sharp third molar. It is only

FIG. 6.
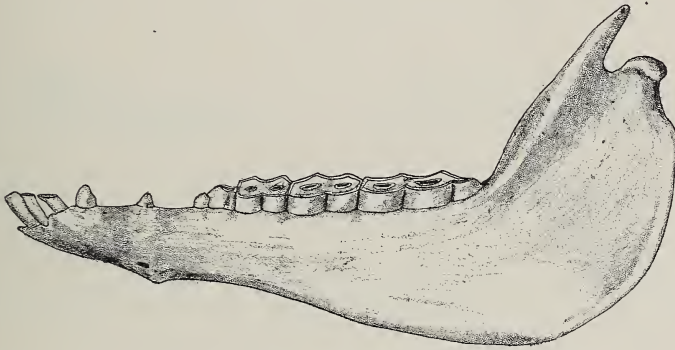
FIG. 6. *Stenomylus hitchcocki*, mandible with lower dentition. × 1 / 2.

the fourth premolar which is to any degree functional as a grinding tooth, and this is a short, narrow, single-cusped tooth without any pit, of molariform adaptation. The three molars, however, are developed into deep hypsodont and compressed teeth, each with its deep pits. The first molar is the smallest of the three, consisting of two lobes, which like the others have a straight face on the inner side, there being no columns except the parastyle on the front margin of each molar. This tooth cuts the gum apparently at about the end of the first year and wears very rapidly, for when the third molar appears this tooth has worn below the base of the pit; but it is to be remembered that in the lower teeth the pits are not nearly as deep as in the upper molars. While the second lower molar is somewhat larger, it is otherwise like the first. But the third molar has three lobes, the last one being only a little smaller than the two preceding it. The extreme depth of this tooth is shown by the illustration (fig. 7), which is a typical young specimen of *S. hitchcocki,* and shows that in a crown 34^{mm} high the pit is

but 9^{mm} deep. However, the tooth is available for much greater wear than the depth of the pit; for as age increases the pulp cavity fills with dentine and makes some 18^{mm} more available. The great height of these teeth is the cause of the great depth of the lower jaw noticed in the description of the mandible.

Milk dentition.—Young jaws are found in surprisingly large numbers, practically all of them being of about the same age, and showing the full milk dentition, together with the unworn first molar. These skulls are entirely disarticulated, and I have seen no incisor or canines of the upper jaw, though they were doubtless there. The first upper premolar is situated near the canine and behind it is a considerable diastema, between it and the second small pointed premolar. It is on

FIG. 7.   FIG. 8.

FIG. 7. *Stenomylus hitchcocki*, section of third lower molar to show depth of pit. × 1/1.
FIG. 8. Upper premolars of the milk dentition. × 1/2.

the third and fourth of this series that the burden of grinding is thrown. Like adult molars, they are strongly hypsodont with high crescentric crests and deep pits. They differ, however, in having the outer face more convex over the paracone and metacone, and in having a well-developed mesostyle as well as a parastyle; from which it may be concluded that these features were also present on the teeth of the ancestral

FIG. 9.

FIG. 9. *Stenomylus hitchcocki*, mandible with the milk dentition. × 1/2.

form. The third and fourth deciduous premolars are each two-lobed and in general resemble the permanent molars.

Lower jaws are usually the better preserved, the alveoli for the three incisors and the canine being present on several specimens. The canine is grouped with the incisors as in the adult. The first premolar is represented by a tiny alveolus

scarcely larger than a pin hole, from which I judge that the tooth was vestigial. The second premolar stands isolated with a considerable diastema on either side of it, and like the third premolar is still a single-cusped tooth. The grinding tooth of the lower jaw is the fourth premolar, and this is developed as a large three-lobed, molariform tooth, with high crescentic cusps, and deep pits in each lobe. In all the specimens this tooth is well worn as though it had been used for grinding grass some time, which is the reason that I have assigned the age of one year to the individuals with this and the first molar just showing, as is uniformly the case.

Cervical vertebræ.—The neck as a whole is long and slender, each constituent vertebra being markedly elongated, as is usual among Tylopoda. The atlas is relatively long and narrow, the anterior cotyli being deeply excavated to make the articulation for the occipital condyles. In the lower side the two articular facets are separated by a groove in *S. hitchcocki* (confluent in *S. crassipes*), while on the upper side the two cotyli are separated by a wide notch. The posterior ends of the transverse processes are prolonged backward to make short horn-like projections, which extend behind the facets for the axis much as in Pöebrotherium. The posterior facet for the axis is high and inflexed along the upper border, for the under side of the odontoid process. The edges of the transverse processes make a nearly straight line, in contrast to the sinuous one commonly found. The vertebrarterial canal enters the

FIG. 10.   FIG. 11.
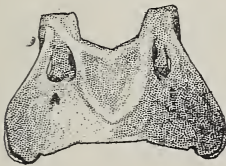
FIG. 10.   *Stenomylus hitchcocki*, atlas seen from the dorsal side.   × 1/2.
FIG. 11.   Axis seen from the side.   × 1/2.

neural pedicle just to one side of the axial facet and passing through the arch comes out again about the middle of the centrum. The first spinal nerve had its exit adjacent to the anterior opening of the vertebrarterial canal.

The axis is also a long and slender bone, with a long, low spinous process ending to the rear in two small tubercles, a feature very characteristic of the camels. The transverse processes begin just in front of the middle of the centrum and make moderately expanded wings to either side, their outer

edges being slightly flexed downward. The anterior facet for the atlas is a wide concave face extending in a trifle over half a circle, and dying out on the neural arches. The odontoid process is short and thick with a tubercle on its upper surface. In this the genus differs from the early tylopods, which have a semicylindrical odontoid, while that of the modern genera is spout-like. The vertebrarterial canal is confluent with the neural canal through the posterior third of the vertebra, then enters the pedicle of the neural arch, passing obliquely through and coming out about a third of the way from the front of the centrum. Just in front of the vertebrarterial foramen there is a wide opening for the exit of the second spinal nerve.

The third, fourth and fifth cervicals are so similar that they may be treated together. They are all long and slender, having only the smallest vestiges of a spinous process, in which feature they resemble the modern camels, even having the characteristic to a more marked degree than any of the other genera in the family. The transverse processes, expanding wing-like on either side, extend the whole length of the centrum, and then are prolonged into slender projections as seen in fig. 12. These transverse processes do not have the anterior portion of the wing prolonged into a distinct lobe, as is the case in the modern Tylopoda; but rather have the lobe barely indicated, as is the case in Pöebrotherium and Oxydactylus. A ventral keel develops on the posterior third of the centrum, expanding to the rear until it is very prominent. In none of these three vertebræ is the vertebrarterial canal visible externally. On cervicals 3–7 the anterior of the centrum is moderately convex, the posterior end concave.

The sixth cervical is markedly different from the others. First its dorsal spine is vestigial, which is well developed in the modern camels and in Pöebrotherium: then the transverse process is a short thin plate the distal end of which is bent backward. The interior lamellæ are developed into wide

Fig. 12.
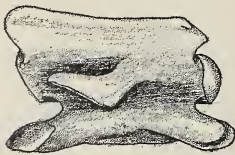
Fig. 12. *Stenomylus hitchcocki*, sixth cervical seen from the side. × 1/2.

plates which extend the whole length of the centrum and project downward. These are not, however, divided into an anterior and posterior lobes as in the modern tylopods, but have a straight lower border as is the case in Pöebrotherium. The vertebrarterial canal enters the base of the neural pedicle at the rear and penetrates the entire length, leaving just under the prezygaphysis.

The seventh cervical is much shorter than the others, and has a moderate neural spine. The transverse processes are

developed as wings to either side and about half the length of the centrum, the outer margin being prolonged fore and aft and thickened. The wide posterior facet is placed obliquely to the length of the centrum, indicating a marked upward bend to the neck, so it is fair to conclude that the head was carried high. On the rear there are facets for the first ribs.

From the foregoing it is clear that this genus in such deepseated characters as the position of the vertebrarterial canal, the reduction of the neural spines, and the characters of the transverse processes, relates itself closely to the Tylopoda, having especial affinity to the primitive genus Pöebrotherium.

The following measurements give the relative sizes of the various vertebræ in the three known species and in Pöebrotherium.

Length of Centrum × Width of Vertebra.

	1st.	2d.	3rd.	4th.	5th.	6th.	7th.
S. hitchcocki	33 long	54	68	58	54	49	35
	39 wide	29	41	37	37	37	40
S. crassipes	35	62	67	54		48	
	51	33	35	—	38	45	
S. gracilis					75	72	—
P. wilsoni	36	66	63	58	56	45	36

Dorsal vertebræ.—The dorsal series consists of twelve vertebræ, measuring 242^{mm}. The neural spines are all wide thin plates, so closely set in front as to leave almost no intervals between vertebræ, and reaching a maximum in height on the fifth dorsal, from which point on they are lower with increasing intervals between successive spines. The anticlinal vertebra is the eleventh dorsal. Metapophyses appear first on the eighth dorsal and occur on each successive centrum, situated each time a little higher and further forward, until on the eleventh the metapophysis unites with the prezygapophysis and together they make a concave facet which incloses the cylindrical postzygapophysis.

Fig. 13.

Fig. 13. *Stenomylus hitchcocki*, sixth dorsal seen from the side. × 1/2.

Lumbar vertebræ —The lumbar series consists of seven vertebræ, which total 190^{mm} in length. Each one is characterized

by having the above described interlocking series of concave prezygapophyses and cylindrical postzygapophyses as is typical of Tylopoda generally. While the neural spines only rise to moderate heights, they are wide, thin plates, considerably expanded above. The transverse processes extend, attaining the (for so small a form as *S. hitchcocki*) considerable length of 34^{mm}.

Sacrum.—The sacrum consists of four fused vertebræ having a total length of 59^{mm} and a width of 62^{mm}. The first of the component vertebræ sends out a stout and much expanded pleurapophysis to receive the ilium. To this is added the smaller but still stout pleurapophysis of the second sacral vertebra. These two sacrals are heavy, but the two posterior vertebræ having only to support the tail are reduced and have become very slender.

Caudal vertebræ.—The tail is supported by 14 vertebræ, of which the proximal ones are short and wide with well-marked transverse processes. Beginning with the seventh, however, the vertebræ are without transverse processes, and become approximately cylindrical rods, the last one being but 5^{mm} long and but 1^{mm} in diameter. The whole series measures 170^{mm}, indicating a tail of moderate length.

Ribs.—The first of the ribs is short and stocky, while the succeeding eleven are thin and wide (though not so wide as in the living camels), the interval between succeeding ribs being about half the width of the rib itself. A typical rib measures 175^{mm} long by 18 wide. Each rib has two heads rather close together, followed by a narrow abruptly curving neck, and then expands and stretches in a gentle curve toward the sternum. The uncrushed ribs show the body to have been decidedly narrow and moderately deep. The first five ribs were attached directly to the sternum by short calcified costal cartilages; the sixth and seventh by longer calcified cartilages; and the succeeding three are connected by long costal cartilages to each other and indirectly to the sternum; while the eleventh and twelfth are free ribs.

Sternum.—The sternum consists of a slender presternum of 22^{mm} length, followed by five wide sternal segments fused to each other. Opposite the point of union of each two segments the margin is expanded and offers an attachment for the costal cartilages. The sixth joint receives the two longer costal cartilages. Finally there is the xiphisternum, a thin expanded lamella of bone extending some 42^{mm} behind the rest of the sternum.

Fore limb.—The scapula is relatively long and narrow, the anterior margin extending upward in a decidedly concave curve, while the posterior margin is bounded by a like though less

concave curve. The high spinous crest divides the blade into a smaller prescapular and a larger postscapular fossa, the latter being bounded on the outside by a raised ridge running along the posterior margin. Along the upper edge, the spine of the scapula is thickened and rugose for muscular attachments. Proximally it extends forward, making a slender acromian

FIG. 14.
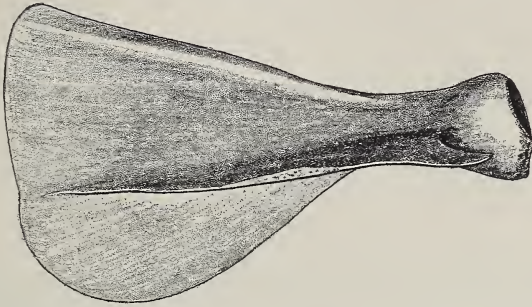
FIG. 14. *Stenomylus hitchcocki,* scapula seen from the dorsal side. x 1/2.

process which does not extend quite to the level of the glenoid fossa. The coracoid process is of but moderate dimensions and rolled inward, making a hook-like process. The shallow glenoid fossa is wider than high in the ratio of 4 to 3.

The humerus is slender and moderately long, the shaft having a well-marked sigmoid curvature. Corresponding to the shallow glenoid, the sessile head is but moderately convex. The greater tuberosity spreads along fully half of the width of the head, rising high above it, and overhanging the narrow bicipital groove; while the low lesser tuberosity of only half the width of its neighbor bounds the groove on the inner side. The bicipital groove when viewed from the front is seen to lie

FIG. 15.

FIG. 15. *Stenomylus hitchcocki,* humerus, seen from the dorsal side. × 1/2.

just to the inner side of the median line; and while narrow at the bottom, it expands up onto the lesser tuberosity, so that its width is about equal to that of the tuberosity. There is no trace of the bicipital tubercle dividing the groove into two

parts as in modern camels. The deltoid ridge is well-marked, rising just under the head and reaching down to about the middle of the shaft. The supinator ridge is barely visible. The trochlea stands at almost right angle to the length of the shaft, is a little higher on its inner than on its outer margin, and has the intertrochlear ridge but feebly developed and situated near the middle of the ulnar side. The anconeal fossa is low and deep, but does not perforate the shaft.

The radius and ulna are completely fused throughout their entire length, thus making a long, slender curved shaft. Using the length of the humerus as a unit, the length of the ulnar-radius would be 1·38, which is relatively longer than is the case in Póebrotherium (1·15) or the modern camel (1·25), but does not compare with the length of Oxydactylus. At both the upper and lower ends of the radius occurs a groove indicat-

Fig. 16.
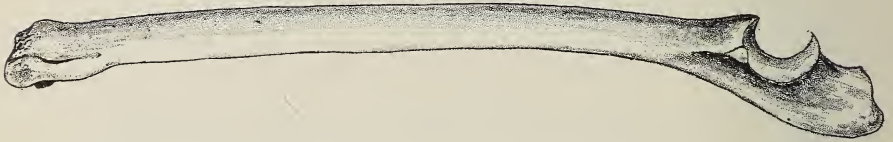
Fig. 16. *Stenomylus hitchcocki*, fused radius and ulna outer aspect. × 1/2.

ing the original boundaries of the ulna, the lower end of the groove penetrating so as to make a complete foramen. The compressed olecranon process is moderately high and wide, the upper anterior edge having in it a wide groove for the extensor tendon.* The humeral facets on the ulna are confined to the superior border of the sigmoid notch and are not confluent with the facets on the inferior border on either the inner or outer side. To this statement I found in ten cases but one exception, in which case the upper facet was confluent with the lower along the inner side of the sigmoid notch. It is a peculiarity of Póebrotherium and the Tylopoda generally that the humeral facet on the upper border of the sigmoid notch is confluent with the facets on the lower border only along the inner side. This typical tylopod condition is characteristic of the species *S. gracilis*† and *S. crassipes* also. On the distal end of the radius there are three facets for articulation with the carpal bones, that for the scaphoid being the largest and rectangular in outline ; that for the lunate being narrow and

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* This groove is characteristic of Pöebrotherium and Oxydactylus but not found in modern Tylopoda. Peterson does not find the groove in *S. gracilis*. Ann. Carnegie Museum, vol. iv, p. 292.

† Last cit. p. 455.

obliquely placed; while that for the cuneiform is triangular in outline and about half of it carried on the lower end of the ulna.

The carpus is compact and relatively high, the upper row of bones being the scaphoid, lunate and cuneiform as is typical for Tylopoda, their only peculiarity being that the lunate is relatively high and narrow. In the distal row the unciform is considerably deeper than the magnum; magnum and trapezoid are distinct, as is characteristic of tylopods; and the trapezium is represented by a tiny ossicle found also in Pöebrotherium. The pisiform is light and slender in its outlines.

Fig. 17.

Fig. 17. *Stenomylus hitchcocki*, carpus from the anterior side. × 1/2.

The metacarpus consists of the functional digits III and IV, together with tiny nodules representing the upper ends of digits II and V. Metacarpus II is a nodule some 10^{mm} in length, occupies a pit on the outer side of the third metacarpal, and carries two tiny artificial facets, one for the trapezium, the other for the trapezoid. Metacarpals III and IV are relatively long, almost equaling the humerus in this dimension, and separate from each other throughout their entire length. Along the upper two-thirds they are closely appressed and flattened, but through the distal third they spread apart and each metacarpal bone has a circular cross section. At the proximal end metacarpal III rises slightly above mc. IV and has on the end a larger facet for the magnum and a smaller one for the trapezoid, behind which is a tiny facet for the trapezium, while on the lateral border there is a smoothed surface for the vestigial mc. II. The proximal end of the fourth metacarpal has almost the entire

Fig. 18.

Fig. 18. *Stenomylus hitchcocki*, metacarpus from the anterior side. × 1/2.

upper surface given up to a large facet for the unciform, only a small spur rising behind and presenting facets to the magnum and trapezoid. On the ulna side there is a small excavation for a tiny nodule some $5-7^{mm}$ long and representing the fifth metacarpal. The distal ends of the third and fourth metacarpals carry the enlarged trochlea for the phalanges,

each with a high carina, which is, however, confined to the plantar side.

The two first phalanges are long and slender, with the distal ends expanded in true tylopod manner. The upper articular surface is a shallow concavity, a notch in the lower margin being the only indication of the carina of the metapodial. The distal phalanges are a trifle over half the length of the proximal ones, and like them are considerably expanded, though not to the extent found in modern camels. The upper articular face is a shallow groove, while that on the lower end extends from on the upper clear around on to the plantar surface. The ungual phalanges are high, long pointed, rounded on the outer side and nearly vertical on the inner face. They are typical for a distinctly digitigrade artiodactyl.

FIG. 19.

FIG. 19. *Stenomylus hitchcocki*, phalanges from the upper side. × 1/2.

The following figures give the measurements for the various front limb bones in the three known species:

	Scapula			Humerus			Ulnar-radius *		Metacarpus		Phalanges		
	length	width	width of fossa	length	diameter of head	diameter of trochlea	length	thickness	length	thickness	length		
											1	2	3
S. hitchcocki	138	78	22	168	26	27·5	225(191)	10·5	158·5	11·25	35	20	17
S. crassipes				194	32	28·57	229(194)	13	166	13·5	41		
S. gracilis				195	37	33	254(225)		184		44		

FIG. 20.

FIG. 20. *Stenomylus hitchcocki*, os innominatum seen from the lateral aspect. × 1/2.

Hind limb.—While in general the innominate bone is of the tylopod type, it is longer and relatively less expanded,

* In parenthesis is given the length of the radius.

especially in the iliac region. The upper end of the ilium is widely expanded and has a large area for the attachment on the sacrum. The neck of peduncle is longer and slenderer than usual. In the neighborhood of the acetabulum this bone is marked by several transverse ridges for the attachment of muscles quite as in the modern camels. The ischium is stout and expanded behind, a high slender process with its tuberosity rising on the superior ridge, and a second, the ischial tuberosity, being well developed at the posterior angle. The pubis is short and stocky, being expanded along the wide symphysis until it meets the ischium. In general conformity to the elongation of the pelvis the thyroid foramen is oval. The acetabulum is deep with a wide notch below.

The short femur has a marked curvature, being generally tylopod in character. Its head is small and rounded, with the pit for the round ligament well to the posterior side. The bridge between the head and the greater trochanter is both short and high, as is common to the camels generally ; and the greater trochanter rises high above it, making a wide notch, as

Fig. 21.

Fig. 21*a*.
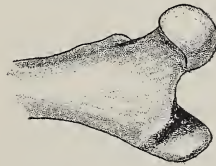
Fig. 21. *Stenomylus hitchcocki*, femur seen from the inner side. × 1/2.
Fig. 21*a*. Head of femur from the posterior side.

is also found in Pöebrotherium. The bridge is compressed antero-posteriorly, so that the digital fossa makes a deep pit, the bottom of which is about on a level with the lesser trochanter. This latter is situated high on the shaft, and from it runs a long ridge for muscular attachments. The rotular trochlea is broad and shallow and does not extend far up on the shaft. The external condyle is larger than the inner, which stands obliquely to the transverse axis of the shaft.

The patella is broadly oval and simple in outline, having nothing of the prolonged process common to later Tylopoda.

The slender tibia is about a fourth longer than the humerus, which, when compared with other tylopoda, is not long. The facets for the femoral condyles are wide and

nearly flat, being separated by a bifid tubercle. The cnemidial crest is extremely prominent, and extends about a third of the way down the bone. In the regions of the crest the cross section is triangular, but below the section is transversely oval. The distal end of the bone is expanded and the inner astragular facet much wider and shallower than the outer, the two being separated by a prominent septum. Both these facets and that on the septum are interrupted in the middle by a shallow depression, which extends from near the inner margin of the inner facet all but to the outer margin of the outer facet. This is a very marked characteristic of the modern camels, and begins as far back as in Pöebrotherium at least. The fibular facet is divided by the groove for the fibula shaft into anterior and posterior portions.

The proximal end of the fibula is reduced to a tiny spine fused to the fibula; the distal end to a nodular bone wedged
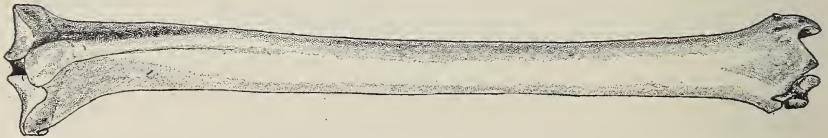
Fig. 23. *Stenomylus hitchcocki*, tibia and fibula from the anterior side. × 1/2.

in between the tibia and the calcaneum. It presents a tiny spur above, vestige of the original shaft, which fits into the groove on the tibia; and has a long continuous facet for articulation on the tibia. On the inner surface is a crescentic grooved facet for the astragulus, and on the lower surface a concave face for the calcaneum.

In conformity to the slender build the tarsus is narrow and high. The astragulus is narrow, with the external condyle somewhat higher than the internal. On the distal trochlea the facet for the cuboid is relatively narrow, while that for the navicular is proportionally wide. The plantar facet is comparatively narrow and small. In general, however, the astragulus would be recognized as tylopod. The calcaneum is of moderate length, being distinguished only by the consider-

able antero-posterior diameter of its shaft, this depth being especially great near the facet for articulation on the cuboid.

FIG. 24.

FIG. 24. *Stenomylus hitch-cocki,* tarsus. ×1/2.

The cuboid is compressed transversely, developed in the antero-posterior diameter, and carries a heavy plantar hook in the rear. The navicular is moderately developed, having a large concave face for the astragulus, which facet is notched on the inner margin. The lower side has a large facet for the ecto-meso-cuneiform and a smaller one for the ento-cuneiform, beside the lateral articulations where it rubs against the cuboid. The ecto-meso-cuneiform is free from the navicular, rectangular in

FIG. 25.

FIG. 25. *Stenomylus hitchcocki,* metatarsus from the anterior side. ×1/2.

form, and carries a single facet above for the navicular, a second below for the third metatarsal, and a third laterally for the ento-cuneiform. This last bone is a small nodule, with facets for the navicular, the ecto-meso-cuneiform and for the plantar process of the cuboid.

FIG. 26

FIG. 26. *S t e n o m y l u s hitchcocki,* phalanges of the hind foot, from the upper side. ×1/2.

The metacarpus consists of the functional digits III and IV, fused for a little more than the upper half of their length, a tiny nodule representing mt. II, and a still smaller nodule representing mt. V. In length the metatarsus is a trifle longer than the metacarpus. The vestige of the second metatarsal is 8^{mm} long by 6^{mm} wide and carries a tiny facet for articulation on the ento-cunei-form. The vestige of mt. V is but 3^{mm} long and 5^{mm} wide and has no facets. The upper end of the third metatarsal is occupied by the facet for the ecto-meso-cuneiform, that of mt. IV by the facet for the cuboid; then each contributes a strong process from the plantar side, on the inner side of which is a facet for the ento-cuneiform. The distal ends of the two metapodials spread in a characteristic

manner and each carries a broad trochlea for phalangeal articulation, and on each of these there is a prominent carina, which, however, is confined to the lower side and is not as prominent as the corresponding ones on the front metacarpals.

The proximal phalanges are a trifle shorter than those of the front foot, but otherwise similar in form. The distal and ungual phalanges are also very like those of the front foot.

The following figures give the comparative measurements of the three species of Stenomylus.

	Femur			Tibia		Metatarsus		Phalanges		
	length	diameter of head	diameter of trochlea	length	diameter of upper end	length	thickness	1	2	3
S. hitchcocki	176	18	31	210	32·5	166	11	36	20	17
S. gracilis	205	19	34	248	38	198		44		
S. crassipes	212	20	38·5	213	39	185	12·5			

CLASSIFICATION.

Stenomylus Peterson

The type species is *S. gracilis*, found by Peterson in the Lower Harrison beds of Sioux Co., Neb. The genus may be defined as follows: Stenomylus is a slender member of the Tylopoda, adapted to an upland life, with an extreme hypsodont dentition of $i.\frac{3}{3}c.\frac{1}{4}p.\frac{4}{4}m.\frac{3}{3} = \frac{22}{22} = 44$; the upper canines partly and the lower canines wholly incisiform, the first lower premolar tending the same way; vertebral formula c.7d.12-l.7c.14; an elongated neck; limbs didactyl and digitigrade; magnum and trapezoid free; and navicular and ecto-mesocuneiform free. Horizon, Lower Harrison.

At present three species are distinguished as follows:

Stenomylus gracilis Peterson

Distinguished by larger size, narrower upper molars, lower canine less incisiform, diastema between lower premolar 1 and 2 shorter, lower jaw narrower, metacarpals coössified a part of their length, and in details the most specialized of the three species.

Stenomylus hitchcocki sp. nov.

See preceding description of osteology for details. The species is distinguished by its small size, relatively narrow

molars, lower canine completely caniniform, diastema between lower premolar 1 and 2 relatively long, premolar 2 greatly reduced, lower jaw deep, metacarpals separate their entire length. In general the species is the least specialized of the three.

Stenomylus crassipes sp. nov.

The species is distinguished in that while the size of the skull is approximately that of *S. gracilis*, the neck and limbs are markedly shorter and heavier; the premolars are much more reduced; and the lower canine is completely incisiform.

To this the following details may be added as a description of the species. The type is number 2150 in the Amherst College collection, and was found seven miles northeast of

FIG. 27.
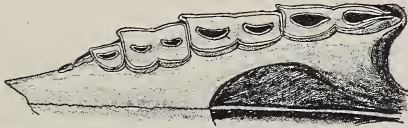
FIG. 27. *Stenomylus crassipes*, upper dentition and palate. × 1/2.

Agate, Sioux Co., Neb., in the uppermost sandstones of the Lower Harrison beds. The type consists of the skull (lacking premaxillæ) and lower jaws, together with 6 cervical, and 3 dorsal vertebræ, scapula, humerus, ulno-radius, carpals, metacarpals, and phalanges. With this has been used specimen 14220 of the American Museum of Natural History, consisting

FIG. 28.
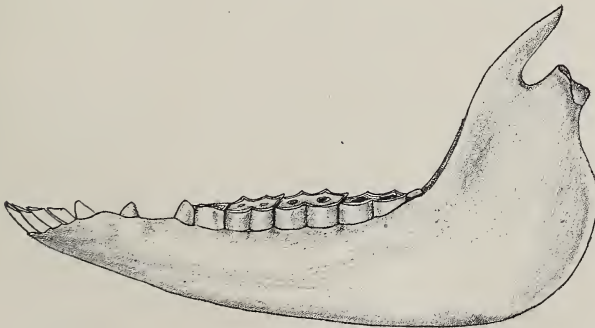
FIG. 28. *Stenomylus crassipes*, mandible and lower dentition for the outer side. × 1/2.

of nearly all parts of the skeleton; but the find is composed
of the bones of more than one individual.

As is characteristic of the skeleton, the skull is heavily
built, the cranial region being short, and the frontals wide.
The premaxillæ and premolar regions are shortened over the
corresponding regions of *S. gracilis*, but the back of the skull
is about the same size. In dentition the upper incisors are the
usual well-developed chisel-shaped teeth crowded together;
the canine is reduced and separated from the incisors by a
diastema of 4^{mm}, being a like distance from the tiny first

Fig. 29.
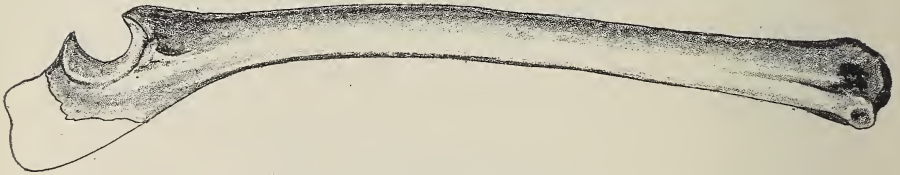
Fig. 29. *Stenomylus crassipes*, fused radius and ulna from the outer
aspect.   × 1/2.

premolar. The second premolar is also much reduced, as is
the third and the fourth, this last being 2^{mm} shorter than its
counterpart in *S. gracilis*. The molars, however, are relatively
enlarged, corresponding in length and width with those of
S. gracilis. The lower jaw is shortened in the regions in
front of the molars, the lower canine being wholly incisiform,
as is also the first premolar which is placed close to the canine,
all five of these teeth being grouped in the incisor aggregation.
The second premolar has a considerable diastema, both in
front and behind it, both being, however, shorter than those of
S. gracilis. The third and fourth premolars are also reduced,
and the molars are enlarged corresponding to those in the
upper jaw.

The cervical vertebræ resemble those of *S. hitchcocki* in
character, but are thicker and shorter than in that of the *S.
gracilis* species. From the table of measurements it will appear
that the humerus is about the same length as that of *S. gracilis*,
but the ulno-radius is some 30^{mm} shorter and at the same time
much stockier. In the same way the metacarpus is materially
shorter and heavier, mt. III and mt. IV being fused together
for about half their length as in *S. gracilis*. The femur is
relatively long, actually longer than that of *S. gracilis*, but as
in the fore limb the tibia is extremely short, 35^{mm} shorter than
that of *S. gracilis*. The metatarsus is also short and stocky, mt.

	Hypisodus	Stenomylus	Poëbrotherium
1	$i\frac{3}{3}c.\frac{1}{1}p.\frac{4}{4}m.\frac{3}{3}$	$i\frac{3}{3}c.\frac{1}{1}p.\frac{4}{4}m.\frac{3}{3}$	$i\frac{3}{3}c.\frac{1}{1}p.\frac{4}{4}m.\frac{3}{3}$
2	Dentition hypsodont	Dentition extremely hypsodont	Dentition brachydont.
3	Upper canine subincisiform	Upper canine subincisiform	Upper canine caniniform.
4	Lower canine incisiform	Lower canine incisiform	Lower canine caniniform.
5	Lower premolar 1 incisiform	Lower premolar 1 subincisiform	Premolar 1 normal.
6	Bulla large, hollow, fused to paroccipital process	Bulla large filled with canceolated tissue, fused to paroccipital process	Bulla large filled with canceolated bone, fused to paroccipital process.
7		Hard palate ends opposite front of second molar	Hard palate ends opposite back part of second molar.
8		Vertebral formula c.7d.12l.7s.4c.14.	Formula c.7d.12l.7s.4c.14.
9		Vertebrarterial canal passes through the pedicle of the neural arch	Vertebrarterial canal passes through pedicle of neural arch.
10		Cervical vertebræ elongated, neural spines on 2-6 vestigial	Cervical vertebræ elongated, neural spines on 2-6 greatly reduced.
11	Magnum and trapezoid fused	Magnum and trapezoid free	Magnum and trapezoid free.
12		Ulna facets on upper border of sigmoid notch interrupted on outer or both sides	Ulnar facets interrupted along the outer side.
13	4 functional digits on fore limb, upper and lower ends of mc. retained	2 functional digits retained on fore limb, upper ends only of vestigial digits retained	2 functional digits retained on fore limb, upper ends only of vestigial digits retained.
14	Navicular and cuboid fused	Navicular and cuboid free	Navicular and cuboid free.
15		Distal tibial facets interrupted	Distal tibial facets interrupted.
16	2 functional digits on hind foot, lateral mt. retain both upper and lower ends and digits	2 functional digits on hind foot, lateral mt. lose lower ends and digits	2 functional digits retained on hind foot. Lateral digits lose lower ends and digits.

III and mt. IV being fused rather more than half their length. From the foregoing it will appear that *S. crassipes* is a species closely resembling *S. gracilis*, but differentiated by the shortening of the limbs, especially below the elbow and knee, a heavier shorter-limbed type being thus evolved.

Affinities.—In his descriptions Peterson has placed the genus Stenomylus among the Tylopoda, near the long-limbed

FIG. 30.
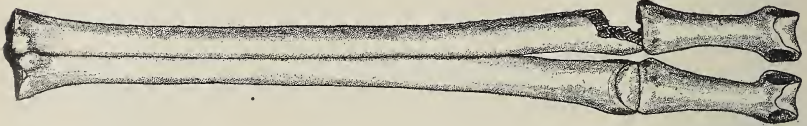
FIG. 30. *Stenomylus crassipes*, metatarsus and proximal phalanges. × 1/2.

type Oxydactylus; while Matthew* has associated the genus with Hypisodus among the Hypertragulidæ. In order to show concisely the points of likeness and difference to one or the other of these types, the characters of Stenomylus are in the above diagram arranged in parallel columns with those of Hypisodus on the one side and with Pöebrotherium on the other, the latter being used as illustrating a primitive tylopod.

From the foregoing table it is evident that in the matter of dentition (number 1-5) the genus Stenomylus approximates Hypisodus; but in the other skeletal features it is distinctly allied to the Tylopoda. This is especially marked in such deep-seated and fundamental characters as the cancellous bone in the bulla, the position of the vertebrarterial canal, the matter of the fusion of the magnum and trapezoid, the matter of fusion of the navicular and cuboid, and the manner in which the lateral digits have been reduced. These are characters less liable to modification on a change of habit, while the dentition is the first to respond to changes in the matter of food. I feel therefore that Stenomylus should be placed among the Tylopoda. Then as it is evident that the dentition is aberrant in its extreme hypsodont specialization, and presuming that this characteristic has been acquired in conjunction with a special feeding habit (which feeding habit would presumably be the same as characterizes Hypisodus, but a parallel adaptation), I feel that Stenomylus should be set off by itself. The habit, which is general to forms having this hypsodont dentition, is feeding on hard grasses, usually on the open prairies, the grass having in its stem considerable quantities of silica which causes extremely rapid wear of the teeth. I take it then that while

* Bull. Amer. Museum Nat. Hist., xxiv, 1908, p. 539.

the typical tylopod contemporaries of the Protomeryx type, fed on a generalized diet, and retained their brachydont dentition, and while the long-limbed Oxydactylus group were feeding on leaves and shrubbery, and likewise retained their brachydont dentition, that there arose another group of upland tylopods which took up the grazing habit, and these developed the hypsodont dentition. These then represent a separate branch of the Tylopoda, which must have had its beginning in the later part of the Oligocene, being derived from Pöebrotherium, which genus Stenomylus resembles in most of its characters. This group of tylopods seems to have flourished greatly during the lower Miocene, especially during the Lower Harrison, outside of which horizon it has not been found. I see no especial affinity to Oxydactylus other than that common to all Tylopoda. The affinities may be graphically indicated as follows:

Middle Miocene	Alticamelus	Protomeryx	
Lower Miocene	Oxydactylus	Protomeryx	Stenomylus
Upper Oligocene	Paratylopus		
Middle Oligocene	Paratylopus	Poebrothérium	
		Poebrotherium	

The Lower Harrison beds then will show three types of Tylopoda, each presumably in a different type of habitat, the Stenomylus in the upland, the Protomeryx near or in the valleys where a considerable variety of vegetation flourished, and the Oxydactylus in the intermediate country and probably feeding on leaves and twigs of trees.

Collectors in the Lower and Upper Harrison beds can not but be greatly impressed by the great variety of tylopods which occur in these beds, there being beside the already known species certainly as many more indicated by the great variety of toe and isolated bones found. The Lower Miocene seems to be the period of especial luxuriant development for all types of camel-like forms.

Amherst College.

ART. XXV.—*The Refractive Index of Canada Balsam;* by
WALDEMAR T. SCHALLER.

THE refractive index of Canada balsam, as it occurs in the
thin sections made for the U. S. Geological Survey, was
determined on the request of Mr. F. C. Calkins, who had
found* that the index, or n, was not absolutely constant but
varied between two extremes. By the examination of 300
slides, he found n to reach and even slightly exceed ω of quartz
(1·544), though n was found greater than 1·544 only in the
proportion of one slide in a hundred. The excess was very
small and the balsam was decidedly yellow. The lowest value
found by him was about 1·535 ± ·002.

The value of n for sodium light was determined on an Abbe-
Zeiss refractometer by total reflection on three kinds of slides,
which were (1) not cooked as much as usual, (2) cooked as
ordinarily done, and (3) over-cooked. The differences found
between (1) and (2) are very slight, and, in fact, the individual
values show almost as much variation as between the different
groups. The values obtained are :

(1)	(2)	(3)
		1·543
1·539	1·536	1·540
$n = $ 1·538	$n = $ 1·538	$n = $ 1·540
1·539	1·539	1·542
		1·541

The average values are for (1), 1·5387 : for (2), 1·5377 ; for
(3), 1·5412, or, as the average of all, 1·5395, which is almost
identical with the value (1·5393) given by Becker† in 1898.
A determination of n in a slide six years old gave the value
1·5390. These values show that, in general, n lies very close
to 1·539 and that this value may well be used in a study of a
thin section, while the actual possible variation was found by
Mr. Calkins to be from 1·535 to 1·545, though the extreme
values are but seldom reached. The uncooked, liquid balsam
has a refractive index of 1·524, which, after cooking, rises to
1·54. The older a slide, the higher the index of the balsam
becomes, which after a time, especially if the air has access,
reaches towards the highest value, or 1·545.

Chemical Laboratory, U. S. Geological Survey.

* Science, vol. xxx, p. 973, Dec. 31, 1909.
† This Journal [4], v, p. 349.

Art. XXVI.—*Stratigraphy of the upper Carboniferous in West Texas and Southeast New Mexico;* by G. B. Richardson.[*]

Introduction.

In the trans-Pecos portion of Texas and New Mexico, everywhere that basal strata of upper Carboniferous age have been observed they lie unconformably on older Paleozoic strata or on pre-Cambrian rocks. This unconformity marks one of the important time breaks in the geological history of the southwest. The upper Carboniferous rocks consist of limestone, shale, sandstone, and variegated red beds. Limestone, with locally a basal conglomerate, usually forms the lower part of the section, and the uppermost strata are red beds which are unconformably overlain by deposits of Triassic age. The sequence, however, is extremely varied. The lowest rocks are Pennsylvanian and the uppermost are Permian, but where to draw the dividing line between Pennsylvanian and Permian in this region is an open paleontological question. These rocks comprise a maximum of more than 15,000 feet and thus constitute one of the thickest upper Carboniferous sections known.

In connection with work in the Van Horn quadrangle in west Texas, it became desirable to examine the northward continuation of the rocks there exposed, and last summer (1909) I had the opportunity to make a short trip to the Guadalupe and Sacramento mountains and adjacent portions of New Mexico. The result enables a comparison of several upper Carboniferous sections in the little-known area between the Rio Grande and Pecos River. In the following descriptive sections I have summarized the results of my own work of the past several seasons, and for comparison I have referred to the work of J. A. Udden in the Chinati Mountains and of C. H. Gordon and Willis T. Lee in Rio Grande Valley. I gratefully acknowledge my obligations to Dr. Girty, who has accompanied me on several trips into the field and has examined all of my collections of fossils.

Section in Chinati Mountains, Texas (No. 1, figs. 1 and 2).— J. A. Udden[†] in 1904 reported the presence of some 6,000 feet of upper Carboniferous rocks in the Chinati Mountains, about 175 miles southeast of El Paso. These consist of conglomerate, sandstone, shale, and limestone, which he separated into

three formations called the Cibola beds, the Alta beds, and the Cieneguita beds, and named the whole the Chinati series. These rocks are delimited below by intrusive granite and are unconformably overlain by Lower Cretaceous strata. The fossils obtained from Udden's Chinati "series," Dr. Girty

FIG. 1.

FIG. 1.   Map of New Mexico and west Texas showing location of sections.

informs me, are more suggestive of the Hueco fauna than of the typical Guadalupian.   Recently Stuart Weller,* in describing some crinoids from the Cibola beds, has referred to them as Permian.   Correlation by stratigraphic tracing is precluded by the isolated occurrence of the rocks in the Chinati Moun-

* Journal of Geology, vol. xvii, pp. 623–635, 1909.

FIG 2.
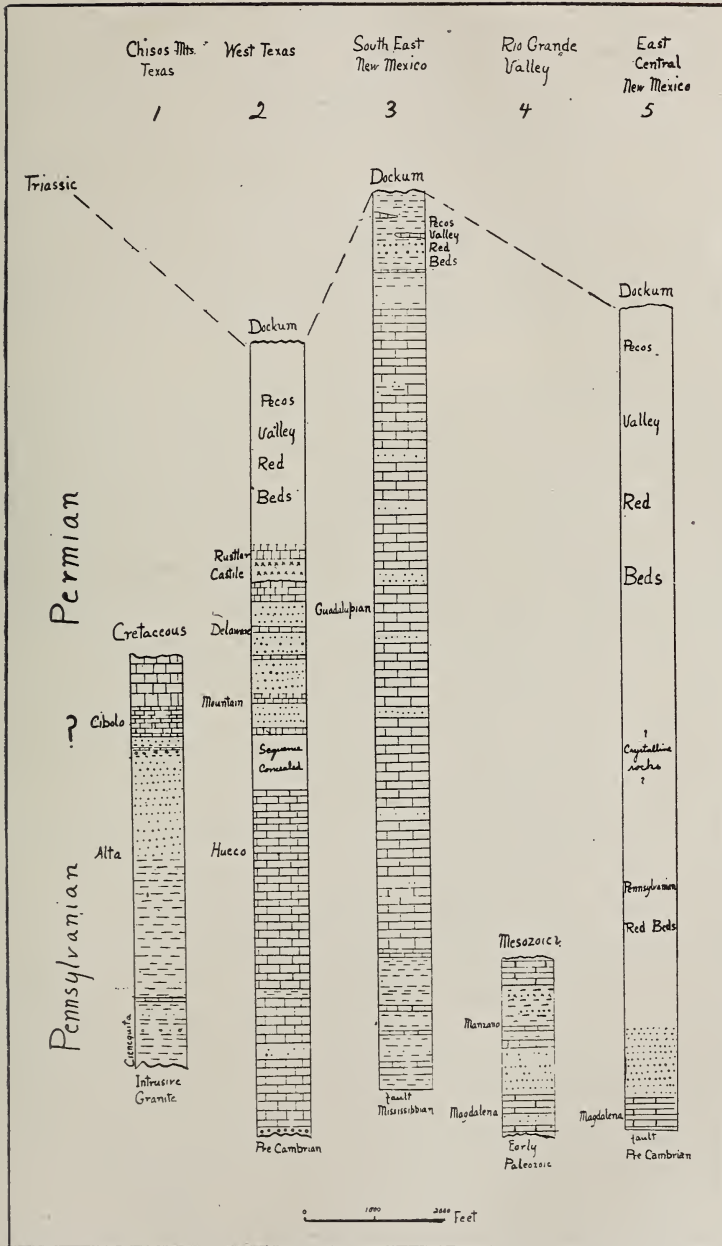
FIG. 2. Generalized columnar sections of upper Carboniferous strata in southeast New Mexico and west Texas.

tains, they being more than 50 miles distant from the nearest known Carboniferous outcrops farther north, in the vicinity of the Texas and Pacific Railway, where what are presumably equivalent beds are all limestone. The section in the Chinati Mountains compared with those described below illustrates the variability of the upper Carboniferous deposits in the area under consideration.

Section in Rio Grande Valley, New Mexico (No. 4, figs. 1 and 2).—Rocks of Carboniferous age have long been known to occur in the ranges on both sides of the Rio Grande in New Mexico, although the section there exposed is not nearly as complete as farther east. Gordon, Lee and Girty* have recently summarized the knowledge of the upper Carboniferous in that region and they divide the rocks into the Magdalena and Manzano groups.

The Magdalena group, the older of the two, consists chiefly of limestone but it contains minor beds of shale and sandstone. Gordon states that in Socorro, Valencia, and Bernalillo counties the Magdalena group comprises 1,000 to 1,300 feet of sediments, which he divides into the Sandia formation (consisting of sandstone, shale, and limestone) and the overlying Madera limestone. In southern New Mexico the Magdalena group is chiefly limestone and its outcrop in the San Andreas Range, save for minor interruptions caused by intrusive igneous rocks and by deposits of unconsolidated Quaternary debris, can almost be traced into the Hueco limestone on the western flanks of the Franklin Range in Texas. Pennsylvanian fossils from the two limestones confirm this correlation. The Magdalena is separated from the overlying Manzano group by a local unconformity which is not persistent throughout southeast New Mexico and west Texas.

In the northern part of Rio Grande Valley the Magdalena group is overlain by a mass of red beds to which Herrick applied the name Manzano. Lee has recently revised the nomenclature and includes in the Manzano group the following three formations named, in ascending order: the Abo sandstone, consisting of a maximum thickness of 800 feet of coarse red to purple sandstone with subordinate shale and earthy limestone; the Yeso formation, consisting of 1,000 to 2,000 feet of alternating vari-colored strata of shale, friable sandstone, gypsum, and earthy limestone; and the San Andreas, a massive limestone of variable thickness which overlies the red beds in the southern part of the Rio Grande region. Farther north the San Andreas limestone becomes less promi-

* Gordon, C. H., Notes on the Pennsylvanian Formations in the Rio Grande Valley, New Mex., Jour., of Geology, vol. xv, 1907, pp. 805–816; Lee, Willis T., and Girty, Geo. H., The Manzano Group of the Rio Grande Valley, New Mex., Bull. U. S. Geol. Survey, No. 389, 1909.

nent and finally disappears and the top of the Manzano group is marked by an erosional unconformity above which are strata of unknown age. Numerous fossils, which are described by Dr. Girty in the bulletin above referred to, have been found in the Manzano group, those occurring in the several formations being not radically different. They are referred to the Pennsylvanian and the Manzano group is correlated with part of the Hueco formation.

Section in west Texas north of the Texas and Pacific Railway (No. 2, figs. 1 and 2).—One of the thickest sections of the upper Carboniferous in the area considered in this paper is exposed in Texas between the western escarpment of the Staked Plains and the Rio Grande. Although this section is not complete, being interrupted by faults and by a local unconformity, it is more than 10,000 feet thick.

The lower part of the section consists of the Hueco formation, which underlies an area of several hundred square miles and outcrops in the Hueco, Franklin, Finlay, Cornudas and Sacramento mountains and in the Sierra Diablo. It is in many areas mainly limestone but in other areas consists also of shale and sandstone, including red beds, and in places a basal conglomerate is well developed. A well recently sunk in the Hueco formation in the drift-covered area between the Sierra Diablo and the Cornudas mountains, about 40 miles north of Sierra Blanca, is reported to have encountered a thin deposit of red beds intercalated in the prevailing limestone. This is of interest in the correlations discussed below (p. 335). Exact measurements are difficult to obtain, but in Texas the Hueco formation is approximately 5,000 feet thick. Wherever exposed, the base of the Hueco lies unconformably on rocks ranging in age from pre-Cambrian to Silurian. Over wide areas the top of the formation has been eroded; locally the Hueco is overlain by Lower Cretaceous strata and relations to higher rocks in the Carboniferous section are completely concealed in Texas by the bolson plain known as Salt Flat.

The Hueco formation bears a rich Pennsylvanian fauna which Dr. Girty states is widely distributed over the Western States and which he provisionally correlates with the fauna of the Aubrey group in Arizona, etc.

The upper Carboniferous section is continued east of the Salt Flat bolson, in the Delaware and Guadalupe Mountains, by 4,000 feet of strata which contain Girty's[*] Guadalupian fauna. These rocks have been separated into the Delaware Mountain formation, consisting of 2,200 feet of variable beds of sandstone and limestone, and the overlying Capitan limestone,

[*] Girty, George H., The Guadalupian Fauna: Prof. Paper U. S. Geol. Survey, No. 58, 1908.

which is at least 1,800 feet thick.   The stratigraphic position of these formations is not determinable in Texas, but their position in the upper Carboniferous section is shown in the northern part of the Guadalupe Mountains in New Mexico and will presently be referred to.   On the eastern flanks of the Delaware Mountains, which constitute virtually a dip slope, the Capitan limestone is missing—presumably either because of non-deposition or erosion—and the Delaware Mountain formation is directly overlain by a mass of bedded gypsum. This deposit, named the Castile gypsum, is approximately 300 feet thick and covers an area of several hundred square miles. The gypsum is overlain by magnesian limestone and associated lenses of sandstone, in all about 200 feet thick, which have been named the Rustler formation.   The section is here interrupted by Quaternary deposits in Pecos Valley, but occasional outcrops of red beds, which overlie the Rustler formation, are locally exposed and it is evident that both the Castile gypsum and the Rustler formation are members of the red bed complex that underlies the valley of Pecos River.

Red Beds of Pecos Valley.

The red beds of Pecos Valley were examined in 1891 by W. F. Cummins,[*] and they have been studied in the vicinity of Roswell by C. A. Fisher,[†] but thick deposits of unconsolidated Quaternary debris conceal complete exposures and comparatively little is known of them.   They consist of a group of vari-colored sandstone and shale, red predominating, interstratified with beds of magnesian limestone and gypsum.   In detailed study it is desirable to divide these rocks into a number of formations of comparatively limited extent similar to the Castile gypsum and the Rustler formation, which when traced for a number of miles beyond the area in which they were named, lose their individual character and become difficult to recognize as such.   The formations of the red bed group are lenticular in character but the group as a whole is a distinct unit.

Measurements of thickness are practically impossible to obtain short of drilling, and as yet no hole has been sunk through the entire group.   Minimum figures, however, are afforded by two deep wells ; one, sunk by Capt. John Pope in 1855–57, about ten miles east of where Delaware Creek enters Pecos River in New Mexico near the Texas boundary, was 1,050 feet deep and appears to have been in red beds all the

[*] Cummins, W. F., Notes on the Geology West of the Plains :   Third Ann. Rept. Geol. Survey of Texas, 1892, pp. 201–218.

[†] Fisher, C. A., Geology and Underground Waters of the Roswell Artesian Area, New Mexico :   Water Supply Paper U. S. Geol. Survey, No. 158, 1906.

way;[*] another was sunk by H. J. Hagerman in 1909 about 20 miles east of Roswell, New Mexico, in section 5, T. 11 S., R. 28 E., to a depth of 2,850 feet. Apparently this well was begun near the top of the local section of red beds and was continued in them to a depth of 1,625 feet, beneath which limestone, including some thin sandy layers, was encountered down to the bottom of the well. A minimum thickness therefore of these red beds is 1,600 feet.

The red beds of Pecos Valley are delimited above, as Cummins and Drake[†] determined a number of years ago, by an erosional unconformity which separates them from the overlying Dockum formation of Triassic age.

The lower limit of the red beds of Pecos Valley, defined as the lowest occurrence of either red strata or of gypsum, is variable and is not a definite horizon, but rather forms a zigzag line extending diagonally across the strike of the rocks. In Texas the basal formation of the red bed group, the Castile gypsum, rests directly on the Delaware Mountain formation. Farther north in New Mexico, southwest of Carlsbad, the red beds rest on strata which are a few thousand feet above the Capitan limestone but which are conformable with it.[‡] On the eastern flanks of the Guadalupe Mountains west of Carlsbad red beds occur at a somewhat lower horizon interbedded with these strata which lie above the Capitan limestone. Local exposures clearly show the "fingering out" of red beds and their merging into the more sombre-colored deposits, the occurrence of the red coloration extending across the strike of the rocks. West of Roswell the main red beds lie upon a massive limestone which is the northern continuation of the rocks that have just been referred to. Deposits of red sandstone and shale are also intercalated in the limestone west of Roswell. Farther north, along the line of the Eastern Railway of New Mexico, as shown below, almost the entire Carboniferous section is composed of red beds.

Fossils are of rare occurence in these red rocks, although at a few localities shells have been obtained from the interbedded limestones, and fragments of fossil wood also have been found. Dr. Girty does not feel justified in saying anything definite as to the age of the fossils collected from the red beds either by Mr. Fisher or by myself. These include *Schizodus ovatus*

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[*] Annual report of Capt. A. A. Humphreys to the Secretary of War, December, 1858.

[†] Drake, N. F., Stratigraphy of the Triassic Formation in Northwest Texas : Third Ann. Rept. Geol. Survey of Texas, 1892, pp. 227–235.

[‡] When detailed work is done in this region these strata which lie above the Capitan limestone will be separated into formations and probably included in the same group with the Delaware Mountain formation and the Capitan limestone, but it is not desirable now to introduce new names.

and *Pleurophorus aff. subcostatus* from seven miles northwest of Roswell, New Mexico, and a *Schizodus* having the general shape of *S. harei*, and a form suggesting by its shape a small *Myalina* from the Rustler Hills, El Paso County, Texas. Nevertheless the stratigraphy indicates that the red beds of the Pecos Valley are to be correlated with part of the Permian red beds of Oklahoma and northwest Texas, for they were connected by tracing around the northern border of the Staked Plains by W. F. Cummins in 1891 ; and on my map of trans-Pecos Texas, published in 1904, the Castile gypsum and Rustler limestone were referred to the Permian with a query. Cummins' work has been confirmed by C. N. Gould, who has mapped the Greer and Quartermaster formations, which are part of the Permian red beds of Texas and Oklahoma, across several counties in the panhandle of Texas, and along Canadian River as far as the Texas–New Mexico boundary.*

This stratigraphic correlation is in agreement with paleontologic data recently obtained by Dr. J. W. Beede, with whom I was associated in the field for a few days in 1909 and who found fossils in a limestone in the red beds south of Lakewood, New Mexico, which he correlates with the Whitehorse–Quartermaster fauna. A discussion of this correlation, however, is outside the scope of the present paper, and is left to Dr. Beede.

Section across east central New Mexico (No. 5, figs. 1 and 2).—In 1905 I traversed the line of the Eastern Railway of New Mexico, then under construction, and made the following observations between the Manzano Range and Pecos River.

This region, considered as a whole, is an undulating plateau 125 miles wide. On the west the plateau is separated from Rio Grande Valley by the Manzano Range, and on the east the escarpment of the Staked Plains rises above Pecos Valley. The western portion of the plateau, averaging about 6,000 feet in elevation, is dissected by the north-south trending Estancia and Encino valleys and is surmounted by occasional isolated mesas, while the eastern portion slopes gradually to an elevation of 4,000 feet at Pecos River. The topography of this belt is in marked contrast to that of the mountainous area south of it in New Mexico and Texas, where other sections of upper Carboniferous rocks described in this paper are exposed, the difference in topography being largely due to the varying hardness of the rocks. This contrast further emphasizes the variability of the upper Carboniferous stratigraphy.

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* Gould, C. N., Geology and water resources of the eastern portion of the Panhandle of Texas : Water Supply Paper U. S. Geol. Survey, No. 154, 1906 ; and Geology and water resources of the western portion of the Panhandle of Texas : Water Supply Paper U. S. Geol. Survey, No. 191, 1907.

At the base of the Manzano Range the extreme western part of the plateau is underlaid by several feet of limestone (Magdalena ?) containing a Pennsylvanian fauna, allied to that of the Hueco formation, and above the limestone there is a great mass of red beds that outcrop as far as the vicinity of Lucy, a railroad station about 45 miles east of the Manzano Range. The rocks consist of prevailing fine-textured dark red sandstone with which are associated layers of red sandy shale and lenses of gypsum ; and thin beds of limestone, containing numerous Pennsylvanian fossils, also occur towards the upper part of the section.

Five miles south of the town of Willard, at the crossing of the Santa Fe Central Railway, 25 miles east of the Manzano Range, the following section was measured :

Section Five Miles South of Willard, New Mexico.

	Feet.
Limestone, grey, cherty, fossiliferous	50
Sandstone, grey, friable	300
Sandstone, red	10
Gypsum, massive, bluish white	100

The fossils in the limestone are of Pennsylvanian age, so that the great mass of red beds lying between limestones containing Pennsylvanian fossils clearly are of that age. These beds belong to the Manzano group, but on account of the varied stratigraphy it cannot at present be stated that the limestone at the top of this local section is the San Andreas limestone, or one of several other lenses in the Manzano group.

The eastward continuation of the red beds is interrupted at the divide between Estancia and Encino valleys by an area of low relief, about ten miles wide, that is underlain by a crystalline complex consisting of granite and other igneous rocks, slate, etc., which apparently represent the southward continuation of the pre-Cambrian core of the Rocky Mountains. About fifteen miles southeast of this area, northeast of Torrance on the El Paso and Southwestern Railroad, isolated areas of mica schist surrounded by unconsolidated deposits were also found. The relations of these ancient rocks to the red beds is obscured by Quaternary material and is not known.

East of this crystalline area the character of the underlying rocks is much obscured by surface debris, but the general low eastward dip apparently prevails throughout the region. Lion Summit, just east of Encino Valley, is formed by about 50 feet of white sandstone capped by a bed of limestone in which no fossils were found. Thence eastward down the long, gentle slope of 60 miles to Pecos River there are few exposures of

bed rock. The surface is generally covered by Quaternary debris, but a number of exposures show the presence of red beds and gypsum dipping low to the east, and records of deep wells indicate that all of this area is underlain by red beds. For instance, a well at Vaughan, a station at the crossing of the El Paso and Southwestern Railway near the western end of this long slope, is 1,355 feet deep in red beds all the way; and a well at Ricordo, 62 miles southeast of Vaughan along the railroad and thirteen miles west of Pecos River, shows red beds, below a superficial coating of sand, down to a depth of 595 feet. It appears then that red beds dipping eastward at a low angle underlie the entire area between Vaughan and Pecos River, and assuming a dip of only one degree a thickness of approximately 6,000 feet of strata is thus indicated. Practically the entire plateau, therefore, between the Manzano Range and Pecos River, with the exception of a small area of ancient crystalline rocks, is underlain by gently east dipping red beds which, unless they are duplicated by faulting, of which no evidence has been obtained, are more than 9,000 feet thick.

No fossils, excepting fragments of wood, have been found in the red beds between Willard and Pecos River. A thin section of a fragment of wood from the red beds one mile east of Pecos River, 65 miles north of Roswell, New Mexico, was reported on by David White as follows: This fragment "has lost many of its trachial punctations by reason of advanced bacterial action which has also obliterated many of the medullary rays. On the basis of the remaining ray features and the occasional obscure pores, I am disposed to regard this specimen as post-Pennsylvanian. These rocks are the northern continuation of the red beds of Pecos Valley described above, and here also they are unconformably overlain by the Dockum formation (Triassic), which in turn is succeeded by the Tertiary deposits of the Staked Plains.

The point to be emphasized about this section between the Manzano Range and Pecos Valley is that almost the entire history of upper Carboniferous sedimentation is a record of red bed deposition, which is in marked contrast with the corresponding record in southern New Mexico and Texas.

Section across southeast New Mexico between Tularosa Desert and the Staked Plains (No. 3, figs. 1 and 2).—The section in the Sacramento and Guadalupe Mountains in southeast New Mexico exposes a great thickness of rocks and reveals the stratigraphic position of the strata which contain Girty's Guadalupian fauna, the correlation of which has caused dispute.

East of Tularosa Desert, the local name of the bolson plain

along which the El Paso and Southwestern Railroad extends between El Paso and Alamogordo, a zone of faulting marks the western foot of the Sacramento Mountains. Red beds, in fault contact with limestones of Mississippian age, form the local base of the upper Carboniferous section in this vicinity. These red beds constitute the western escarpment of the Sacramento Mountains, and are at least 2,000 feet thick, the section being obscured by faulting. They consist of a variegated group of prevailing red sandstone and shale, minor beds of buff sandstone and drab shale, and lenses of gray limestone. The red beds are overlain by a great mass of limestone and subordinate gray sandstone having a minimum thickness of 3,000 feet. These upper strata form the eastern slope of the Sacramento Mountains, which is thirty miles long, the strata dipping low to the east at an angle slightly greater than the inclination of the surface. Numerous fossils have been collected at various horizons from the limestone lenses in the red beds and from the overlying strata. Dr. Girty states they are all unmistakably Pennsylvanian and correlates them with the fauna of the Hueco formation. This correlation is strengthened by the partial tracing of the beds from the southeastern base of the Sacramento Mountains into limestones in the upper part of the Hueco formation exposed in Texas east of the Cornudas Mountains; and by the recent discovery of red beds in a well north of Sierra Blanca (p. 329). This latter occurrence appears to represent the southern wedging out of the mass of red beds exposed in the escarpment of the Sacramento Mountains.

The description of this section may here be interrupted to revert to the rocks of the Guadalupe Mountains, the northern end of which coalesces with the eastern base of the Sacramento Mountains. It will be recalled that the rocks of the Guadalupe Mountains at their southern termination in Texas, near the New Mexico boundary, consist of about 4,000 feet of sandstone and limestone which have been separated into the Delaware Mountain formation and the Capitan limestone, the relation of which to the Hueco limestone, in Texas, is concealed by the Quaternary deposits of the Salt Flat bolson. In the New Mexico portion of the Guadalupe Mountains a more complete section is exposed than in Texas, and there the Capitan limestone is overlain by a few thousand feet of limestone and sandstone as stated above (p. 331). Throughout this entire region, the general dip is eastward at a low angle. The stratigraphy is varied, and both the Delaware Mountain formation and the Capitan limestone lose their individuality when traced far along the strike. The massive Capitan limestone, for

instance, locally gives way to or is replaced by thinner bedded limestone and intercalated beds of sandstone, so that it is difficult to distinguish the northward continuation of the formation from the overlying and underlying beds. Considered as a whole the rocks of the Guadalupe Mountains constitute a group which in detailed work will be separated into units similar to the Delaware Mountain formation and the Capitan limestone. A red bed phase is developed in the upper part of the Guadalupe Mountain section 25 miles southwest of Carlsbad, where, as stated above, deposits of red sandstone and shale are present in the prevailing limestone and gray sandstone. To the east the red sediments become more abundant, and in Pecos Valley the strata of the Guadalupe Mountains are overlain by the red beds of Pecos Valley.

Followed along the strike to the northern termination of the Guadalupe Mountains in the vicinity of Penasco River, a distance of fifty miles north of the Texas–New Mexico boundary, the Guadalupian series are found to overlie the limestones and sandstones, which have just been described, on the eastern flanks of the Sacramento Mountains. No evidence of any disturbance which would alter the apparent simple relations of the rocks was observed. The zone of faulting developed along the western base of the Guadalupe Mountains near the state boundary fades away northward, and is represented in Panasco Valley, if at all, by a belt of gently undulating dips. The strata of the Guadalupe Mountains, therefore, overlie the Hueco formation conformably, and in turn are overlain by the red beds of Pecos Valley into which they tend to merge.

Comparatively few fossils have been obtained from the rocks in the New Mexico portion of the Guadalupe Mountains, and these Dr. Girty states show but little relationship to the typical Guadalupian fauna from the Texas portion of the mountains.[*] It is not within the province of this paper to consider the Guadalupian fauna or its relation to others which is discussed by Dr. Girty. It seems probable, however, that the difference in the fauna in the same group of rocks in the Texas and the New Mexican portions of the Guadalupe Mountains is due to changed environment, which is indicated by the varied stratigraphy.

Summary.

The following is a summary of the chief facts, which I wish to emphasize in this review of the upper Carboniferous stratigraphy of southeast New Mexico and west Texas:

[*] Girty, George H., The Guadalupian Fauna and New Stratigraphic Evidence: Annals N. Y. Acad. of Sciences, vol. xix, pp. 135–147, 1909.

The upper Carboniferous strata in the area considered are separated from underlying and overlying rocks by major erosional unconformities. The lower beds are Pennsylvanian and the upper beds are Permian, but the separation of the two series is not well marked.

The total thickness is enormous, the stratigraphy is extremely varied, and two local unconformities occur in the upper Carboniferous section. In the east central New Mexico section, excepting a relatively thin deposit of limestone at the base of the section, almost the entire upper Carboniferous record is of red bed deposition. In southeast New Mexico a great body of sandstone and limestone occurs between and merges into red beds. In west Texas, north of the Texas and Pacific Railway, red beds are practically confined to the top of the upper Carboniferous section, and in the Chinati Mountain region no red beds have been reported.

The sections which have been described can be approximately correlated and together they comprise the local complete upper Carboniferous column. It appears: (*a*) that the Hueco formation embraces both the Magdalena and Manzano groups of the Rio Grande Valley section in New Mexico; (*b*) that the Guadalupian series lies between the Hueco formation and the red beds of Pecos Valley; (*c*) that the red beds of Pecos Valley constitute a variable group, the base of which is not a definite horizon, the occurrence of the red color extending irregularly across the strike of the rocks; (*d*) and that the upper part of the red beds of Pecos Valley is equivalent to the upper part of the Permian red beds of northwest Texas and Oklahoma.

The varied stratigraphy is an expression of changing geographic conditions which accompanied the emergence of the continent at the close of Paleozoic time. Apparently an open sea gave way, with some alterations, to shallower water and to local enclosed basins. The Guadalupian fauna probably migrated from the south, and its spread northward and eastward seems to have been checked by changing environment. It is to be noted that while from Kansas to Oklahoma shales and limestones merge into red beds from north to south, in west Texas and New Mexico a similar transition occurs from south to north, indicating an east-west zone in the upper Carboniferous area of deposition in which red beds accumulated.

Art. XXVII.—*The Gravimetric Determination of Free Bromine and Chlorine, Combined Iodine, and Oxidizing Reagents by means of Metallic Silver;* by Claude C. Perkins.

[Contributions from the Kent Chemical Laboratory, Yale Univ.—ccix.]

In a former paper* a method for the gravimetric determination of free iodine by means of metallic silver was described in detail. This paper has to do with the application of the same process to the determination of free bromine and chlorine, other members of the halogen group, to the estimation of combined iodine, and, indirectly, to the determination of the oxidizing power of certain oxidizing reagents.

The silver best adapted for this process is obtained electrolytically in a very finely divided state, being deposited as a black mass (probably silver hydride†) upon a small moving cathode. As long as the mass adheres to the electrode it remains perfectly intact but as soon as it is shaken off into the solution it immediately turns to a dull gray color, the hydrogen escapes, and the silver settles to the bottom in a fine flour-like powder. The mass of silver hydride should not be allowed to adhere to the electrode after it begins to change color, as the silver then collects in a crystalline form which does not absorb iodine readily.

Determination of Free Bromine and Chlorine.

In applying the process to the determination of bromine and chlorine a definite amount of the aqueous solution of these haloids was introduced into a flask containing an excess of potassium iodide made acid with hydrochloric acid and the whole shaken in an atmosphere of hydrogen with a weighed amount of silver. The residue of silver and silver iodide was collected in a Gooch crucible, washed, dried, and weighed. The increase in weight of the silver should represent the weight of iodine liberated from the iodide and from this the amount of halogen may be easily calculated. Table I shows the results of three determinations with bromine and five determinations with chlorine in which the average error falls within 0·0002 grm.

Determination of Potassium Iodide.

In applying the process to the determination of combined iodine a definite amount of a solution of potassium iodide, previously standardized by the distillation method with sul-

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* This Journal, xxviii, 33, 1909.
† Bartlet and Rice, Am. Chem. Jour., xix, 49.

TABLE I.

Silver taken grm.	Halogen taken grm.	Iodine found grm.	Calculated amt. of halogen grm.	Error grm.
(a) Determination of bromine.				
3·0000	0·0213	0·0336	0·0211	−0·0002
3·0000	0·0426	0·0678	0·0427	+0·0001
3·0000	0·1065	0·1694	0·1067	+0·0002
(b) Determination of chlorine.				
3·0000	0·0161	0·0574	0·0160	−0·0001
3·0000	0·0322	0·1146	0·0320	−0·0002
3·0000	0·0322	0·1145	0·0320	−0·0002
3·0000	0·0322	0·1141	0·0318	−0·0004
3·0000	0·0483	0·1716	0·0479	−0·0004

phuric acid and potassium hydrogen arseniate,* was introduced into a flask with an excess of the calculated amount of an oxidizing reagent (usually potassium nitrite or hydrogen peroxide), the whole made acid with hydrochloric acid, and shaken with a weighed amount of silver. The increase in the weight of the silver indicates the amount of iodine liberated from the potassium iodide and from this the amount of potassium iodide may be easily calculated. Table II shows the results of five determinations with potassium iodide in which the average error is −0·0002 grm. between limits of −0·0005 and +0·0002 grm.

TABLE II.

Determination of potassium iodide.

Silver taken grm.	KI taken grm.	Iodine found grm.	Calculated amt. of KI grm.	Error grm.
2·7803	0·1144	0·0872	0·1141	−0·0003
3·0028	0·1346	0·1026	0·1342	−0·0004
2·7800	0·1279	0·0978	0·1281	+0·0002
2·0008	0·1279	0·0974	0·1274	−0·0005
3·0001	0·1346	0·1029	0·1346	±0·0000

Determination of Oxidizing Reagents.

The process has also been applied to the indirect determination of several of the common oxidizing reagents with a view to showing that it may be used for the estimation of oxidizers that will liberate iodine quantitatively. In these experiments definite amounts of the oxidizer, standardized in the usual way, were added to an excess of a solution of potassium iodide acidified with hydrochloric acid, and the whole shaken with a

* Gooch and Browning, this Journal, xxxix, 188, 1890.

weighed amount of silver in an atmosphere of hydrogen. The value of the oxidizer is then calculated from the increase in weight of silver which represents the amount of liberated iodine. Table III shows the results obtained in the determination of potassium permanganate, hydrogen peroxide, potassium dichromate, and ferric chloride, in all of which the error is well within experimental variation.

TABLE III.

Silver taken grm.	Oxygen represented by oxidizer grm.	I found grm.	Calculated amt. of oxygen grm.	Error grm.
(a) Determination of potassium permanganate.				
3·0000	0·0123	0·1956	0·0123	±0·0000
3·0000	0·0123	0·1936	0·0122	−0·0001
3·0100	0·0123	0·1964	0·0124	+0·0001
3·0100	0·0123	0·1968	0·0124	+0·0001
4·0101	0·0185	0·2926	0·0184	−0·0001
4·0101	0·0247	0·3886	0·0245	−0.0002
(b) Determination of hydrogen peroxide.				
3·0000	0·0202	0·3200	0·0202	±0·0000
3·0000	0·0202	0·3214	0·0203	+0·0001
3·0100	0·0404	0·6427	0·0405	+0·0001
3·0000	0·0311	0·4937	0·0311	±0·0000
3·0000	0·0322	0·5128	0·0323	+0·0001
3·0000	0·0606	0·9590	0·0604	−0·0002
(c) Determination of potassium dichromate.				
3·0000	0·0080	0·1272	0·0080	±0·0000
3·0000	0·0160	0·2552	0·0161	+0·0001
3·0000	0·0201	0·3141	0·0198	−0·0003
3·0000	0·0402	0·6390	0·0403	+0·0001
3·0000	0·0160	0·2552	0·0161	+0·0001
3·0000	0·0160	0·2571	0·0162	+0·0002
(d) Determination of ferric chloride.				
3·0000	0·0218	0·3470	0·0219	+0·0001
3·0000	0·0218	0·3476	0·0219	+0·0001
3·0000	0·0437	0·6922	0·0436	−0·0001
3·0000	0·0218	0·3489	0·0220	+0·0002
3·0000	0·0262	0·4183	0·0264	+0·0002
3·0000	0·0218	0·3516	0·0222	+0·0004

The results obtained fully justify the statement that metallic silver may be used for the determination of free bromine and chlorine, and combined iodine, and for the estimation of the oxidizing power of those reagents whose reaction with potassium iodide is definitely known to set free iodine quantitatively.

Art. XXVIII.—*Discharges of Electricity through Hydrogen;* by John Trowbridge.

1. Reflection of Cathode Rays.
2. Striæ.
3. A method of rectification of alternating discharges.
4. The Doppler effect.

Reflection of Cathode Rays.

In the course of this paper I shall refer to certain hydrodynamic analogies which the discharges of electricity through gases present; but not with the conviction that in these discharges we have to deal solely with questions of flow. The complicated phenomena give large scope both to theories of flow and molecular theories; the hydrodynamical analogies are more striking in discharges through gases at comparatively high pressures; while molecular theories apply best in highly rarefied gases. There seems to be a certain continuity here similar to that between motions of matter in the liquid state and in the gaseous state, when such matter is subjected to forces that can produce movement or flow of the particles.

The condition of electrical discharges in a tube represented in fig. 1 remind one of the flow of a fluid, interrupted by a

Fig. 1.
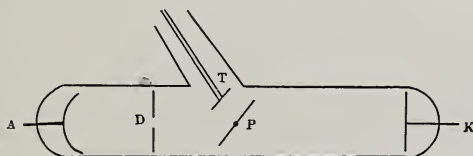
plane lamina. A is a cathode, K an anode, D a diaphragm, P a plane lamina which can be moved about an axis perpendicular to the plane of the paper: fig. 1 being a plan of the discharge tube. P can also serve as an anode.

At the striæ stage the electrical conditions in the tube are very little modified by turning the lamina through small inclinations to the line of discharge. The striæ remain practically unaffected in shape and position until the angle between the normal to the lamina and the axis of flow reaches 50°. This phenomenon is analogous to the case of a lamina subjected to the flow of a liquid (Lamb's hydrodynamics, p. 94 and p. 111). It is also analogous to the conditions presented by the impact of wind on sails fronts.

By means of a side adjunct, a thermopile, T, was introduced in order to measure the heat excited by the reflection of the cathode rays passing through the diaphragm D and being reflected from the lamina, when the latter was inclined to the axis of the cathode rays at varying angles. Here also there was an action similar to the reflection of a stream of liquid from the lamina, proceeding in the direction of the cathode rays. The angle between the normal to the lamina and the axis of flow or discharge could vary largely without affecting the amount of heat from the reflected cathode beam, shown by the thermopile.

Striæ.

The striæ, or stratifications in Geissler tubes, constitute a very beautiful and mysterious phenomenon of the discharge of electricity through gases, and if one could follow perfectly the

Fig. 2.
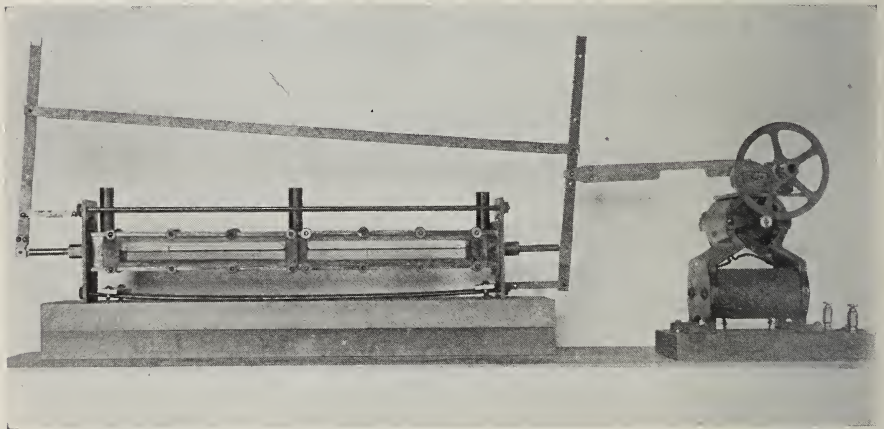
FIG. 2 represents an apparatus by means of which two pistons driven by a motor in opposite directions cause waves in a trough filled with water.

mechanism involved one could feel sure of having penetrated far into questions of the method of propagation of electricity. There seems no reason to doubt that the striæ are phenomena of ionization; but the regularity of the striæ leads one to ask if this regularity could arise from some pulsation or rhythmical action—the ionization being, so to speak, on top of such rhythmical action. When the striæ are excited by a storage battery they are perfectly steady, and when it is certain that there are no breaks in the circuit a telephone introduced into

the circuit is silent ; moreover, a large self-induction included in the circuit does not affect the striæ.

Under certain conditions the current from a storage battery oscillates, or pulsates, but such oscillations or pulsations do not seem to modify the appearance of the stratifications. If, on

FIG. 3.
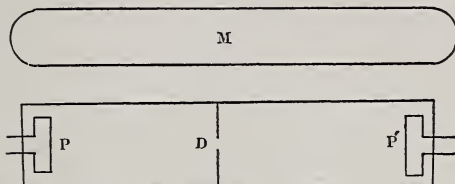
FIG. 3 shows the arrangement in plan by means of which the ripples are studied. M is a mercury lamp of the Cooper-Hewitt form. This is placed directly behind the trough containing the pistons. The surface of the water, totally reflecting the light, forms a dark line which, under the motion of the pistons, undulates in waves which can be studied by instantaneous photography. P and P′ are the pistons, and D is a diaphragm with a rectangular orifice.

the other hand, there is a flow from the cathode which pulsates at a different rate from a supposititious flow from the anode, one might expect striæ, or accumulation of ionic disturbances at regular intervals. An hydrodynamical analogy is afforded by the motion of two pistons moving against each other at different rates in a channel filled with water.

FIG. 4.

FIG. 4 represents a case in which P moves twice as fast as P′. The waves are formed nearer the slower-moving piston. The method seems to be useful in studying ripples and waves.

All who have worked in the field of discharge of electricity through gases must recognize the suggestiveness of the theory of ionization by collision, especially with reference to striæ ; but one who was ignorant of this theory, seeing the action of the cathode in driving back striæ into the anode, might attribute this action to an actual repelling force, arising from the cathode. When this supposititious force is diverted by a magnet the striæ appear and more current flows. One ignorant of the many facts of ionization by collision might further suppose that heavier particles of slower motion might be held back by swifter particles issuing from the cathode. These

views of a mind not biased by ionization theories would appear
to be supported by the phenomena presented by the tube rep-
resented in fig. 5.

One branch of this tube is at right angles to the other
branch.   There are two anodes, A and A′, and two perforated
cathodes, K and K′.   When a multiple circuit is formed by
leading in the current to the two anodes and out by one
cathode, K, striæ form in the branch A′K′ after they disappear
in the branch AK; and they persist in A′K′, when the
branch AK appears to be nearly at the X-ray stage.   One
looking at the branch A′K′ would suppose that the rarefac-
tion of the entire tube was low; and gazing at the branch AK
would think it very high.   The bend in the tube acts like a
magnet in allowing the striæ to emerge from the anode A′;

FIG. 5.
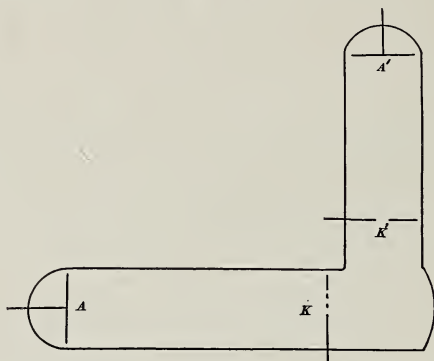
and it does this by enfeebling by reflection the effect of the
cathode rays in the branch A′K′.

The function of the cathode beam seems to be twofold; it
forces back the striæ; and at higher exhaustions it ionizes the
gas; for the current ceases to flow at high exhaustions when the
cathode beam is strongly diverted by a magnet.   These func-
tions are illustrated by the phenomena in a tube represented
in fig. 6.

Between the anode, A, and a cathode, D, the glass tube is con-
stricted.   The cathode D is a circular disc with an orifice a
little larger than the glass orifice.   The cathode rests upon the
walls of this orifice, presenting no metallic surface toward the
anode A.   The cathode beam produces fluorescence toward D′
and is marked in the direction toward A by a white beam
which produces hardly a perceptible fluorescence.   The latter
beam does not come from the metallic surface of the cathode;
but seems to come from the gas in the region DD′.   At com-

paratively high exhaustions this latter portion of the cathode beam ceases to ionize the gas; the current ceases and the potential between A and D rises to the full potential of the battery, indicating an open circuit. When, however, D′ is made the cathode, the current is immediately re-established and the cathode beam from D′ ionizes the gas between D′ and A. The tube acts as a rectifier; for when D is made the anode and A the cathode a current passes; on reversal of the current, as I have said, no current passes in the opposite direction.

FIG. 6.

It is interesting to observe the effect of a transverse magnetic field on the discharge in this tube when A is made a cathode and D′ an anode and striæ appear in the portion DD′. The magnetic field placed near A diverts the cathode beam and striæ advance in the portion DD′. While this field is still on, another transverse magnetic field placed near D′ diverts the striæ independently of the action of the field at A. This indicates the well-known fall of potential from striæ to striæ.

The rectification observed under proper conditions in the tube fig. 6 suggests other forms of tubes by which rectification can be produced. Even with a straight cylindrical tube the
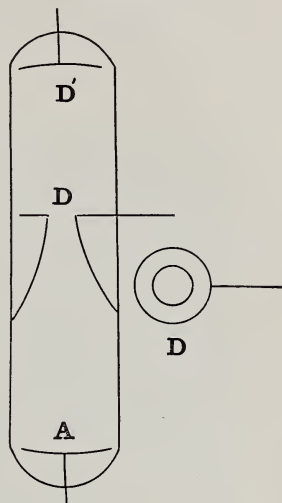
FIG. 7.
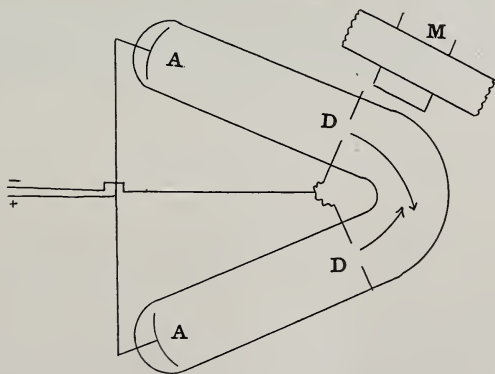
current can be stopped at high exhaustions by touching the outside of the tube with the finger, thus diverting the cathode

beam by electrostatic action ; it readily passes when the current is reversed. The phenomenon of rectification is shown in a practical way in the U-shaped tube represented in fig. 7, which is provided with two anodes, A and A, and two cathodes, D and D'. The cathodes have orifices at their centers. The two anodes are connected together, and also the two cathodes—the tube forming a multiple circuit. A transverse magnetic field can be so placed near one cathode that no current will pass in the branch of the tube of which it is a part, while the current passes freely in the other branch of the U tube. This form of tubes rectifies an alternating current.

The apparent repelling, or driving back action, of the cathode beam on striæ is shown in a suggestive manner in a straight cylindrical tube when a diaphragm is inserted between the anode and the cathode. We will take for illustration one branch of the U-shaped tube (fig. 7), and suppose that the current is led into the tube at A and out at D. A metallic diaphragm with a small hole at its center is inserted in the tube about one-third of the distance between A and D, measured from the cathode to anode, the latter also having an orifice at its center. The striæ are slowly driven back by the cathode rays as the exhaustion proceeds. At a definite stage of this exhaustion a stria takes refuge behind the diaphragm near the anode, where it is protected from the driving back action of the cathode rays ; finally at higher exhaustions this stria is driven through the orifice in the anode and shelters itself behind the anode.

At a higher state of rarefaction a stria issues from the orifice in the anode and this also shelters itself behind the diaphragm on the side toward the anode. There are, thus, three definite stages of stratification in this form of tube. At a pressure of four centimeters fine striæ appear on the side of the orifice in the diaphragm opposite to the anode. These soon disappear with increasing rarefaction. At a pressure of approximately 3^{mm} a large stria shelters itself behind the diaphragm opposite the anode. This disappears with diminishing pressure ; and at a pressure of approximately 15^{mm} a large stria wells up out of the orifice in the anode and takes a similar place near the diaphragm. When the state of canalstrahlen is reached, all striæ have been driven into the anode. Can we regard these strahlen as a stratification which cannot be driven back by the cathode rays ? In this form of tube we find evidence of successive states of stratification which may depend upon positive rays of different velocity.

When we turn our observation of stratification in the neighborhood of the cathode instead of in the neighborhood of the anode, we find that a stratification always takes place on the glass wall close to the entrance of the cathode, or to its sealing in place. It can be produced equally well by causing the

cathode to approach the wall of the tube opposite to the sealing in place. Fig. 8 represents the phenomenon in a tube with a dome-shaped chamber near the electrode. We seem to have two dissected striæ; one on the wall of the tube nearest to the cathode, which provides a beautiful light blue cathode beam thrown into the dome; and another stria on the opposite wall of the dome. The original cathode beam excites both positive and negative rays in these striæ.

Fig. 8.
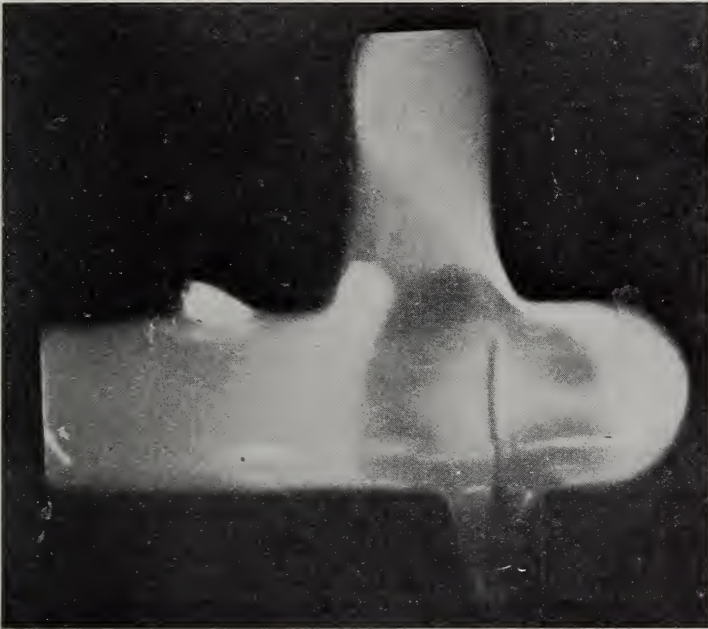
In considering these detached striæ it seems that the cathode rays in striking the glass walls can excite both positive and cathode rays.

When a spark gap is inserted in a circuit containing a discharge tube which is properly exhausted to the striæ stage, the latter apparently disappears, the light of the tube becomes more brilliant and fluorescence is generally manifested. This is also the case when a condenser is discharged through the tube. The eye cannot perceive any evidence of stratifications; for the brightness of the pilot spark, together with the fluorescence both of the gas and the glass walls, effectually shield any striæ of lesser radiance which might be present. It is not

possible to employ the revolving mirror. The only method which seemed to promise any results in detection of possible stratifications was the employment of a portrait lens of large aperture—four inches—in photographing single discharges. Accordingly a discharge tube was filled with hydrogen and exhausted to the striæ stage. A condenser of ·02 mf. capacity was charged to a difference of potential of 10,000 volts and discharged through the rarefied tube by flat copper bands of inappreciable self-induction. The photographs showed unmistakable striæ, superposed upon the general illumination of the tube. It is difficult to reproduce the photographs by half tones.

With an anode consisting of a rim of wire placed in a cylindrical tube ·5^{mm} internal diameter a striation is formed at a short distance from the anode by condenser discharges and there are traces of similar striations at greater distances along the tube. If these striations are formed by ionization by collision, the time of ionization is that of the duration of the pilot spark, a time which at present is beyond our power of measurement.

Doppler effect.

When two anodes and two cathodes are employed in the form of tube represented in fig. 7, there are two canalstrahlen which emanate from orifices in the cathodes in opposite directions. One might suppose that the Doppler effect would be modified by collision of the particles in these rays and that the effect would certainly be less than when only one anode and one cathode were employed—the current thus passing through but one branch of the U-tube. It is true that the difference of potential is less between Δ and D when the tube is coupled in multiple circuit than when only one branch of the tube is connected to the battery; but this difference in the case I studied was comparatively small. With both branches of the tube constituting a multiple circuit there were two strong canalstrahlen passing through the orifices in D which were undistorted and which gave the same Doppler effect which was obtained when only one branch of the tube was excited. It seems difficult to reconcile this result with any theory of flow.

Conclusions.

1. The striæ in Geissler tubes are analogous to waves set up in narrow channels by opposite pulsations of different periods.

2. Striæ are greatly influenced by the direction of cathode rays.

Certain forms of tubes, described in this article, can imitate the action of a transverse magnetic field in apparently increasing the conductibility of the rarefied gas and restoring the condition of stratification.

3. Striæ can be formed by condenser discharges; and such striæ lead one to suppose a time of ionization beyond our power of measurement.

By means of a suitably placed diaphragm, successive stages in stratification can be produced.

4. By modification of the form of discharge tubes rectification of alternating discharges is possible.

5. The Doppler effect in hydrogen is not modified by causing two canalstrahlen to oppose each other.

Jefferson Physical Laboratory,
    Harvard University.

ART. XXIX.—*A New Pennsylvania Meteorite;* by O. C. FARRINGTON.

To the iron meteorites known from Pennsylvania, Bald Eagle, Pittsburg and Mount Joy, a fourth is now added. This last cosmic accession was found in 1907 on a farm about seven miles north of Shrewsbury, York County, Pennsylvania. It was discovered by being struck by a plow while plowing and attracted attention on account of its unusual weight. As the region is one in which more or less brown limonitic iron ore occurs, the meteorite was supposed by its finder to be an unusually heavy specimen of such ore and as such was shown to Mr. F. Justice Grugan of Philadelphia when in the vicinity in June, 1909. Mr. Grugan, in whose possession the meteorite now is and to whom the writer is indebted for the history here given, at once recognized the meteoric nature of the mass, and took steps for its preservation. He also instituted a search for any associated specimens that might be in the vicinity. In this he was successful to the extent of finding several fragments that had been distributed as curiosities, but no important additional individuals were found. The smaller pieces obtained were reported to have been found about three-quarters of a mile northwest of the main mass. If this distribution was a natural one, a southeasterly course of the meteor is indicated. The fragments and mass placed in the hands of the writer for examination had evidently all belonged to a single individual. The main mass as received weighed twenty-four pounds and the fragments three pounds more, giving a total weight to the meteorite as now known of twenty-seven pounds (12·2 kgs.). The form of the meteorite as restored by adding the fragments is roughly rhombohedral, with dimensions of about six inches (15^{cm}) on a side. At the same time there is much rounding of the solid angles and there are many depressions and irregularities which make the above characterization of the form only an approximate one. Owing partly to decomposition from lying in the soil and partly probably to rough handling, the appearance of the original surface of the meteorite remains over less than half the mass. Where seen it shows the usual rounded and smooth exterior of iron meteorites with broad, shallow pits, the broadest being about three inches (7^{cm}) in diameter. There has been considerable alteration of this surface through weathering, so that its substance has become more or less friable and limonitic in character. This alteration appears to extend in places to a depth of about half an inch (1^{cm}). Where the original surface is not present the meteorite shows a jagged, fractured appearance and exhibits typical octahedral structure. It is probable that over such portions the original surface has disintegrated and fallen away, though the appearance at one

point would indicate a rending of the mass in the air like that shown by one of the Glorieta Mountain individuals.

On account of oxidation the mass as a whole presents a generally rusty brown color with spots of a green incrustation, due doubtless to the formation of some nickel salt. The undecomposed nickel-iron is easily cut by a file, but is not malleable owing to a well-developed laminated structure. Under

Fig. 1.

Fig. 1.   Shrewsbury meteorite—3/5 nat. size.

the hammer, therefore, it is inclined to crumble. Plates of bronze-yellow, flexible, magnetic tænite can be easily separated both from the decomposed and undecomposed nickel-iron.

Analysis of the meteorite by Dickman and Mackenzie of Chicago gave the following result:

Fe	Ni	Co	S	P		
90·84	8·80	tr.	·01	·29	=	99·94

Sections of the meteorite show a firm, homogeneous interior with little or no disintegration. Broad, straight lamellæ almost entirely prevail. These lamellæ average a little over

one millimeter in width, thus placing the meteorite in the
group of medium octahedrites.   For the most part the lamellæ
show simple, broad bands of kamacite, but some of these are
seen on closer examination to be made up of smaller lamellæ
grouped together.   The kamacite shows considerable hatching,
generally in a single direction.   Where fields occur they
appear to be mainly of two kinds: 1, those made up of
numbers of minute tænite foliæ with parallel arrangement and
parallel to the adjoining bands, and 2, those made up of

FIG. 2.
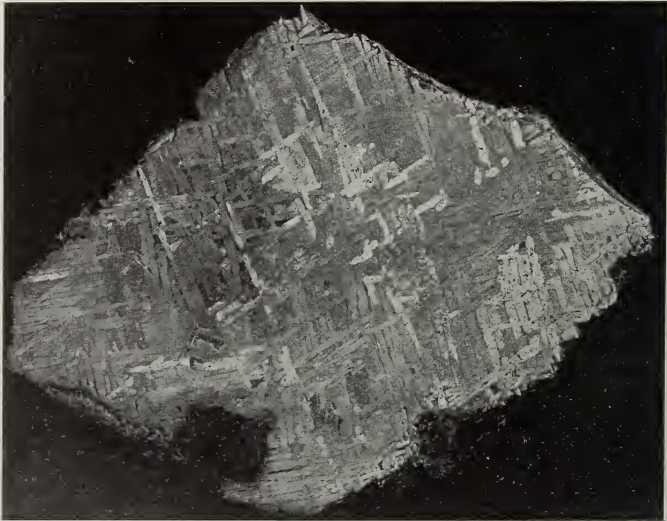
FIG. 2.   Etched section of Shrewsbury meteorite—1/2 nat. size.

kamacite grains bordered by tænite and showing a more or
less divergent arrangement.   Accessory constituents are com-
paratively abundant and scattered irregularly over the section
though somewhat more numerous toward the periphery.   They
include troilite and schreibersite, the troilite occurring in sphe-
roidal and the schreibersite in hieroglyphic forms.   The troilite
is characterized by a bronze-yellow color and dull luster, the
schreibersite by a tin-white color and shining luster.   One
troilite nodule in the section especially studied by the writer is
nearly circular in form, 2^{cm} in diameter and has an irregular
border of schreibersite.   In other places the troilite has a
more nearly vein-like distribution and is more or less mixed
with schreibersite.   Hieroglyphic schreibersite occurs at
several points, usually in groups of three.   The grains are
from 4 to 8 millimeters in length.   Swathing kamacite from
2 to 4 millimeters in width surrounds the scheibersite
inclusions, but there is none about the troilite.

ART. XXX.—*Remarks on the Pentamerous Symmetry of the Crinoidea;* by AUSTIN H. CLARK.

THE pentamerous symmetry of the echinoderms is now admitted to be a feature of phylogenetically secondary importance—a radial symmetry superimposed upon a primarily bilateral symmetry and so perfectly developed as almost entirely to mask the original condition. It has been pertinently suggested that the sedentary life of the animals has induced a radial arrangement of their structures, analogous to what has occurred in certain other groups, though in the echinoderms this has been carried so far as to result in a complete absence of any head region, and, consequently, a complete decentralization of the nervous system, so that, in many cases, the only trace of the original bilateral symmetry is found in the digestive system. In the Astroradiata* (Asteroidea and Ophiuroidea) even this has yielded to the radial tendency, through here the water-vascular system, as evidenced by the so-called "stone-canal," shows indications of a former bilateral arrangement.

The larva of all echinoderms are bilaterally symmetrical, and pronouncedly so, the pentamerous symmetry only appearing when the adult form is acquired. The astroradiate echinoderms are all, except for the stone canal, radially symmetrical in every respect; but in the heteroradiate forms (Pelmatozoa, Echinoidea, and Holothuroidea) there is often, one might almost say usually, a more or less pronounced leaning toward the bilateral type, as seen, for instance, in the Comasteridæ among the crinoids, in the clypeastroids and spatangoids among the urchins, and in the Elasipoda, and in such forms as *Lophothuria* and *Psolus*, among the holothurians. There are two possible explanations of this bilateral condition in the heteroradiate echinoderms; (1) the animals may never have attained the perfected radial symmetry, or (2) they may have passed through a radially symmetrical condition and, reacquiring the habit of moving in a definite direction, have again taken on a bilateral habit, this bilateral condition having been superimposed upon the previous pentamerous condition, which itself was superimposed upon the primitive bilateral state. It is probable that the so-called "irregular" urchins (the clypeastroids and spatangoids) as well as the Elasipoda and other bilateral holothurians exemplify the latter condition, while certain of the Pelmatozoa furnish an instance of the former. It is among the crinoids, then, of the living echinoderms that an explana-

*American Naturalist, vol. xliii, p. 686, Nov., 1909.

tion of the origin of pentamerous symmetry must be sought, and a review of the data gleaned from a study of certain species offers some points of considerable interest. But just because certain of the crinoids appear never to have attained a true and complete radial symmetry, it does not at all follow that the marked bilateral arrangement of all types can be thus explained; for instance, in the recent representatives of the family Comasteridæ there are several species having the arms arising from the two posterior rays much shorter than the others, and devoid of ambulacral grooves or tentacles. This is a bilateral symmetry derived through a pentamerous symmetry clearly, for in the less specialized species belonging to the same genera, and in their own young before adolescent autotomy, the two posterior rays and the arms arising therefrom are just like all the others.

That classical genus *Antedon*, the "*Comatula*" of most text-books, represents a form with the most highly perfected pentamerous symmetry, yet exhibiting no advance whatever toward the more highly specialized secondary bilateral symmetry seen in the comasterids. *Antedon* is strictly pentamerous in all respects, excepting only the digestive system; but that this pentamerism is really quite superficial is strikingly shown by a variant described by Professor Bateson[*] in which one of each of the posterior pairs of arms was abnormally palmate. It would seem, then, that *Antedon* was a good genus in which to search for an explanation of the origin of pentamerism.

Dr. P. H. Carpenter had the good fortune to be able to examine several four-rayed comatulids, most of them belonging to the genus *Antedon*; and it is a fact of the highest interest that in every case *it was the anterior ray, the one directly opposite the anal area, that was missing.* The U. S. National Museum possesses a four-rayed specimen of that magnificent comasterid *Comanthus polycnemis*, which was brought from the Philippine Islands; on examining it I found that here again it was the anterior ray that was missing. Such a remarkable coincidence of observations can mean but one thing; there must be some good reason why the anterior ray should be deficient rather than any of the other four. Since we can safely say that there is no physiological reason why the anterior ray should be suppressed in preference to the others— indeed in the case of comasterids one would think that one of the normally abortive posterior pairs would be the first to

[*] Proc. Zool. Soc. London, 1890, p. 584, fig. 4. The eleven and twelve armed specimens of *Antedon* described by Dendy and Carpenter are not bilaterally arranged; but probably they arose through accident and are not congenital, not being, therefore, strictly comparable.

disappear, since it is quite useless for the collection of food—we are forced to look for some phylogenetic cause.

Young crinoids are, as has been mentioned, bilaterally symmetrical; all the four-rayed adults of the comatulids so far observed are bilaterally symmetrical; the normal five-rayed adults are the equivalent of the four-rayed adults, plus the interpolation of an additional ray between the two of the anterior pair. The more or less frequent reversion of the five-rayed crinoids to a four-rayed form (a permanent condition in *Tetracrinus*) would appear to be an index pointing back along the phylogenetic path travelled by the race: and this index becomes all the more significant when we glance at the record of six-rayed variants in which there is no such uniformity of place of interpolation.

It would appear as though the evidence pointed to an original bilateral condition among the adult crinoids in which there were two pairs of body processes that had become, through similarity of function, the same; in other words, a bilateral condition which had become as well, through induced radial symmetry due to inactive habit, quadriradial. We may readily imagine that, by sporadic variation, an additional ray might sometimes be produced between the two of the anterior pair, especially in animals of such remarkable regenerative powers as the crinoids. This additional ray would be just like those on either side of it; and in a sessile animal it would cause no inconvenience but would, on the contrary, be of distinct advantage in furnishing a very marked increase in food-collecting power. Animals with this additional ray would therefore have, in the case of sessile forms like the crinoids—passive feeders which must wait for their food to come to them—a great advantage in the struggle for existence, and we might well imagine that nature would be quick to take advantage of such a variant, and to fix permanently this pentamerous condition.

If we can admit that the four-rayed condition which, so far as is known, always arises from the loss of the anterior ray, is a true phylogenetic index—and there is no good reason why we should not—then we would be led to the conclusion that the crinoids are primarily animals possessing a bilateral symmetry, with two pairs of similar appendages, an anterior and a posterior, upon which a secondary pentamerous symmetry has been superposed, due to interpolation of one half of one of the bilaterally symmetrical pairs of appendages between the two components of the original anterior pair.

It might be urged that supernumerary paired appendages would be unlikely to put in an appearance except in pairs; but we find instances of just that thing in other widely different

animals which possess two similar pairs of appendages like our theoretical ancestral crinoid. I may mention in this connection three-legged (five-limbed) chickens among the birds, and five-winged butterflies and moths (in cases where the additional wing does not replace a leg). In one case of the latter, a beautiful female of *Platysamia cecropia*, which has recently come under my notice, the similarity to the theoretical phylogenetic condition among the crinoids is very striking, for the additional wing (which unfortunately failed to spread properly)
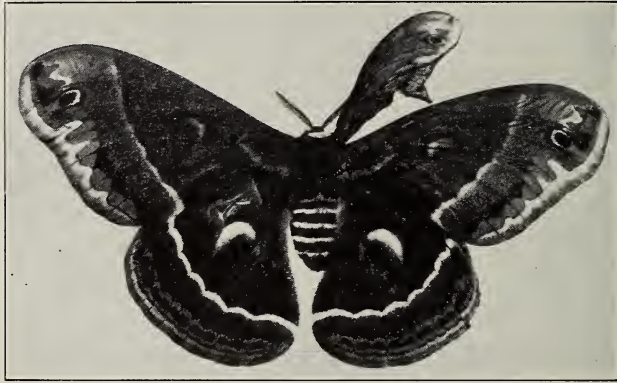
Specimen of *Platysamia cecropia* with an additional primary inserted just anterior to the normal right primary.

is inserted anterior to one of the primaries, where, were the animal sessile and incapable of motion, it might, through fixation in subsequent generations, very well give rise to as truly a pentamerous condition as is exhibited by the crinoids.

Although I have treated in detail only the evidence brought out by the crinoids, I have no doubt that the pentamerous symmetry in all the other groups has arisen in the same way, by the interpolation of an extra ray between the two original anterior rays; and that this accounts for the excess of plasticity of this ray in certain groups, and its more or less frequent suppression in others. In six-rayed specimens almost invariably the sixth ray is obviously formed by a more or less complete division of one of those already existing—a sort of echinodermal polydactylism—and these six-rayed examples, therefore, are very suggestive in indicating that echinoderm symmetry is not by any means radial, but is a composite of five equivalent parts, two paired and one, the anterior, odd.

The echinoderms as known to us are extremely ancient animals, zoologically speaking, so ancient that they were

brought to their present state of perfection, or were even more highly specialized, in the earliest geologic epochs of which we have any record. The enormous time through which they have passed without any appreciable change toward further specialization has resulted, by the operation of the law of acceleration of development, in pushing the various ontogenetic steps further and further back until all such stages as the biserial arrangement of the crinoid arm, the change from bilateral to pentamerous symmetry, the reduction and transformation of the ambulacral plates in the crinoids into division series, etc. have been entirely lost. The echinoderms as a whole I believe can be compared with the other invertebrate groups in their mode of development only in the way that the curiously specialized *Gecarcinus* can be compared with other crabs, or *Hylodes* with other frogs; in other words, they form a group in which extreme specialization and its effect upon the earlier stages of the ontogeny has obscured or obliterated much of the phylogenetic data ordinarily available.

Larval echinoderms are as extraordinarily specialized as the adults, but along radically different lines; many of them have specially developed skeletons, entirely different from those of the adults, which are lost in later life. It seems to me that the echinoderm larvæ, owing to their extraordinary specialization, must be treated almost as a different class of animals from the adults, specialized along entirely different lines, and fitted for an entirely different mode of life; and that we can expect to learn little more about the interrelations of the echinoderm groups from the study of their larvæ than we could of the relationships of the groups of lepidoptera, diptera or coleoptera from a study of their caterpillars or maggots.

Art. XXXI.—*An Association of Enargite, Covellite, and Pyrite from Ouray Co., Colorado;* by William M. Thornton, Jr.

In October, 1906, Professor William H. Echols received a curious sample of copper ore from the Genesse Vanderbilt mine in the Red Mountain district, Ouray county, Colorado. The specimen was seen to consist of three distinct metallic minerals, which were subsequently identified by physical properties, behavior before the blowpipe, and quantitative analysis as enargite, covellite, and pyrite.

General Description.

The enargite is closely interlocked with pyrite—both growing out from a quartz gangue. The color of the enargite is dark grey; and the luster metallic. The structure is columnar. The cleavage is easy in one direction. Specific gravity=4·49. A few crystals are present but badly crushed and distorted. The covellite joins the other two minerals, and includes here and there a little pyrite or gangue. The color is indigo-blue and the luster sub-metallic. The structure is foliated, and the mineral can be easily cleaved into thin plates.

Analysis of enargite by Wm. M. Thornton, Jr.

Copper	50·82	per cent.
Zinc	0·33	"
Arsenic	17·28	"
Sulphur	32·53	"
Silver	None	"
Iron	Trace	"
	100·96	

Corresponds approximately to the formula : $Cu_3AsS_4 \leftrightarrows 3Cu_2S, As_2S_5$.

Analysis of covellite by John E. Seabright.

Copper	68·38	per cent.
Sulphur	32·51	"
	100·89	

Corresponds to the formula: CuS.

Methods of Analysis.—The enargite was first treated with nitric acid and the resulting mass thoroughly dried. A fusion was then made with sodium carbonate and potassium carbonate

(weight for weight) and potassium nitrate, and the melt leached with water. An aliquot part (3/4) of the filtrate was concentrated for the precipitation of arsenic as ammonium magnesium arsenate. The precipitate was ignited to magnesium pyroarsenate. A trace of arsenic was recovered from the filtrate by hydrogen sulphide and weighed as arsenic trisulphide. In one-fourth the original solution the sulphur was determined as barium sulphate in the usual manner. The residue, consisting chiefly of copper oxide, was dissolved in sulphuric acid and a little nitric acid; and the copper precipitated with sodium thiosulphate, ignited under hydrogen sulphide, and weighed as cuprous sulphide. In the filtrate from the cuprous sulphide the zinc was precipitated by ammonium sulphide and ignited to the oxide.

The covellite was dissolved in nitric acid; and with the aid of potassium chlorate the separated sulphur was converted into one clean globule. The sulphur thus separated was weighed as free sulphur. One-fifth of the filtrate was employed to determine the remaining sulphur as barium sulphate. In two-fifths of the original solution the copper was estimated as above.

This cuprous sulpharsenate is not among the commonly occurring ores of copper. Cupric sulphide, as compared with cuprous sulphide, or ordinary copper glance, is rare. This association, therefore, is in the author's opinion a very interesting one and deserving the brief notice here given. It may also be mentioned that the minerals of this aggregate contain no silver, which is quite the exception for ores of the Red Mountain district.

Virginia Geological Survey,
University of Virginia,
January 22, 1910.

SCIENTIFIC INTELLIGENCE.

I. Chemistry and Physics.

1. *The Detection of Sodium, Cæsium, and Rubidium.*—Some years ago W. C. Ball described some complex nitrites of bismuth, prepared from the yellow liquid obtained by the interaction of bismuth nitrate and sodium or potassium nitrite. Among these were the triple salt $Bi(NO_2)_3.2NH_4NO_2.NaNO_2$, and the double salt $Bi(NO_2)_3.3KNO_2.H_2O$, both very soluble compounds. On attempting to prepare similar rubidium and cæsium derivatives, it was found that dilute solutions of the nitrates of these metals produced yellow, crystalline precipitates with the reagent obtained from sodium nitrite and bismuth nitrate. These are triple nitrites of bismuth, sodium, and rubidium or cæsium, and their formation serves as a very useful method of detecting these metals in the presence of an excess of potassium. The reaction for cæsium is especially delicate. Furthermore, a reagent may be prepared by the addition of a cæsium salt to the product of the reaction of bismuth nitrate and potassium nitrite, which serves as a remarkably delicate test for sodium in producing a precipitate of the same triple bismuth-sodium-cæsium nitrite.

The bismuth-sodium nitrite reagent is best prepared by dissolving 50 g. of pure sodium nitrite in 100^{cc} of water, neutralizing with nitric acid if necessary, and adding 10 to 20 g. of powdered bismuth nitrate. The resulting orange-colored solution must then be filtered and kept in a well-stoppered bottle, as it absorbs oxygen and becomes turbid when exposed to the air. In using this reagent to test for rubidium and cæsium, the solution to be tested is added to a large excess of the reagent acidified with one or two drops of nitric acid to prevent the formation of a basic bismuth salt. In all these tests it is better to use nitrates or sulphates, rather than chlorides, on account of the tendency of bismuth oxychloride to precipitate when concentrated solutions of chlorides are used. The reagent gives a precipitate quickly with a 0·5 per cent solution of rubidium. Only heavy metals and cæsium interfere with the test, which affords an easy method for distinguishing rubidium from potassium, ammonium, lithium, thallium, etc. The precipitate is bright yellow and crystalline, and probably corresponds to the formula $Bi(NO_2)_3.2RbNO_2.NaNO_2$. The test for cæsium with this reagent is still more delicate, 1^{cc} of a 0·2 per cent solution of cæsium nitrate giving an immediate yellow crystalline precipitate with 4 or 5^{cc} of the reagent.

The reagent for sodium is prepared by dissolving 50 g. of potassium nitrite in double its weight of water, neutralizing with nitric acid, adding 10 g. of powdered bismuth nitrate, filtering, adding a 10 per cent solution of cæsium nitrate until the powdery

yellow precipitate, invariably produced by traces of sodium present, ceases to be formed after keeping the liquid for several hours. The liquid is then filtered and the addition of cæsium nitrate continued until about 2·5 g. have been used. The reagent is most sensitive when a precipitate of yellow, hexagonal plates, a nitrite of cæsium and bismuth, is formed on further addition of the cæsium salt. With 2^{cc} of this reagent $0·1^{cc}$ of a 0·5 per cent solution of sodium, as nitrate, gave a considerable precipitate within 5 minutes, and by long standing it was found possible to detect as little as 0·01 mg. of sodium in the presence of much potassium salt. Most of the heavy metals interfere with this test, but zinc, cadmium, magnesium, barium, calcium, strontium, lithium, thallium and potassium do not interfere with it. The formula for the precipitate appears to be $5Bi(NO_2)_3.9CsNO_2.-6NaNO_2$.

Preliminary experiments indicate that small amounts of sodium may be quantitatively determined very accurately by means of this method. The precipitate contains only 3·675 per cent of sodium.—*Jour. Chem. Soc.*, xcv, 2126. H. L. W.

2. *Volumetric Determination of Sulphates.*—MITCHELL and SMITH have worked out the details of a method for this purpose, which is based on well-known reactions, and which had been suggested, in its essential features, by Precht as early as 1879. They take a convenient quantity of a sulphate, dissolve it in water or pure hydrochloric acid, or, if necessary, dilute nitric acid, and then add a slight excess of 1/5 normal barium chloride solution. They then boil the mixture, make it neutral with ammonium hydroxide, add ammonium acetate, acetic acid, and a slight excess of 1/10 normal ammonium dichromate solution, make up the mixture to 100^{cc}, allow the precipitate to settle, take out 25^{cc} of the clear liquid and titrate it with 1/20 normal ferrous ammonium sulphate, using potassium ferricyanide as an external indicator, and taking the first tinge of green as the end point. They use ammonium dichromate on account of the fact that barium dichromate appears to carry down with it traces of the potassium salt. The method was tested with ammonium sulphate, sodium sulphate, potassium sulphate, zinc sulphate, magnesium sulphate, and copper-ammonium sulphate. With potassium sulphate there was evidence of adsorption, to the extent of nearly 2 per cent, but this was minimized by boiling the precipitate for several hours with a little dilute hydrochloric acid, neutralizing with ammonia, and proceeding as before. It is to be observed in applying this method that ammonium dichromate which is 1/10 normal in regard to oxidizing power, is only 1/30 normal in regard to precipitating power. The test analyses give very satisfactory results, and it is stated that, excluding weighings, five determinations can be made in an hour.—*Jour. Chem. Soc.*, xcv, 2198. H. L. W.

3. *The Action of Metals on Fused Caustic Soda.*—As there are conflicting statements in respect to the stability of sodium

hydroxide at high temperatures, and its action upon metals when heated in contact with them, LeBlanc and Bergmann have made an investigation of these matters. They find that caustic soda can be easily dehydrated, as far as accidental water is concerned, by heating it in a gold crucible to 400° C., and that it shows no tendency to give off water of composition at 720°. Gold is the only metal experimented with which is not at all acted upon at the temperature just mentioned. Silver and sodium, in the absence of air, cause the evolution of hydrogen alone, while under the same conditions platinum, copper, iron, nickel, aluminium, zinc and magnesium cause the evolution of both hydrogen and water vapor. The ideal reaction is $Me + xNaOH = Me(ONa)_x + xH$, so that the reason for the production of water in nearly all cases is somewhat obscure. This point the authors will study by means of further experiments.—*Berichte,* xlii, 4728.					h. l. w.

4. *Transformation of Diamond into Graphite.*—Vogel and Tammann have investigated the temperature at which this change takes place. Splinters of diamond were placed in sealed porcelain tubes and heated in an electric furnace. At 1000° C. the change is exceedingly slow, and may not occur at all ; at 1200° a considerable transformation takes place within 24 hours, and at 1500° the change is comparatively rapid. A piece of diamond, which was heated to 1600° in fused calcium silicate, so as to exclude air, was also changed superficially into graphite. —*Zeitschr. physikal. Chem.,* 69, 598.					h. l. w.

5. *The Johns Hopkins University Circular, No. 2.* Pp. 92. Baltimore, Md., February, 1910.—The recent circular of the Johns Hopkins University has a double interest. It opens with a series of papers, seventeen in number, from the physical laboratory, edited by Professor Ames. Five of these are by Professor Wood, including two on his recent photography with infra-red and ultra-violet rays ; three each by J. B. Whitehead, J. A. Anderson, and W. W. Strong, and others by A. H. Pfund, P. H. Edwards, and C. M. Sparrow. A list of recent publications (since April, 1906) by those who are, or have been, members of the University fills pages 55–76.

This circular also contains the record of the commemorative meeting held on December 19, 1909, of Professor Simon Newcomb, whose active connection with the University extended over the sixteen years from 1884 to 1900. The address delivered by Professor Milton Updegraff, of the U. S. Navy, is given in full.

6. *Meteorologische Optik;* von J. M. Pernter. IV Abschnitt; von Felix M. Exner. Pp. xviii, 559–799. Vienna, 1910 (Wilhelm Braümuller).—Earlier parts of this valuable work have been noticed in this Journal (see vol. xiii, 472, xxii, 81.) As will be recalled, the work as planned by Professor Pernter in 1901 was intended to embrace all the material dealing with meteorological optics, a field which has never been filled before. The author unfortunately died in December, 1908, before it was possible for

him to finish his task. The completion of the work, therefore, has been placed in the hands of his associate, Dr. Exner, who with much thoroughness and industry has prepared a well-arranged digest of the special subjects to be covered. As this field, however, is one to which he had not devoted particular attention, he disclaims any attempt at originality of presentation, except in regard to Lord Rayleigh's theory of the blue color of the sky. Some of the topics treated are as follows: The apparent form of the firmament; atmospheric refraction and the connected phenomena, as the Fata Morgana, scintillation, etc.; halos and rainbows and their explanation; the color and polarization of the sky, the weakening of light in the atmosphere and twilight phenomena.

II. Geology and Mineralogy.

1. *Publications of the U. S. Geological Survey*, Geo. Otis Smith, Director.—Recent publications of the U. S. Geological Survey are noted in the following list (continued from vol. xxviii, p. 557).

Folios.—Geological Atlas of the United States.—No. 167. Field edition, in octavo form. Trenton, New Jersey–Pennsylvania Folio. Description of the Trenton Quadrangle : F. Bascom, N. H. Darton, H. B. Kümmel, W. B. Clark, B. L. Miller, and R. D. Salisbury. Pp. 185 ; 2 maps. Structure section sheet, columnar sections, 3 figures.

No. 169. Watkins Glen–Catatonk Folio, New York ; by Henry S. Williams, Ralph S. Tarr, and Edward M. Kindle. Pp. 33, 3 colored maps, 37 figures.

Professional Papers.—No. 65. Geology and Water Resources of the Northern Portion of the Black Hills and Adjoining Regions in South Dakota and Wyoming ; by N. H. Darton. Pp. 105, 24 plates, 15 figures. See p. 267.

Mineral Resources of the United States. Calendar year 1908. Part I—Metallic Products. Pp. 816, 2 plates, 3 figures. Part II—Non-Metallic Products. Pp. 899, 1 plate, 6 figures. These important volumes, each with its own index, bring together the numerous separate chapters, prepared by many different authors, which have already been issued in advance. The general summary of mineral production in 1908, with which Part I opens, has been prefaced by W. T. Thom.

Bulletins.—No. 378. Results of purchasing Coal under Government Specifications; by John Shober Burrows. With a paper on Burning the Small Sizes of Anthracite for Heat and Power Purposes ; by Dwight T. Randall. Pp. 44.

No. 386. Pleistocene Geology of the Leadville Quadrangle, Colorado ; by Stephen R. Capps, Jr. Pp. 99, 7 plates, 18 figures.

No. 390. Geology of the Lewistown Coal Field, Montana ; by W. R. Calvert. Pp. 83, 5 plates, 1 figure.

No. 396. Paleontology of the Coalinga District, Fresno and Kings Counties, California ; by Ralph Arnold. Pp. 173, 30 plates.

No. 397. Mineral Deposits of the Cerbat Range, Black Mountains and Grand Wash Cliffs, Mohave County, Arizona; by F. C. Schrader. Pp. 226, 16 plates, 37 figures.

No. 400. Iron Ores, Fuels, and Fluxes of the Birmingham District, Alabama ; by Ernest F. Burchard and Charles Butts. With Chapters on the Origin of the Ores ; by Edwin C. Eckel. Pp. 204, 17 plates, 19 figures.

No. 404. The Granites of Vermont ; by T. Nelson Dale. Pp. 138, 5 plates, 25 figures.

No. 405. The Mercury Minerals from Terlingua, Texas; by W. F. Hillebrand and W. T. Schaller. Pp. 174, 6 plates, 44 figures.

No. 408. A Reconnaissance of Some Mining Camps in Elko, Lander and Eureka Counties, Nevada; by William H. Emmons. Pp. 130, 5 plates, 22 figures.

No. 409. Bibliography of North American Geology for 1908, with subject index; by John M. Nickles. Pp. 148.

No. 410. The Innoko Gold-Placer District, Alaska, with accounts of the Central Kuskokwim Valley and the Ruby Creek and Gold Hill Placers ; by A. G. Maddren. Pp. 87, 5 plates.

No. 411. Results of Spirit Leveling in Ohio, 1898 to 1908, inclusive ; compiled by S. S. Gannett and D. H. Baldwin. Work done in coöperation with the State of Ohio during 1901 to 1908, inclusive. Pp. 147.

No. 412. Tests of Run-of-Mine and Briquetted Coal in a Locomotive Boiler ; by Walter T. Ray and Henry Kreisinger. Pp. 31, 9 figures.

No. 413. A Reconnaisance of the Gypsum Deposits of California ; by Frank L. Hess, with a Note on Errors in the Chemical Analysis of Gypsum ; by George Steiger. Pp. 36, 4 plates, 2 figures.

No. 414. Notes on Some Mining Districts in Humboldt County, Nevada; by Frederick Leslie Ransome. Pp. 75, 1 plate, 7 figures.

No. 416. Recent Development of the Producer–Gas Power Plant in the United States ; by Robert Heywood Fernald. Pp. 82, 2 plates, 3 figures.

No. 418. The Fire Tax and Waste of Structural Materials in the United States ; by Herbert M. Wilson and John L. Cockrane. Pp. 30.

No. 421. Results of Spirit Leveling in Illinois 1896 to 1908, inclusive ; compiled by S. S. Gannett and D. H. Baldwin, in coöperation with the Illinois State Geological Survey during 1905 to 1908, inclusive. Pp. 74.

No. 423. A Primer on Explosives for Coal Mines. By

Charles E. Munroe and Clarence Hall. Pp. 61, 9 plates, 12 figures.

No. 424. The Valuation of Public Coal Lands. The Value of Coal Land ; by George H. Ashley. Depth and Minimum Thickness of Beds as Limiting Factors in Valuation ; by Cassius A. Fisher. Pp. 75.

Water-Supply Papers.—No 233. Water Resources of the Blue Glass Region, Kentucky; by George Charlton Matson. With a chapter on the Quality of the Waters; by Chase Palmer. Pp. 223, 3 plates, 6 figures.

No. 236. The Quality of Surface Waters in the United States. Part I. Analyses of Waters East of the One Hundredth Meridian ; by R. B. Dole. Pp. 123.

No. 238. The Public Utility of Water Powers and their Governmental Regulation ; by René Tavernier and Marshall O. Leighton. Pp. 161.

2. *Canada Department of Mines.* Geological Survey Branch, R. W. Brock, Director.—The following publications of the Survey have been recently received :

No. 973. Catalogue of Canadian Birds ; by John Macoun and James M. Macoun. Pp. viii, 761, with index.

Nos. 980, 1081. Reports on a portion of Algoma and Thunder Bay Districts, Ontario ; by W. J. Wilson. Pp. 49, 6 plates. Report on the Region Lying North of Lake Superior, between the Pic and Nipigon Rivers, Ontario ; by W. H. Collins. Pp. 24.

No. 1035. The Coal Fields of Manitoba, Saskatchewan, Alberta, and Eastern British Columbia ; by D. B. Dowling. Pp. 111, 11 plates, 1 map.

No. 1050. The Whitehorse Copper Belt, Yukon Territory; by R. G. McConnell. Pp. 63, 2 figures, and maps.

No. 1059. A Geological Reconnaissance of the Region traversed by the Transcontinental Railway between Lake Nipigon and Clay Lake, Ontario ; by W. H. Collins. Pp. 67, 2 plates, 1 diagram.

No. 1073. Catalogue of Publications of the Geological Survey, Canada. (Revised to January 1, 1909.) Pp. 181.

No. 1085. A Descriptive Sketch of the Geology and Economic Minerals of Canada ; by G. A. Young. Introduction by R. W. Brock. Pp. 151, 82 plates, 2 maps.

Mines Branch.—Eugene Haanel, Director.—No. 23. Report on the Iron Ore Deposit along the Ottawa (Quebec side) and Gatineau Rivers ; by Fritz Cirkel. Pp. vii, 147, 5 plates, 15 figures, 2 maps.

No. 62. Preliminary Report on the Mineral Production of Canada during the calendar year 1909 ; prepared by John Mc-Leish. Pp. 18.

Special reports (Nos. 42–46) have also been issued on the production for the calendar years of 1907–08 of the following : iron and steel; chromite ; asbestos; coal, coke, and peat ; natural gas and petroleum.

Nos. 55 (Mines) and 1107 (Geologic Survey). Joint Report on the Bituminous or Oil-Shales of New Brunswick and Nova Scotia ; also on the Oil-Shale Industry of Scotland. Part I, Economics ; Part II, Geology ; by R. W. ELLS. Pp. 75, 15 plates, 6 figures.

3. *Kilauea and Mauna Loa, Hawaiian Volcanoes ;* by WM. T. BRIGHAM, Mem. Bernice Pauahi Bishop Mus., vol. ii, No. 4. Pp. 222, 4°, 67 plates, 143 figs. Honolulu, 1909.—The author states in the beginning of his work that it is mainly for the purpose of presenting his studies, which have continued for nearly half a century, on the Hawaiian volcanoes, and thus supplying a collection of material which may be used by students of vulcanology ; he modestly disclaims any attempt to solve by theorizing the deeper problems of this science, the source of volcanic heat and energy ; in short, the cause of volcanic action. The work is thus mainly a record of observations of volcanic phenomena, and the writer has compiled so largely from the writings of other observers in this region, that the whole forms practically an historical account, in considerable detail, of the activity displayed here during the past fifty years. Particularly valuable in this connection are the various maps showing the changes which have taken place from time to time in the different craters. Much of the work, entirely aside from the standpoint of its being a collection of recorded observations, is very interesting reading, and the author's personal knowledge has enabled him to correct a number of errors, which at one time or another have crept into various publications on the volcanic phenomena of the islands.

The volume is well printed and bound, and embellished with a large number of half-tone cuts and plates from photographs, which greatly enhance its value and interest ; the only criticism which might be offered in this connection is, that had a different kind of paper been employed, the half-tone cuts would have given much better results. The work as a whole is a very useful addition to the literature of vulcanology.   L. V. P.

4. *Deviations from the Normal Order of Crystallization in Granite.*—MACKIE, in an article entitled "Micropegmatites in Granite," gives the results of a study of a number of Scotch granites in which deviations from the usually assumed order of crystallization of the minerals occur. While ostensibly a study of various types of micropegmatite, its chief interest consists in the discussion of the order of crystallization and the explanations devised to account for irregularities. He finds in granite that quartz is the most aberrant mineral, its occurrence in abnormal position being equal to orthoclase and plagioclase together, and there are two maxima of this, one in the hornblende of hornblendic rocks, the other in the orthoclase of the more acid rocks. He explains this by supposing that in the molten solution the liquid hornblende is able to keep a certain amount of silica (or quartz) dissolved, but when the hornblende crystallizes this is also forced to crystallize ; later the rest of the quartz would

appear in normal position. By thus considering the various solu-
bilities of the different minerals in one another, the solvent
action of contained water, and rises of temperature and resolution
occasioned by successive crystallization, he is able to devise a
scheme which will account for abnormalities in the order of
appearance. In connection with this the reviewer would point
out that it has scarcely been shown as yet that hornblende, as such,
can exist in the molten solution ; the trend of investigation, indeed,
tends to prove that the mineral molecules existent in the magma
are of much simpler composition, and it seems probable that
hornblende comes into being only in the act of crystallization.—
Trans. Edinb. Geol. Soc., ix, pt. iv, 247, 1909.　　　L. V. P.

5. *New Occurrence of Lujavrite.*—The very rare and remark-
able rock lujavrite was first found and named by W. Ramsay,
from its occurrence at Lujavr Urt in the Kola Peninsula, Rus-
sian Lapland. It has been subsequently described by Ussing
from southern Greenland. A new locality is now announced by
H. A. Brouwer from Pilandsberg in the Transvaal. Like the two
former occurrences, it consists of very flattened alkalic feldspars
intermingled with nephelite and eudialyte and is pegged through
with acicular aegirite. It also contains the associated rare min-
erals astrophyllite, mosandrite and lâvenite. The eudialyte is
apt to be changed into catapleiite, while considerable quantities of
secondary pectolite are present. The following analyses of two
varieties of the rock are by F. Pisani :

	SiO_2	TiO_2	ZrO_2	Al_2O_3	Fe_2O_3	FeO	MgO	CaO	Na_2O	K_2O	H_2O
I	52·35	0·59	0·39	14·11	7·98	2·17	0·66	4·65	9·30	2·78	3·20
											= 100·30
II	51·35	2·75	0·54	11·45	9·40	2·41	0·54	3·27	10·80	2·52	3·20
											= 99·48

The total includes in I, MnO = 0·62 and CO_2 = 1·50 ; in II,
MnO = 1·25. These correspond closely with the analyses of the
Kola and Greenland rocks. It may be also mentioned that rocks
resembling lujavrite have been described by Lacroix as a marginal
facies of nephelite syenite from the Los Islands, French Guinea.
The association with nephelite syenites occurs also with the
lujavrites previously mentioned.— *Comptes Rendus*, Nov. 29, 1909.

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6. *The Mercury Minerals from Terlingua, Texas.*—The
remarkable minerals from Terlingua, several of them new, were
described by Moses in 1903 (this Journal, vol. xvi, 253) ; later a
preliminary account of their chemical examination was given by
Hillebrand and Schaller (vol. xxiv, 259, 1907). The latter
authors have now published their complete results in Bulletin
405 of the U. S. Geographical Survey. Many points of interest
are brought out, particularly the remarkable complexity of the
crystallization of the new species : thus montroydite is shown to
have 56 forms, terlinguaite 134 forms, and even the isometric
eglestonite 20 forms.

7. *The Rochester Collection of Meteorites ; Descriptive List of Specimens ;* by KENNETH S. HOWARD. Pp. 28, with 2 plates. Rochester, 1909.—The Rochester collection of meteorites, of which a catalogue has been recently published, contains a total of 234 falls, represented by 267 specimens : these include 89 siderites, 19 siderolites and 126 aerolites. A large part of the material was accumulated by the late Professor Henry A. Ward as duplicates in the course of his labors in bringing together the Ward-Coonley meteorite collection. Many fine individual specimens are noted in the catalogue, the collection being particularly rich in the irons, two-thirds of which weigh over 100 grams each.

8. *A new Meteorite from Georgia.*—A new meteoric stone has been recently described by G. P. MERRILL from Thomson, McDuffie county, Georgia. It was found on October 15, 1888, but has been in private hands and its existence has only now been made public. Its present weight is 218 grams and could not have been greater originally than 250 grams ; it is largely covered with a black crust. The specific gravity is 3·51 and a polished surface shows a light gray ground resolved with a lens into a compact mass of gray chondrules, with small particles of metallic iron and iron sulphide. It is somwhat similar to the Möcs meteorite.—*Smithsonian Misc. Conts.*, lii, pp. 473–476, 2 plates.

III. MISCELLANEOUS SCIENTIFIC INTELLIGENCE.

1. *Carnegie Institution of Washington.*—Recent publications of the Carnegie Institution are noted in the following list (continued from vol. xxviii, p. 564) :

No. 74. The Vulgate Version of the Arthurian Romances, edited from Manuscripts in the British Museum ; by H. OSKAR SOMMER. Vol. I, Lestoire del Saint Graal. Pp. xxxii, 296. Vol. II, Lestoire de Merlin. Pp. 466.

No. 85 (Kentucky). Index of Economic Material in Documents of the States of the United States. Kentucky, 1792–1904. Prepared for the Department of Economics and Sociology of the Carnegie Institution of Washington ; by ADELAIDE R. HASSE. Pp. 452.

No. 100. The Seal Cylinders of Western Asia; by WILLIAMS HAYES WARD. Pp. xxix, 428, 1315 illustrations.

No. 108. The Atrium Vestæ ; by ESTHER BOISE VAN DEMAN. Pp. ix, 47, frontispiece, 10 plates and plans A–F, showing walls of various periods.

No. 116.—The Differentiation and Specificity of corresponding Proteins and other vital Substances in relation to Biological Classification and Organic Evolution : The Crystallography of Hemoglobins ; by EDWARD TYSON REICHERT, and AMOS PEASLEE BROWN. Pp. ix, 338, 100 plates and 56 tables.

No. 121. Inheritance of Characteristics in Domestic Fowl ; by CHARLES B. DAVENPORT. Pp. iii, 100, with 12 colored plates.

2. *Publications of the Allegheny Observatory of the University of Pittsburgh.*—The following has been recently issued : Vol. I, No. 20. · The Algol—Variable δ Libræ. Pp. 123–134.

THE

AMERICAN

JOURNAL OF SCIENCE.

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ART. XXXII.—*Contributions to the Geology of the Grand Canyon, Arizona.—The Geology of the Shinumo Area;* by L. F. NOBLE.

Part I.

PREFACE.

EXPOSURES of unaltered pre-Cambrian sediments are of great interest to the geologist in any part of the world. Especially is this true in the Grand Canyon of Arizona, where the certainty of stratigraphic position and completeness of exposure are almost without a parallel, and where the spectacular nature of the occurrence partakes of the stupendous and fantastic scenery of that mighty gorge, from the spell of which the observer is never entirely free. During a pleasure trip in the Grand Canyon region in January, 1908, in company with Professor H. E. Gregory of Yale and others, the writer chanced to visit a hitherto undescribed exposure of these rocks on the

Colorado River at the foot of Bass Trail. Although only a few hours were spent in the vicinity, the diagrammatic simplicity with which the structural relations were revealed was such that the interest could be immediately realized. In the summer of that year the writer returned with the intention of making a detailed study of these pre-Cambrian rocks. He speedily found that the interest in this part of the Grand Canyon did not end with the study of the pre-Cambrian alone: it was found that the line of displacement of the West Kaibab fault which runs into the Grand Canyon at this point was itself a remarkable structural feature and worthy of considerable attention; that the entire Paleozoic section of the canyon wall was here, as elsewhere, undescribed in absolute detail; and finally that there were problems of physiographic interest in the Grand Canyon region the ultimate solution of which could be greatly helped by a detailed study at this point. It was therefore decided to extend the work to a complete areal study of the region, including for this purpose the greater part of the new Shinumo topographic sheet of the United States Geological Survey. This report, accompanied by an atlas containing the geologic maps, sections, and plates, was presented to the faculty of the Graduate Department of Yale University in June, 1909, as a thesis in partial fulfillment of the requirements for the degree of Ph.D., under the title of "The Geology of the Shinumo Area, Grand Canyon, Arizona."

It is intended to present the substance of the thesis in two or more articles in this Journal. The entire report is to be published *in extenso* at a later date as a Bulletin of the United States Geological Survey. For this reason, as well as because of the large scale and elaborate nature, the geologic map, sections, and plates will not be published here.

The first article will be presented in two parts. Part I, now published, comprises a general introductory description of the Shinumo area and deals with the basement rocks of the Archean. Part II, to follow in a later number, will be devoted to the Algonkian rocks of the Grand Canyon series and will include a map showing the distribution of the Vishnu and Grand Canyon series in the Grand Canyon.

It is also proposed to devote a later article or articles to the Paleozoic section of the canyon wall; to a structural study of the area, including both the pre-Cambrian and later structure and a study of the displacements on the line of the West Kaibab fault; and finally to features of physiographic interest in the area,—such as the drainage system of the plateaus and the origin of the Esplanade and Tonto platforms.

Introduction.

Location and geography.—The area studied lies in Coconino County in the northern part of Arizona in what is known as the Plateau Province of the Territory. It is inclosed between meridians 112° 25' and 112° 15' and parallels 36° 20' and 36° 05', and includes about 150 square miles. It comprises rather more than the eastern half of the area of the Shinumo topographic sheet of the United States Geological Survey.

The greater part of the area lies within the depths of the Grand Canyon and includes the Shinumo Amphitheater, which is the largest of the great amphitheaters in the Kaibab division. The eastern and northern parts of the area include that part of the "mainland" north of the canyon which forms the immediate rim of the Shinumo Amphitheater, reaching from the promotory of Point Sublime on the east to the Muav Saddle on the west; this northern mainland is a part of the Kaibab Plateau. The northwestern part of the area includes the surface of Powell Plateau, a great butte, or "island," lying athwart the course of the Grand Canyon. The southwest corner includes a part of the southern "mainland" which culminates in the great promontory known as Havasupai Point; this southern mainland belongs to the Coconino Plateau.

About a mile west of Havasupai Point is situated Bass Camp, the only habitation in the area. The camp was established by Mr. W. W. Bass some twenty-five years ago to accommodate the tourist traffic. From this point a trail was constructed to the river, which was crossed by boat at times of low water. A permanent camp was established in the bottom of the canyon on the north side of the river about a mile up Shinumo Creek, where an irrigated garden was made upon the site of an ancient one cultivated by the prehistoric inhabitants of the region. Later a trail was constructed up Muav Canyon to the north rim, by means of which access may be had to points on the Kaibab Plateau and the settlements in Southern Utah. Recently deposits of copper and asbestos have been discovered by Mr. Bass in the depths of the canyon, to which he has constructed additional trails. In March, 1908, three wire cables were suspended across the granite gorge at the foot of Bass Trail. On these cables travels a wire car, so that at the present time the Colorado River may be crossed at this point regardless of high water. Bass Camp is most easily reached by wagon road from Bass Station on the Grand Canyon branch of the Sante Fe Railroad, a distance of 20 miles southeast; or from the El Tovar Hotel at the terminus of the railroad 25 miles east. Another road leads 20 miles southwest to the rim of Cataract Canyon, into which a trail leads down to the Supai

Indian village. Roads also lead to the towns of Williams and Ash Fork, about 60 miles respectively south and southwest.

Field Work.—The geological field work upon which the thesis is based was begun upon the 23d of August, 1908, and ended upon the 12th day of December of the same year. The greater part of the work was done from a permanent camp on the Shinumo, which served as a base of operations for studying all the region in the greater depths of the canyon. Two trips were made to the north rim. The first was made in September and the second in November. Each trip lasted a week. Camp was established in the Muav Saddle and excursions were made from there over the surface of Powell Plateau and over the Kaibab mainland as far as the head of the Shinumo Amphitheater. The writer was accompanied on these occasions, as well as during his stay in camp on the Shinumo, by Mr. John Walthenberg as guide, whose detailed knowledge of the region and whose assistance in other ways were invaluable. The work in the southern part of the area was done from Bass Camp, from which point excursions were made over the Coconino Plateau and into the upper part of the canyon.

Literature.—Two references to the geology of the area are to be found in geological literature :

Captain Dutton in his monograph entitled " The Tertiary History of the Grand Canyon District" (Dutton, *a*) describes most fully and charmingly the geology of the north rim in this section of the Grand Canyon. In Chapter VII he describes the surface features and scenery of the Kaibab Plateau in the vicinity of Point Sublime. Chapter VIII is devoted to the panorama disclosed from Point Sublime, while Chapter IX describes the walls of the amphitheaters of the north side in detail. The Muav Saddle and Powell Plateau are described on pp. 162–167, and the Shinumo Amphitheater on pp. 167–174. His work, however, did not extend into the depths of the canyon.

Mr. J. S. Diller of the United States Geological Survey describes in his report on the production of asbestos in " Mineral Resources for 1907 " (Diller, *a*) the deposits of asbestos occurring in the Algonkian sediments of this area near Bass Ferry. This is the only reference in the literature to the presence of Algonkian strata in this part of the Grand Canyon.

Acknowledgments.—In 1901 Mr. Charles D. Walcott and Mr. G. K. Gilbert spent several days at Mr. Bass's camp on the Shinumo and at that time worked out the structure of the pre-Cambrian sediments, which Mr. Walcott correlated with the section described by him in Unkar Valley (Walcott, *a*, *b*, *c*, *d*, and *e*). His notes, however, are unpublished, and it is due to his kindness and courtesy that the writer is enabled to present the first description of the area. To Mr. Walcott the

writer is also indebted for the identification of Cambrian fossils, for a list of the Cambrian fossils found in the region, and for assistance in interpreting the stratigraphy.

To Professor Joseph Barrell, to Professor Charles Schuchert, and to Professor Louis V. Pirsson, all of Yale University, the most sincere thanks are due for continued interest and advice during all stages of the work. To Mr. W. W. Bass the writer is indebted for material assistance and guidance during his work in the field.

Geologic Nomenclature.—The geologic names employed in this article are revised names recently authorized by the United States Geological Survey, with the exception of those of the Cambrian, which as yet have not been formally revised. The first table below gives the rock formations of the Shinumo area in terms of the revised terminology, while the second table gives the equivalent of the newer in the older nomenclature.

I.

Geologic column of the Shinumo Area.

System	Series	Group	Formation
Carboniferous	Pennsylvanian	Aubrey	Kaibab limestone Coconino sandstone Supai formation
	Pennsylvanian and Mississippian	Redwall	Redwall limestone

(Unconformity of erosion without uniformity of dip)

Cambrian	Acadian (and Saratogan?)	Tonto	" Marbled limestone" " Tonto shale " " Tonto sandstone "

(Great angular unconformity)

Algonkian _____ Grand Canyon ___ Unkar

(Greatest angular unconformity)

Archean _____ Vishnu

II.

Revised Nomenclature	Classic Nomenclature of the reports of Dutton, Gilbert, and Walcott.	
Formation	Formation	Group
Kaibab limestone_____	Cherty limestone _____	Upper Aubrey
Coconino sandstone_____	Cross-bedded sandstone __	
Supai formation_____	Lower Aubrey sandstone__	Lower Aubrey
Redwall limestone_____	Redwall limestone_____	Redwall
" Marbled limestone" __	Marbled limestone _____	Upper Tonto
" Tonto shale" _____	Tonto shale _____	
" Tonto sandstone "____	Tonto sandstone_____	Lower Tonto

Topography, Climate, and Vegetation.

The surfaces of the plateaus in the Shinumo area through which the pathway of the Grand Canyon is trenched are everywhere developed at the same horizon on the highest member of the Paleozoic series occurring in the Canyon wall and known as the Kaibab limestone, the Mesozoic and Tertiary formations having been stripped back to the terraces of southern Utah.

The surface of the southern, or Coconino, plateau slopes to the southwest away from the canyon rim at the rate of about 200 feet to the mile. The drainage system of the plateau surface consists of a series of mature, open-floored valleys with gently sloping sides, which contain no living streams. These valleys trend southwesterly away from the canyon rim with the slope of the plateau surface and drain into the broad, shallow synclinal basin occupied by Cataract Canyon. In tracing one of these mature valleys toward its head, it is a common thing to find it truncated as a hanging valley by the wall of the Grand Canyon. So general is this phenomenon, that the stranger who loses his way on the southern plateau has only to keep in mind that if he follow any valley far enough headward he will come out upon the rim of the Grand Canyon.

The surface of the northern, or Kaibab, plateau is in every respect similar to that of the Coconino. The same system of mature valleys covers its surface, which slopes southwesterly to the rim of the canyon. The only difference is that the surface drainage runs into the Grand Canyon instead of away from it. Neither plateau surface contains a living stream.

Powell Plateau may be regarded as a dismembered part of the Kaibab. Its surface is developed at the same horizon on the Kaibab limestone, slopes southwesterly at the rate of 900 feet in five miles, and contains the same mature drainage system. It is substantially a great island, surrounded on three sides by mile-deep canyons, and isolated from the mainland by erosion in the line of displacement of the West Kaibab fault. The gap that separates Powell Plateau from the mainland is called the Muav Saddle, and is notched 800 feet below the surface of the plateaus. No more striking topographic contrast can be imagined than that between the mature drainage systems of the plateaus and the youthful topography within the deep-trenched canyon.

The strata of the Paleozoic rock system within the area dip gently and almost uniformly to the southwest at the rate of about 200 feet to the mile, and the surfaces of the plateaus are everywhere accordant with the rock structure. A slight local interruption occurs where the line of the West Kaibab fault crosses the area, along which the strata are flexed into a mono-

cline dipping sharply northeastward. A few minor flexures cross the area in a northwesterly direction; all dip to the southwest and are hardly more than gentle swells upon the general warping.

The Shinumo Area is a critical area for the study of the topography within the canyon itself. It is here that the topography undergoes a transition from the profile which is characteristic of the Kaibab division to that which is characteristic of the Kanab.

In the eastern, or Kaibab, division of the canyon, the descent of the wall is unusually abrupt throughout the entire Paleozoic rock series. The only bench or terrace of any extent or definition is that which is developed near the bottom of the canyon upon the summit of the basal sandstone of the Tonto group. The bench is known as the Tonto platform; in it is cut an inner gorge, in which the river flows upon the basement schists of the Archean. The platform averages a mile in width on either side of the canyon, and is so well defined that one may travel upon it throughout the length of the Kaibab division. In the next western, or Kanab, division of the canyon the lower terrace has disappeared. Instead, a wide bench is opened out upon the summit of the hard red sandstones of the Supai formation of the Aubrey group, about a thousand feet below the level of the canyon rim. This bench forms a broad level platform averaging two miles in width on either side of the canyon, and has been named by Dutton the "Esplanade." Through it is cut a deep and narrow inner gorge, at the bottom of which flows the river.

The topography of the Kaibab division is characterized by a much greater dissection than that of the Kanab; great amphitheaters are eroded back into the north wall, thronged with buttes and outliers fashioned out of every formation of the Paleozoic rock series and trenched by a multitude of side gorges. The topography of the Kanab division is very simple, consisting only of a broad outer canyon in which is cut the inner gorge; the great dissection which makes the fantastic scenery of the Kaibab division is entirely lacking.

Eastward from Havasupai Point in the Shinumo area the topography in the canyon is that which is characteristic of the Kaibab division. Westward, however, the upper platform or "Esplanade" begins to appear. The Shinumo amphitheater, which occupies the greater part of the area to be described, presents a combination of both types of topography; the great dissection and the presence of the Tonto platform are features characteristic of the Kaibab division, but the Esplanade characteristic of the Kanab division is developed to quite an equal extent upon the upper surface of the Supai sandstone. In the

western part of the area the Tonto platform fades out, the river closes in a deep inner gorge in the Esplanade, and the profile of the canyon becomes that of the Kanab division,—the view of the canyon westward from Bass Camp discloses a broad expanse of Esplanade for fifteen miles, through which the inner gorge sweeps in two great meanders almost from wall to wall. In the center of the Shinumo area the Esplanade is rather more dissected than in the Kanab division farther west, but its identity as a topographic feature is already well established.

The floors of the Esplanade and Tonto platforms, like the surfaces of the plateaus, are structural surfaces developed everywhere at the same horizon on the underlying formation. In conformity with the dip of the rock system they likewise slope to the southwest at the rate of about 200 feet to the mile.

Another topographic contrast is presented in the difference in dissection of the two sides of the Grand Canyon, a feature which is characteristic of the entire pathway through the Kaibab. The north rim lies three times as far back from the river as the south rim; the great amphitheaters with their limiting promonotories extending far into the canyon, the buttes and temples, and the deep lateral gorges all belong to the north side of the canyon. The south wall presents a simple aspect: the side gorges rarely extend back into the rim of the canyon, there are few buttes and outliers, and the great amphitheaters are wholly lacking. Compared with the fantastic topography of the north side, the scenic effect of the south wall is precipitous and somber.

The Colorado River enters the area in the southeast corner, flows northwestwardly to the center of the area, and turns sharply west at the point where it is joined by the Shinumo. The Shinumo is the only living tributary in the area, and is the master stream that drains the Shinumo amphitheater of the north wall. It is a stream of clear water of the same order of magnitude as Bright Angel Creek twenty miles east, and is in striking contrast to the muddy Colorado.

The topography of the Shinumo amphitheater, besides presenting an equal development of both the Esplanade and Tonto platforms, is remarkable in another way. In the other great amphitheaters of the Kaibab division the master gorges trend to the southwest; the tributary gorges trend in the same general direction and lateral gorges perpendicular to the main axes of the amphitheaters are of minor development. In the Shinumo amphitheater the lateral gorges have become the dominant feature, so that the main axis of the amphitheater trends to the northwest at right angles to the course of the master stream

and parallel to the course of the Colorado River. The greatest lateral gorge extends entirely across the Shinumo amphitheater from Point Sublime on the southeast to the Muav Saddle on the northwest. Only a mile of this lateral gorge is occupied by the master stream of the Shinumo; the remainder is occupied by two small intermittent streams. The western part of the gorge which extends from the Muav Saddle to Shinumo Creek is drained by Muav Creek and is called the "Muav Canyon"; the eastern part extending from the Shinumo to Point Sublime is drained by Flint Creek and has no local name. The entire lateral gorge will be referred to as the "Muav-Flint Creek Canyon." This remarkable linear depression is situated upon the line of the West Kaibab fault and has been conditioned by erosion in that line of fracture. Two smaller lateral gorges cross the heart of the amphitheater parallel to the "Muav-Flint Creek Canyon"; these are situated upon minor lines of fracture.

It may be noted here that Tapeats amphitheater to the westward, in the Kanab division of the canyon, is characterized by similar topographic features where it is crossed by the West Kaibab fault.

In general the surface of the Kaibab plateau at the rim of the canyon is about 1000 feet higher than that of the Coconino plateau directly opposite. But since the surfaces of the plateaus and of the platforms within the canyon are structural surfaces, elevations diminish progressively southwestward in all parts of the area in accordance with the dip of the underlying rock structure. For example: the elevation of the Kaibab Plateau at the head of the Shinumo amphitheater is 8000 feet; at the end of the promontory of Point Sublime, four miles southward, it is 7500 feet. The elevation of the Coconino Plateau at the end of Havasupai Point is 6750 feet; at Bass Camp, a mile southwestward, 6652 feet. The eastern end of Powell Plateau at Dutton Point is 7555 feet; the western end is 6600 feet. Within the canyon the elevation of the Esplanade platform on the north side of the river below Point Sublime is 6250 feet; on the south side of the river below Bass Camp, 5400 feet. In the eastern part of the area the Tonto platform is 3500 feet; in the western part, 2700 feet.

The elevation of the surface of the Colorado River where it enters the area on the east is 2250 feet; where it leaves the area on the west, 2150 feet,—a drop of 100 feet in 10 miles. The river at Bass Ferry is 300 feet wide and 50 feet deep, with a rise of 40 feet at time of high water.

The greatest drops in the shortest linear distance in the area are at Dutton Point, where a drop of 5355 feet to the river is accomplished in a distance of three miles; and at Havasupai

Point, where a drop of 4500 feet is accomplished in a distance of a mile and a half. The latter drop is not equaled elsewhere in the Grand Canyon.

The width of the Grand Canyon in the Shinumo area from Bass Camp to Dutton Point is seven miles; from Bass Camp to the head of the Shinumo Amphitheater it is twelve miles; from Havasupai Point to Point Sublime it is five and one-half miles. The latter is the minimum width of the Grand Canyon in the Kaibab division. Even at this, the narrowest point, the width is over five times the depth.

The differences of climate to be found within the Shinumo area are remarkable. The range in climate between the Kaibab Plateau on the north rim and the bottom of the canyon is as great as that between the mountains of Colorado and the Mojave Desert. The winters on the Kaibab are extremely severe: from November to April the snow lies deep in the woods, often accumulating to a depth of ten feet; even in midsummer the nights are chilly and days delightfully cool. Within the canyon, however, the snow rarely falls below the level of the Esplanade, while on the Tonto platform a fall of snow is practically unknown. The winters in the depths of the canyon are mild, and freezing temperatures are rare. From April to October the entire canyon below the Red Wall concentrates the solar heat, transforming it into a veritable oven; all day the bare rocks absorb the heat of the sun, becoming so hot as to burn the hand; by nightfall the wind becomes a furnace blast, and until after midnight the rocks radiate their heat, feeding the hot wind, which blows without ceasing. The effect of the heat, however, is not enervating, for the dryness of the warm wind evaporates all moisture from the body and keeps it cool. The climate of the southern, or Coconino, Plateau at Bass Camp is characterized by more open winters than the Kaibab, as well as by warmer summers: the snow in winter rarely accumulates on the surface to a great depth, and as a rule vanishes entirely within three days after a storm; in summer the days are unpleasantly hot.

The climate of the Kaibab Plateau is decidedly moist, the precipitation being probably twice as great as that received upon the Coconino Plateau across the canyon; this is chiefly due to its greater altitude. In winter the precipitation takes the form of snow; in summer it comes in the form of showers, which occur through the afternoon and evening. Looking across the canyon from Bass Camp on the south rim, almost any summer evening one may see storm after storm sweeping over the Kaibab surface, usually accompanied by violent electrical display, while the sky overhead and to the westward over the Kanab Desert remains as clear as crystal. Another

phenomenon that contributes to the greater rainfall of the north rim seems to be the presence of the Grand Canyon itself: after every general storm that visits both sides of the canyon alike, there follows on the south rim a day of clearing; but the clouds that rise out of the canyon after the storm sweep back over the north wall and re-precipitate on the Kaibab surface; these secondary storms almost never return over the south rim. The climate of the Coconino Plateau in the area is semi-arid; often no rain will fall for a month at a time. The precipitation is greatest in the winter months and in the month of July. Within the canyon much of the rainfall evaporates before it reaches the greater depths, so that the climate of the lower part of the canyon is more arid than that of the southern plateau.

Powell Plateau, whose higher eastern portion has an altitude equal to that of the Kaibab rim, and whose lower western portion has an altitude equal to that of the Coconino, has an intermediate climate. Its situation as an island in the canyon serves to moderate the cold in winter, for the warm air, rising out of the deep canyons that surround it, acts as a radiator: the snow does not accumulate so deeply on the eastern end as on the Kaibab; and on the western end does not accumulate at all. Its surface is a resort in winter for the game and wild horses that are driven out of the Kaibab by the snow. Its exposed position subjects it to violent gales of wind at all times of the year. The higher eastern end receives an abundant rainfall, while the lower western end is semi-arid.

The variation of the flora in the Shinumo area is as great as that of the climate. The surface of the Kaibab Plateau is covered with a magnificent open forest of yellow pine; the trees grow large and far apart and the ground is free from undergrowth, giving its surface the aspect of a great park; Englemann spruces grow on the north slopes of the washes, and cottonwoods, aspens, and scrub oaks in their bottoms; a minor flora of flowering plants, exceedingly rich in species, covers the floor of the forest. The flora of the plateau surface of the south rim of the canyon differs completely from that of the Kaibab; it is covered with a forest of gnarled and stunted trees of juniper and piñon, with here and there a buckbrush bush; the trees never form thickets, but grow wide apart; while the open stretches are covered with sage brush and mormon tea, with occasional cactus, mescal, and plants of the century family. This difference between the floras of the north and south rim is due to the differences in precipitation and temperature, which vary directly with the altitude. For this reason the floras of the plateaus furnish an almost unfailing index of the elevation. This is beautifully shown on the

southwestward-sloping surface of Powell Plateau, the whole
eastern half of which lies at an elevation of from 7000 to 7500
feet and is covered with the open pine forest characteristic of
the Kaibab. At about 7000 feet the character of the flora
changes, and passes into the gnarled and stunted forests of juni-
per and piñon characteristic of the southern plateau across the
canyon.

Within the canyon itself the variation in the flora is just as
great, and is again an index of the elevation.

The flora of the Esplanade platform, a thousand feet below
the south rim, consists of stunted bushes of juniper and piñon
with greasewood as the ground bush in place of the sagebrush
of the Coconino Plateau. The cactus, mescal, and plants of the
century family are present in greater abundance than on the
plateau, but in less abundance and in more stunted develop-
ment than in the bottom of the canyon. This is due to the fact
that the Esplanade level is within reach of the winter snows
and frosts.

The flora of the Tonto platform, three thousand feet below
the south rim, and of all the interior of the canyon below the
Red Wall, is the flora of a hot and arid desert in its most
characteristic form. The dominant plants are the greasewood
bush, the mormon tea, and the cactus. The mescal and the
plants of the century family here attain their greatest develop-
ment and size. The cacti are particularly rich in species.
Every plant in the flora is either prickly or aromatic; leaf sur-
faces are reduced to a minimum; devices for storing water
attain the greatest perfection; and the dominant color is a
somber gray. The somber colors and the reduction of leaf
surface are apt to deceive the observer, both in regard to the
richness of the flora in species and the abundance of plant
life, which is far greater than one would suspect. The only
tree is the screw-mesquite, which grows in the beds of those
washes that contain living or intermittent streams.

The vegetation in the bottoms of those canyons of the north
side in the Shinumo Amphitheater which contain living streams
is beautiful beyond description, and in refreshing contrast to
the desert flora of the Tonto platform. Tall cottonwoods
grow in the lower canyons; the walls are hung with maiden-
hair fern in the shady places; and willow thickets border the
stream. Grass grows on the banks where there is soil.
Higher up in the canyons, oaks, maples, and other deciduous
trees come in, and often beds of tall rushes. The most
characteristic bush of these upper north-side canyons is the
manzanita, which does not grow on the south side of the
Grand Canyon.

GENERAL GEOLOGY.

ARCHEAN— *Vishnu Schist.*

Name.—The name "Vishnu Terrane" has been given by Walcott (Walcott, c) to the fundamental crystalline complex of the Grand Canyon region that underlies the unaltered sedimentary rocks of Algonkian age, and is separated from them, as well as from the overlying Cambrian, by a profound unconformity. The type locality is situated on the Colorado River thirty miles east of the Shinumo area at the base of one of the great buttes called "Vishnu's Temple," from which he derives the name.

Distribution in the Kaibab division.—The rocks of the Vishnu series are exposed continuously for a distance of over forty miles within the Kaibab division of the Grand Canyon in the bed of the Colorado River and in the walls of its gorge which is cut beneath the Tonto platform. The Shinumo area is at the western end of this long exposure. The eastern limit of the exposure is determined by the appearance of great thicknesses of overlying strata of the Grand Canyon series dipping northeastward into the bed of the river, in the classic locality described by Walcott. The western limit of the exposure is likewise defined by a structural cause : three miles west of the Shinumo area a southward bend of the river causes it to flow parallel to the gentle southwestward dip of the Paleozoic rock system of the canyon wall, carrying the bed of the stream up out of the schists and into the basal Tonto sandstone of the Cambrian.

Occurrence and distribution in the Shinumo area.—The Vishnu schists are exposed for a distance of three miles in the gorge of the Muav-Flint Creek Canyon. They are exposed in the bed of the Colorado river throughout its course across the Shinumo area. Along the south bank of the river for a distance of four miles, and along the north bank for a distance of seven miles, in the eastern half of the area, sediments of the Grand Canyon series intervene between the Vishnu schists and the Tonto sandstone of the basal Cambrian. Elsewhere the schists are exposed without break in the walls of the river gorge beneath the Tonto sandstone.

No detailed study of these rocks was made in the Shinumo area beyond the general location and determination of the various types represented, since the limited extent of the exposures precludes the possibility of unraveling any general Archean structure from the study of this area alone. They are here a metamorphic complex of quartz, mica, and hornblende schists, invaded by a batholithic mass of quartz-diorite, and injected by veins of pegmatite and aplite.

Five main types of rock are found in this complex within the area:

The first type is a quartz schist, with graduations into mica schist. It comprises the greater part of the Vishnu schists that are exposed in the gorge of the Colorado River west of the cable crossing at Bass Ferry. It is also exposed in the bed of Muav Canyon, and in the bed of Flint Creek above the junction with the Shinumo.

The second type is a quartz schist with gradations into quartz-hornblende schist. It is exposed in that part of the Muav-Flint Creek Canyon that is occupied by the living stream of the Shinumo, grading both eastward and westward into the quartz-mica schist.

The third type is a hornblende schist. It occurs in one small outcrop about 200 feet wide, on the east side of "Fault wash," a dry wash which joins the Shinumo just below the mouth of Muav Canyon, and is sharply bounded on both sides by the quartz-mica schist.

The fourth type of rock is a quartz-diorite. So far as observed, it constitutes all of the Vishnu series of the Shinumo area that is exposed in the "granite gorge" of the Colorado River east of the cable crossing. Its western contact is well defined. The eastern limit of the exposure was not located.

The fifth type of rock is a granitic pegmatite which occurs in dikes that cut all the rock types of the Vishnu. These dikes occur in two generations. The older generation is folded with the schists. The younger generation occurs in a great network or mesh of dikes cutting both the quartz-diorite and the schists.

The Vishnu schists have a typical schistose structure. The planes of schistosity have a dip that seldom departs greatly from the vertical. The dominant trend of the schistosity is northeasterly, but varies, from place to place. Locally, the schists are much twisted and contorted.

Lithology.—The less micaceous phase of the *quartz-mica schist* has a dark grey color with a greenish tinge. The cleavage is imperfect and the surfaces have a satin-like luster. The texture is fine-grained and the unaided eye can distinguish no mineral constituents except quartz. The microscope shows the rock to be composed almost entirely of fine interlocking grains of quartz, with occasional small flakes of white mica, arranged in parallel lines. In the extreme quartzose phase the amount of mica is almost negligible, just enough being present to impart a satin-like luster to the rock.

The micaceous phase of the schist has a slight grey color with either a pinkish or greenish tinge on the fresh fracture. Where the rock is weathered, the color becomes red. The

cleavage is rather distinct. The texture ranges from fine to coarse. To the unaided eye both the quartz and mica are visible. Under the microscope the rock is seen to be composed of interlocking grains of quartz, with an almost equal amount of mica. The mica flakes are arranged in parallel lines. The greater part of the mica is muscovite, with occasional flakes of brown biotite.

Locally the schist is garnetiferous, and in one locality tourmaline was observed. All gradations between the quartzose and the micaceous phases occur, but in no instance does the mica exceed the quartz in quantity.

The *quartz-hornblende schist* is dark green in color. The cleavage is imperfect, and the texture fine-grained and uniform. The rock is dense and hard. The mineral constituents cannot usually be distinguished in the hand specimen without the aid of the lens. Under the microscope the rock is seen to consist of about equal proportions of quartz and green hornblende. The quartz is present in interlocking grains. The hornblende tends to form automorphic crystals whose longer axes have a roughly parallel arrangement. No other minerals were present in the slides examined. In some phases of the rock the quartz exceeds the hornblende in amount.

The *hornblende schist* is dark green in color. It is a soft rock, considerably disintegrated, and crumbling under the hammer. The texture is coarse granular. Megascopically the rock appears to consist almost entirely of dark green hornblende. No schistose structure is observable in the mass. The microscope shows the rock to consist almost wholly of large crystals of green hornblende in all stages of alteration. A small amount of interstitial quartz occurs. The quartz granules are strung out in a roughly parallel fashion. The rock is badly altered and the thin section is unsatisfactory.

The *quartz-diorite* found in the river gorge eastward from the cable crossing is a coarse-granular rock of typical granitic texture. It is a hard, resistant rock, which tends to weather into roughly angular blocks, a feature that distinguishes it in the mass from the exposures of the schists. The minerals visible to the unaided eye are white striated feldspar, dark hornblende, and glistening black biotite. The color of the rock is dark grey and the appearance is remarkably fresh. The texture is uniform throughout the exposures observed, and the rock is apparently without contact modifications. No tendency to gneissoid banding was observed.

Under the microscope it is seen to be a coarse-granular rock of granitic texture. The dominant mineral constituents are plagioclase and common hornblende. The plagioclase ranges from oligoclase to labradorite. Microcline, orthoclase, and

quartz are present in about equal proportions, but their total amount does not equal that of the plagioclase. Brown biotite is present in somewhat less quantity than the hornblende. Titanite and magnetite occur as accessories. Occasionally the quartz is poikilitic in the orthoclase. The feldspathic and ferromagnesian minerals are present in about equal proportions. If it were not for the preponderance of the plagioclase the rock might be classed as a quartz-monzonite or grano-diorite. It is probably best classed as a quartz-diorite with a monzonitic aspect. The microscope reveals no cataclastic structure nor other evidence of dynamic action, and the minerals are fresh and unaltered.

The *pegmatites* are pink in color and usually very coarse in texture. They are composed chiefly of quartz and pink orthoclase. Some of the dikes carry large crystals of silvery-white mica. No other minerals were noted. The dikes usually exhibit the typical comb-structure inward from the walls and the graphic arrangement of the quartz and feldspar. Along the walls of some of the dikes the texture becomes aplitic.

Origin.—There is no clear evidence in the Shinumo area by which the original character of the schists of the Vishnu series can be determined. There is no evidence of a banding that can be clearly referred to original sedimentary bedding, nor is there evidence of any original clastic texture. The mineralogical composition, however, suggests a sedimentary origin for the quartz schists of the mica and hornblende type : either might have resulted from the regional metamorphism of an arkose sandstone or shale. According to the lesser or greater abundance of iron in the original sediments the rock would assume the mica or hornblende type of quartz schist. Certainly the great preponderance of quartz as a constituent of these rocks would seem to weigh against an igneous origin in the balance of probability. The causes operating to produce the schists in their present aspect are conceived to be the processes connected with regional metamorphism, namely, subsidence and deep burial, subsequent folding and mashing, and a slow recrystallization in process of time.

The original character of the *hornblende schist* described as occurring in a narrow outcrop between the schists is not clear. The fact that the rock consists of little else than hornblende suggests that it originally constituted an igneous rock of a basic type. The fact that the microscope discloses a schistose structure is evidence that the rock is at least earlier in age · than the period of regional metamorphism that was responsible for the present structural and mineralogical character of the enclosing schists.

The origin of the *quartz-diorite* is reasonably clear. Since

it is a coarse-granular, igneous rock of plutonic aspect occurring over a large area, clearly cutting the schists, and showing no textural modifications at the contact, it is concluded that it represents a deep-seated igneous invasion of considerable size, of the type known as a "batholith." Because of the unaltered character of the rock and the absence of any gneissoid or cataclastic structure, it is argued that the batholithic invasion took place at a time later than the period of regional metamorphism that produced the recrystallization and schistosity of the enclosing schists. The question may arise as to whether the invasion of the batholith was not of itself a partially operative cause in producing this recrystallization and schistosity. The field evidence is against such a conclusion : there is no gradation in the schist away from the contact, either in texture or in mineral composition, nor are the planes of schistosity parallel to the contact.

The *older pegmatite dikes* are folded intimately with the schists. Their injection may have either preceded or accompanied the regional metamorphism.

The *younger pegmatite dikes* cut both the schists and the quartz-diorite. Where they cut the schists they break cleanly across the schistosity. The injection of these dikes is the latest visible event in the igneous activity of Archean time within the area.

Age and correlation.—The rocks of the Vishnu series are rocks which, in the light of present knowledge, can only be conceived to have acquired their present character at great depths beneath the earth's surface in what is technically known as the "zone of flowage." It is therefore evident that the unconformity which separates them from the overlying Algonkian sediments of the Grand Canyon series represents a vast amount of erosion and the consequent lapse of an enormous interval of time,—an interval vastly greater even in events than that represented by the profound unconformity which separates the succeeding Grand Canyon series from the overlying Paleozoic. The Vishnu schists are therefore assigned to the Archean in the usage of the United States Geological Survey ; but whether as a group or a complex is as yet undecided. It seems likely, as stated by Ransome (*a*, p. 21), that they are to be correlated with the Pinal Schist of the Globe and Bisbee regions, and " present somewhat different aspects of the fundamental crystalline complex of Arizona."

Up to the present time no detailed study of these rocks has been made in the Grand Canyon region, and their internal structural relations are unknown. It is not unlikely when such a study is made of their exposures in the Kaibab division of the canyon, in the Shivwits division to the west, and along

the southwest border of the Plateau Province, that a general Archean structure may be unraveled and their relation to the fundamental complex of the southern part of the territory may be definitely established.

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References to the Bibliography are made by name and letter. Thus: In referring to an article by Walcott, entitled " Pre-Cambrian Igneous Rocks of the Unkar Terrane, Grand Canyon of the Colorado, Arizona," (*Walcott, c*) is inserted in parenthesis in the text and the reader will find the reference under that name and letter in the Bibliography.

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   b. Study of a Line of Displacement in the Grand Canyon of the Colorado in Northern Arizona.   (Read Aug. 29, 1889.)   Bull. Geol. Soc. America, I, 1890, (Feb.) pp. 49–64.

   c. Pre-Cambrian Igneous Rocks of the Unkar Terrane, Grand Canyon of the Colorado, Arizona, by Charles D. Walcott ; with notes on the Petrographic Character of the Lavas, by Joseph P. Iddings.   14th Ann. Rept. U. S. Geol. Survey for 1892–1893, Pt. 2, 1894, pp. 497–519 (Walcott) and 520–524 (Iddings), pls. lx–lxv.

   d. Algonkian Rocks of the Grand Canyon of the Colorado.   Jour. Geol., III, No. 3, 1895 (Apr.–May), pp. 312–330, pl. vi.

   e. Pre-Cambrian Fossiliferous Formations.   (Read Dec. 30, 1898.)   Bull. Geol. Soc. America, x, 1899 (April) pp. 199–244, pls. xxii–xxviii.

ART. XXXIII.—*Additions to the Pleistocene Flora of Ala-
bama;* by EDWARD W. BERRY.*

A BRIEF contribution to the Pleistocene flora of Alabama
was made by the writer in 1907† in which twelve species were
described from the Pleistocene clays and peat outcropping
along the Chattahoochee River near Abercrombe Landing in
Russell County, a few miles below Columbus, Georgia. During
the past field season the writer, in company with Dr. L. W.
Stevenson, was engaged in studying the Mesozoic sections
along the principal rivers of Alabama for the U. S. Geological
Survey. In the course of this work Pleistocene plants were
discovered at a number of scattered localities which it seems
desirable to place on record at the present time. The local-
ities will first be briefly described, after which the forms iden-
tified will be enumerated.

The present contribution extends the range of the ten spe-
cies previously recorded from the Alabama Pleistocene and
records the occurrence there of sixteen additional forms, bring-
ing the total flora up to twenty-eight species. Among these
the following existing species have not heretofore been found
as fossils: *Pinus taeda* Linné, *Arundinaria macrosperma*
Michx., *Hicoria villosa* (Sarg.) Ashe, *Populus deltoides* Marsh,
Phoradendron flavescens (Pursh) Nutt., *Acer saccharinum*
Linné, *Acer rubrum* Linné, and *Osmunda spectabilis* Willd.
In addition the range of several species in the Pleistocene is
seen to be quite different from their present range: for one
thing the Fall-line which marks such an important line of
demarcation in the distribution of our existing flora seems to
have largely lost its significance at the time when the glaciers
crowded our eastern Pleistocene flora southward and a large
part of the coastal plain was submerged. However, any general
conclusions may well be postponed until the completion of the
writer's studies of the eastern Pleistocene floras.

Locality No. 1.—This locality is on the right bank of the
Warrior River, about 356 miles above Mobile and about 200
yards above the mouth of Big Creek. The following section
at this point is typical of much of the Pleistocene seen along
the Alabama rivers, lacking only the gravel bed at the base of
the section which is probably present at this point beneath
water level:

Section.

1. Brownish, massive, sandy clay_____ 30 feet
2. Brownish, laminated, iron-stained, sandy clay _____ 6 "
3. Dark, bluish gray, thickly-laminated, sandy clay with
   leaf impressions _____ 8 "

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* Published by permission of the Director of the U. S. Geological Survey.
† Berry, Amer. Nat., vol. xli, pp. 689–697, pl. 1, 2, 1907.

The following species were identified from this outcrop: *Arundinaria macrosperma, Betula nigra, Quercus nigra, Phoradendron flavescens, Liriodendron tulipifera, Platanus occidentalis* and *Acer saccharinum.*

In the absence of topographic maps it is impossible to identify the various systems of Pleistocene terrace deposits which cross the state approximately parallel with the coast and which extend inland up the present rivers, passing insensibly from marine to estuarine, and finally to fluviatile conditions of deposition. The present outcrop is believed to form a part of the Northport terrace, which at Tuscaloosa is about 70 feet above low-water mark in the Warrior River and about 140 feet above sea level.

Locality No. 2.—This outcrop is on the right bank of the Warrior River about 342 miles above Mobile, and shows the following section:

Section.

1. Yellow, massive, compact sandy clay, bedded and
     ferruginous below _   20 feet
2. Light drab, yellowish and brownish sandy clay with
     pockets, thin seams and laminæ of fine micaceous
     sand and numerous thin iron crusts, becoming
     more sandy toward the base where a few pebbles
     of quartz and coal are found _ _ _ _ _ _ _ _ _ _ _ _ _ _   7   "
3. Dark drab clay interbedded with yellowish sand and
     carrying much comminuted vegetable matter and
     leaf impressions toward the base _ _ _ _ _ _ _ _ _ _ _ _   3   "
4. Concealed _   8   "

The following species were identified from this outcrop: *Pinus echinata, Taxodium distichum,* and *Quercus phellos.*

Locality No. 3.—This outcrop is on the right bank of the Warrior River near Fosters Landing, about $328\frac{1}{2}$ miles above Mobile. The following diagrammatical section (fig. 1) well illustrates the character of the materials at this point:

FIG. 1.
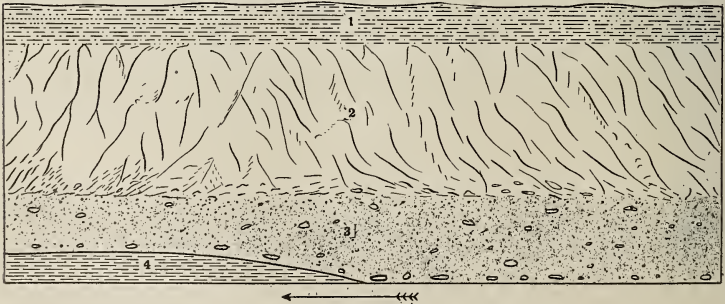
Diagrammatical Section of the Pleistocene at Locality No. 3.

Section.

1. Sandy clay ....about   5 feet
2. Similar materials concealed by landslips........   "   15 "
3. Sand with much gravel containing some pebbles of
     coal and rather angular bowlders of Paleozoic
     rocks up to 2 feet in diameter..................7-10 "
4. Massive, dark gray, finely micaceous, plastic clay with
     leaf impressions and overlain by a thin iron crust 0-3 "

The following species were identified from this outcrop: *Betula nigra, Populus deltoides, Liriodendron tulipifera, Platanus occidentalis,* and *Acer rubrum.*

Locality No. 4.—This outcrop is on the right bank of the Warrior River at Steeles Bluff, 311½ miles above Mobile, and is well illustrated by the following diagrammatical section (fig. 2).

Fig. 2.
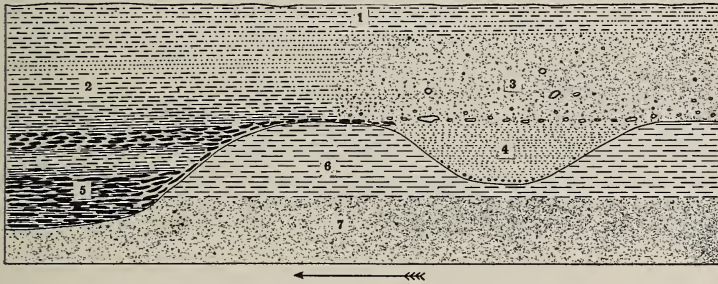
Diagrammatical Section of the Cretaceous and Pleistocene at Locality No. 4.

Section.

Pleistocene.

1. Sandy clay ....about   5 feet
2. Light colored massive clay and sand with lig-
     nitic layers in both the clay and the sand,
     grading laterally, i. e. up the river, into the
     next (No. 3) ....   "   12 "
3. Coarse yellowish sand with gravel and pebbles
     toward the base, lignitic at the base toward
     the lower end..................................
4. Yellowish micaceous stratified sand with scat-
     tered small pebbles...........................   "   10 "
5. Sandy argillaceous peat with fruits, seeds, and
     leaf impressions .... 10-12 "

Upper Cretaceous (Tuscaloosa formation).

6. Blotched purplish, massive, somewhat sandy clay
     with iron crusts, much eroded................. 0-12 "
7. Light gray, finely arkosic, slightly micaceous
     sand, argillaceous and compact in places....   4-8 "

The following species were identified from this outcrop: *Osmunda spectabilis, Pinus taeda, Arundinaria macrosperma, Betula nigra, Fagus americana, Quercus nigra, Quercus prinus, Quercus phellos, Carpinus caroliniana, Ostrya virginiana, Ulmus alata, Hicoria villosa, Juglans nigra, Populus deltoides, Liquidambar styraciflua, Nyssa biflora, Vaccinium corymbosum, Xolisma ligustrina.*

Locality No. 5.—This locality is on the left bank of the Chattahoochee River and therefore in the state of Georgia. It is about one mile above the Abercrombe Landing exposure and is represented by three unimportant species found in pieces of Pleistocene clay along the river cove and not in place. The species are *Arundinaria macrosperma, Betula nigra,* and *Carpinus caroliniana,* all of which occur in the Alabama Pleistocene.

Locality No. 6.—This outcrop is on the right bank of the Chattahoochee River near Abercrombe Landing, about one mile below locality No. 5 and was described in the article previously mentioned.* The following species new to this locality were collected: *Pinus taeda, Populus deltoides, Phoradendron flavescens, Acer saccharinum.*

Locality No. 7.—This outcrop shows the Pleistocene in a pocket of the Lower Cretaceous on the left bank of the Alabama River about one-half mile below Gun Island and about 12 miles above Montgomery. It is shown in the following diagrammatical section (fig. 3):

FIG. 3.
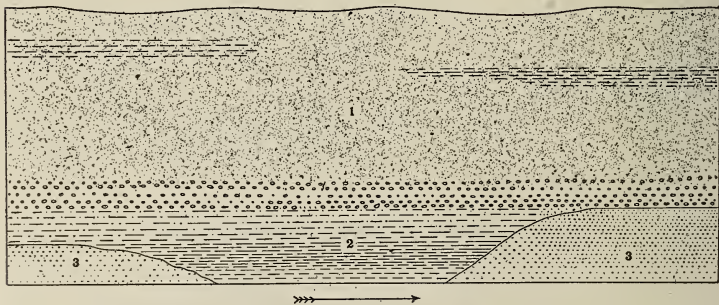
Diagrammatical Section of the Cretaceous and Pleistocene at Locality No. 7.

Section.

Pleistocene.

1. Light yellowish, somewhat argillaceous sand, with gravel base _____about   20 feet
2. Buff sandy clay with leaf impressions_____   "   6   "

* Berry, loc. cit., 1907.

Lower Cretaceous (Cape Fear Formation).

   3. Compact, somewhat arkosic and micaceous sand,
       much eroded _____ 0–5 feet

The following species were identified from this outcrop: *Fagus americana, Quercus nigra, Platanus occidentalis,* and *Vaccinium arboreum.*

There follows a briefly annotated enumeration of the species collected in systematic order, with citations of the fossil records of the various forms.

Osmunda spectabilis Willd.

The royal fern frequents swamps and openings and borders of wet woods. It ranges from Canada to Mexico and probably into South America, but is often confused with the old world *Osmunda regalis* Linné. In the existing Alabama flora it is common throughout the State. None of the existing species of *Osmunda*, which are six or eight in number, have heretofore been found fossil, although Hollick records[*] masses of rootlets attached to rhizomes in the swamp deposits of the Talbot formation in Maryland, which are almost certainly referable to *Osmunda*. The present record is based upon a single specimen showing a part of a pinnule and exhibiting the characteristic venation and marginal characters of this species found at locality No. 4.

Taxodium distichum (Linné) Rich.

Holmes. Journ. Elisha Mitchell Soc. for 1884–85, p. 92, 1885.
Berry, Torreya, vol. vi, p. 89, 1906. Jour. Geol., vol. xv, p. 339, 1907.
Hollick, Md. Geol. Surv., Pli. and Pleist., pp. 218, 237, pl. 68, 1906.

The cypress was probably one of the commonest forest trees of the Pleistocene from New Jersey southward, at least it is the one most frequently met with, having been recorded from New Jersey, Delaware, Maryland, Virginia, and North Carolina. The more northerly occurrences probably represent inter and post glacial warm periods. The recent collections show no trace of this species except at locality No. 2, where impressions of the detached leaves of this species are common in the clays

Pinus taeda Linné.

In the existing flora the Loblolly pine extends from Delaware and Maryland to Florida and Texas. In the northern part of its range it is confined to the coastal plain but farther south it spreads over the Piedmont Plateau and into the mountain region. In the Pleistocene it apparently extended farther north than at the present time since seeds which are

[*] Hollick, Md. Geol. Surv., Pli. and Pleist., p. 214, pl. 67, fig. 3, 1906.

believed to belong to this species have been collected by the writer from the Pleistocene of New Jersey.

The present record is based on cones and cone-scales from locality No. 4 and seeds from locality No. 6. The cones are frequent at the former locality but much water worn; some of the scales, however, preserve the characteristic markings of the species.

PINUS ECHINATA Mill.

Hollick, Md. Geol. Surv., Pli. and Pleist., p. 217, pl. 67, fig. 1, 1906.

This is a species found on sandy soils from New York to northern Florida and west to northeastern Texas, reaching its greatest development in the Mississippi Valley. Cones have been recorded in the Pleistocene as common in the Talbot formation of Maryland and the present record is based upon seeds which are common in the clay at locality No. 2.

ARUNDINARIA MACROSPERMA Michx.

In the recent flora this species forms those remarkable plant associations known as " canebrakes " in the bottom lands along the larger streams from southern Virginia to Florida and Louisiana and extending up the Mississippi Valley to Missouri and Kentucky. It has not previously been recorded in the fossil state but was evidently common in Alabama during Pleistocene time since characteristic fragments of the leaves have been collected from localities No. 1, 4, and 5.

JUGLANS NIGRA Linné.

Berry, Torreya, vol. ix, p. 98, fig. 6, 1909.

In the recent flora this species is found in rich soil from Canada to Minnesota and south to Florida and Texas. In Alabama according to Mohr it is found scattered in rich bottom lands from the Tennessee Valley to the Coast Pine belt, spreading southward along the banks of the larger rivers. As a fossil it was recently recorded by the writer from the Talbot formation in Maryland, the remains consisting of the characteristic nuts. The Alabama occurrence is based upon a single nut from locality No. 4.

HICORIA VILLOSA (Sargent) Ashe.

This species, differentiated from the common *Hicoria glabra* by Sargent, is an inhabitant of the Carolinian zone ranging from Delaware to Georgia and Alabama. In the latter state it is said to be one of the commonest hickories in the upland and mountainous parts of the state, extending southward to the Coast Pine belt. It has not been previously found fossil, the present record being based upon several husks and three

nuts from locality No. 4. The latter are identical with the more globular nuts of the recent tree resembling somewhat in appearance the nuts of *Hicoria minima* but with much thicker shells.

Populus deltoides Marsh.

In the existing flora this species ranges from Canada and New England westward to Colorado and southward to Florida and Texas. In Alabama and throughout the Coastal Plain it is most frequent in the bottoms and alluvial river swamps.

The genus extends back to the late Lower Cretaceous and a large number of extinct species have been described. The present species has not heretofore been found fossil, but both *Populus balsamifera* Linné and *grandidentata* Michx. are present in the Canadian inter-glacial deposits and Hollick has recorded three species from the Pleistocene of Maryland. From the European Pleistocene the following still existing species are known : *Populus alba* Linné, *canescens* Sm., *nigra* Linné, and *tremula* Linné.

The present record is based on the characteristic leaves which are abundant at locality No. 3 and less common at localities No. 4 and No. 6.

Betula nigra Linné.

Knowlton, Amer. Geol., vol. xviiim, p. 371, 1896.
Berry, Journ. Geol., vol. xv, p. 341, 1907. Amer. Nat., vol. xli, p. 692, pl. 2, figs. 2–4, 1907. Ibid., vol. xliii, p. 435, 1909.

This species is common along streams and in bottoms with an existing range from Canada to Florida and Texas, and is common throughout Alabama. It was a common species in the Pleistocene, at least it was frequently preserved, and has been recorded by the writer from several localities in North Carolina and Virginia as well as from near Abercrombe Landing on the Chattahoochee River in Alabama. Knowlton has described it from the Pleistocene river terraces near Morgantown, West Virginia.

The present record is based on leaves from localities No. 1, 3, 4, and 5, they being especially abundant in the peat at locality No. 4.

Fagus americana Sweet.

Hollick, Md. Geol. Surv., Pli. and Pleist., p. 226, 1906.
Berry, Torreya, vol. vi, p. 88, 1906. Journ. Geol., vol. xv, p. 341, 1907. Amer. Nat., vol. xli, p. 692, pl. 2, fig. 7, 1907. Ibid., vol. xliii, p. 435, 1909.
Fagus ferruginea Michx., Lesq., this Journal, vol. xxvii, p. 363, 1859. Geol. Tenn., p. 427, pl. 7 (K), fig. 11, 1869.
Fagus ferruginea Ait., Knowlton, Amer. Geol., vol. xviii, p. 371, 1896. Mercer, Journ. Phila. Acad. (11), vol. ii, pp. 277, 281, fig. 8 (15), 1899.

This common mesophile forest tree of the Alleghenian, Carolinian, and Louisianian zones which is common throughout Alabama is of frequent occurrence in the Pleistocene from Maryland southward and it has been recorded from a large number of localities, the buried swamp deposits usually furnishing remains of nuts or burrs, while the leaves are generally confined to the clays.

This species was recorded from near Abercrombe Landing in 1907 and additional occurrences are locality No. 4 (leaves, nuts, and burrs) and locality No. 7 (leaves).

Quercus phellos Linné.

Berry, Journ. Geol., vol. xv, p. 342, 1907. Amer. Nat., vol. xli, p. 694, pl. 1, fig. 1, 1907.

This common mesophile tree of the Carolinian and Louisianian zones ranges from New York to Florida and Texas. It is common in northern Alabama, but becomes rare south of the central part of the state. It is a common fossil in the North Carolina Pleistocene and at Abercrombe Landing on the Chattahoochee River in Alabama.

The present occurrences are at locality No. 2 (leaves) and locality No. 4 (leaves, cupules and acorns).

Quercus nigra Linné.

Berry, Journ. Geol., vol. xv, p. 342, 1907. Amer. Nat., vol. xli, p. 693, pl. 1, figs. 3, 4, 1907.

In the existing flora this is a widespread species of the Carolinian and Louisianian zones extending northward to Delaware, Tennessee, and Missouri and common all over Alabama in low rich woods and swamps. As a fossil it has been recorded from the Pleistocene of North Carolina and eastern Alabama.

The present records are locality No. 1 (leaves), locality No. 4 (leaves and acorns, common) and locality No. 7 (leaves). One specimen from locality No. 4, while too imperfect for certainty, suggests its reference to *Quercus virginiana* Mill., a species previously recorded by the writer from Abercrombe Landing on the Chattahoochee River in Alabama.

Quercus prinus Linné.

Berry, Journ. Geol., vol. xv, p. 342, 1907. Amer. Nat., vol. xli, p. 693, pl. 1, fig. 2, 1907.

This is an upland tree of the Alleghanian and Carolinian zones, of rare occurrence in the southern Coastal Plain,[*] and

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[*] This species has not been found in the Coastal Plain of Alabama, although Hilgard reported it years ago from Tippah County, Mississippi. In Georgia, according to R. M. Harper, it does not even approach the Fall-line, while in North Carolina it is confined to the Piedmont and mountains, according to Pichot and Ashe. Farther northward, however, it is found in the Coastal Plain from Long Island to Virginia, occurring in this province of New Jersey outside of the pine barrens and common on the upper eastern shore of Maryland and in Delaware.

since it is easy to confuse the leaves of this species with those of *Quercus michauxii*, a common tree of Coastal Plain bottoms, doubt has been expressed regarding the identifications cited above. However, it is believed that the fruit of *Quercus prinus* is sufficiently distinct for certainty, and when it is remembered that at some time during the Pleistocene practically the whole Coastal Plain was submerged by the sea and that there was a massing of species in the emerged portion of the southern Piedmont area, which served as a center of radiation for inter- and post-glacial dispersion,* the propriety of finding the species in the Pleistocene sediments is unquestionable.

The present record is based upon an acorn and leaf fragment from locality No. 4.

CARPINUS CAROLINIANA Walt.

Berry, Journ. Geol., vol. xv, p. 340, 1907. Amer. Nat., vol. xli, p. 692, pl. 1, figs. 8, 9, 1907.

This is a wide ranging species of low rich woods occurring from Canada to Florida and Texas. It is common in suitable situations over the greater part of Alabama and appears to have been frequent in the later Pleistocene of America, previous Pleistocene occurrences being along the Neuse River in the North Carolina Coastal Plain and from near Abercrombe Landing on the Chattahoochee River in Alabama.

The new records are localities No. 4 and No. 5, this species being especially common at the former of these.

OSTRYA VIRGINIANA (Mill.) Willd.

Hollick, Bull. Torrey Club, vol. xix, p. 332, 1892.
Penhallow, Amer. Nat., vol. xli, p. 447, 1907.

In the recent flora this species ranges from Canada to Florida and Texas, ordinarily in dry soil and on hillsides. It is said by Mohr to occur principally on calcareous soils in Alabama, where it ranges from the Tennessee Valley to the upper division of the coast pine belt, its southern limit corresponding roughly to the northern limit of the Cuban pine. In the fossil state it is recorded by Hollick from the late Miocene or Pliocene of Bridgeton, New Jersey, and by Penhallow from the interglacial deposits of the Don valley in Canada. Material indistinguishable from the modern species has been described by Nathorst from the post-Miocene of Japan under the varietal name *fossilis*. Finally the material from Wytheville, Virginia, said to be of Pleistocene age, which was identified by Lesquereux† as *Ostrya Walkeri* Heer, an early

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* See the various papers by C. C. Adams on this subject.
† Lesq., Proc. U. S. Natl. Mus., vol. x, p. 38, 1887.

Tertiary arctic species, is probably identical or closely allied with the present species.

The present occurrence consists of leaves which are infrequent at locality No. 4.

ULMUS ALATA Michx.

Lesq., this Journal, vol. xxvii, p. 365, 1859.
Berry, Journ. Geol., vol. xv, p. 343, 1907. Amer. Nat., vol. xli, p. 694, pl. 1, figs. 6, 7, 1907.

This species is a common element in the recent flora of Alabama in low woods particularly along stream banks. It ranges northward to Virginia, Illinois and Kansas and southward to Florida and Texas. As a fossil it was recorded from the Pleistocene near Columbus, Kentucky, by Lesquereux, and from the Neuse River in North Carolina and Abercrombe Landing on the Chattahoochee River in Alabama by the writer (loc. cit.). Two species of Ulmus occur in the Pleistocene of Maryland, *Ulmus racemosa* is recorded from the Pleistocene near Morgantown, West Virginia, and both the latter and *Ulmus americana* occur in the interglacial beds of the Don valley in Canada.

The present record is based upon infrequent leaves from locality No. 4.

PHORADENDRON FLAVESCENS (Pursh) Nutt.

A species, in the modern flora, of the Carolinian and Louisianian zones ranging northward as far as New Jersey and common throughout Alabama. It has not previously been recorded as a fossil, although certain European Upper Pliocene remains have been described as *Viscophyllum*. However, it is not at all certain that these are not related to the genus *Pistia* rather than to *Viscum*.

The present record is based on the characteristic leaves of the modern species found at localities No. 1 (common) and No. 6 (1 specimen).

LIRIODENDRON TULIPIFERA Linné.

Berry, Amer. Nat., vol. xli, p. 695, 1907. Torreya, vol. ix, p. 71, fig. 1, 1909.

This common mesophile forest type of the Alleghanian, Carolinian, and Louisianian zones finds its present southern limit in Alabama at about latitude 31°. Previous fossil records are based on fruits from Abercrombe Landing on the Chattahoochee River in Alabama and upon abundant leaves from the Wicomico formation near Weldon, North Carolina.

The present record is based upon leaf fragments from locality No. 1 and upon a leaf and a carpel from locality No. 3.

PLATANUS OCCIDENTALIS Linné.

Knowlton, Amer. Geol., vol. xviii, p. 371, 1896.
Penhallow, Trans. Roy., Soc. Can. (II), vol. ii, sec. 4, pp. 68, 72, 1897. Amer. Nat., vol. xli, p. 448, 1907.
Mercer, Journ. Phila. Acad. (II), vol. ii, p. 277, 1899.
Berry, Journ. Geol., vol. xv, p. 344, 1907. Amer. Nat., vol. xli, p. 695, pl. 2, fig. 5, 1907.
Platanus aceroides Göpp., Hollick, Md. Geol. Surv., Pli. and Pleist., p. 231, pls. 73, 74, 1906.

This modern inhabitant of low woods and banks from Canada to Florida and Texas is frequent in the bottom lands of central Alabama but not common elsewhere in the state. As a fossil it is of frequent occurrence in Pleistocene deposits from those of the Don Valley in Canada to Alabama.

The present record is based upon characteristic leaves which occur in considerable abundance at localities No. 1, No. 3, and No. 7.

LIQUIDAMBAR STYRACIFLUA Linné.

Hollick, Bull. Torrey Club, vol. xix, p. 331, 1892.
Knowlton, Amer. Geol., vol. xviii. p. 371, 1896.
Berry, Journ. Geol., vol. xv, p. 343, 1907.

This species ranges from New England to Florida and westward to Texas and Mexico in the recent flora and is found throughout Alabama, more especially in the rich bottoms and swamp borders of the Coastal Plain. It has previously been recorded from the Pleistocene of North Carolina and West Virginia. The present record is based upon leaf fragments and upon two somewhat macerated and flattened but characteristic fruits from locality No. 4.

ACER RUBRUM Linné.

A species of swamps and low ground ranging from Canada to Florida and Texas in the existing flora and common throughout Alabama, not previously known as a fossil. The present record is based upon leaf fragments from locality No. 3.

ACER SACCHARINUM Linné.

This species in the existing flora ranges from Canada to Florida and westward to the Great Plains. It extends from northern Alabama southward along the larger streams. It has not been previously recorded from the Pleistocene, the form described by Penhallow under this name from the Canadian Pleistocene being referable to *Acer saccharum* Marsh.

The present record is based on characteristic samaras from locality No. 1 and No. 6.

NYSSA BIFLORA Walt.

> Hollick, Md. Geol. Surv., Pli. and Pleist., p. 235, pl. 69, fig. 5, 1906.
> Berry, Torreya, vol. vi, p. 90, 1906.   Journ. Geol., vol. xv, p. 345, 1907.

This species in the Recent appears to be confined to the Coastal Plain, ranging from Virginia to eastern Texas. As a fossil it has been recorded from the Pleistocene of Maryland, Virginia, and North Carolina. The present record is based upon leaves from locality No. 4.

VACCINIUM ARBOREUM Marsh.

> Berry, Torreya, vol. ix, p. 73, 1909.

This species, which ranges from Virginia to Indian Territory and southward to Florida and Texas in the Recent, has previously been recorded from the Pleistocene of North Carolina. The present material comes from locality No. 7. The genus is wide ranging and a number of Pleistocene occurrences are known both in this country and abroad. Thus in addition to the next species, *Vaccinium spatulata* Berry occurs in the Pleistocene of North Carolina and *Vaccinium uliginosum* Linné at Scarboro Heights, Ontario, *Vaccinium maderense* Link is known from the Pleistocene of Madeira and *Vaccinium myrtillus* Linné and *Vaccinium vitis-idœa* Linné occur in the interglacial peats of the southern uplands in Scotland.

VACCINIUM CORYMBOSUM Linné.

> Hollick, Md. Geol. Surv., Pli. and Pleist., p. 236, pl. 69, figs. 7-9, 1906.
> Berry, Journ. Geol., vol. xv, p. 346, 1907.

This species ranges in the modern flora from Canada to Louisiana and in Alabama is said to be confined to the mountain region. As a fossil it is recorded from Maryland and North Carolina. The present record is based upon leaves from locality No. 4.

XOLISMA LIGUSTRINA (Linné) Britton.

> Hollick, Md. Geol. Surv., Pli. and Pleist., p. 236, pl. 69, fig. 6, 1906.
> Berry, Journ. Geol., vol. xv, p. 346, 1907.   Amer. Nat., vol. xli, p. 696, pl. 2, fig. 6, 1907.

This species has been previously recorded in the Pleistocene of Alabama as well as from Maryland and North Carolina. The present record is based on leaves from locality No. 4.

Johns Hopkins University,
    Baltimore, Md.

ART. XXXIV.—*The Application of Potassium Ferricyanide in Alkaline Solution to the Estimation of Arsenic, Antimony, and Tin;* by HOWARD E. PALMER.

[Contributions from the Kent Chemical Laboratory of Yale Univ.—ccx.]

In 1892, Quincke[*] published a method for estimating arsenic and antimony gasometrically, consisting essentially in oxidizing the arsenic or the antimony by a known excess of potassium ferricyanide in the presence of alkali, and determining the excess by measuring in a gasometer the oxygen evolved by the action of hydrogen peroxide on it according to the following equation:

$$2K_3FeC_6N_6 + H_2O_2 + 2KOH = 2K_4FeC_6N_6 + 2H_2O + O_2.$$
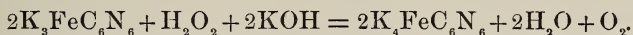
In previous papers from this laboratory, methods for the estimation of cerium in the presence of the other rare earths,[†] and for the estimation of thallium,[‡] have been described, based on oxidation by potassium ferricyanide in alkaline solution and titration with permanganate of the ferrocyanide formed.

The work to be described is the result of an attempt to apply this reaction to the estimation of arsenic, antimony, and tin, which are oxidized according to the following equations:

$$As_2O_3 + 4K_3FeC_6N_6 + 4KOH = As_2O_5 + 4K_4FeC_6N_6 + 2H_2O.$$
$$Sb_2O_3 + 4K_3FeC_6N_6 + 4KOH = Sb_2O_5 + 4K_4FeC_6N_6 + 2H_2O.$$
$$SnO + 2K_3FeC_6N_6 + 2KOH = SnO_2 + 2K_4FeC_6N_6 + H_2O.$$
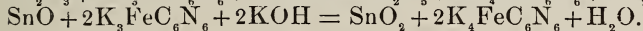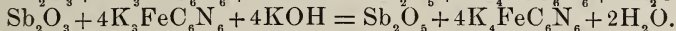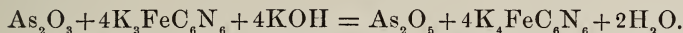
The ferrocyanide formed is then oxidized by permanganate according to the equation

$$10K_4FeC_6N_6 + 2KMnO_4 + 8H_2SO_4 =$$
$$10K_3FeC_6N_6 + 6K_2SO_4 + 2MnSO_4 + 8H_2O.$$
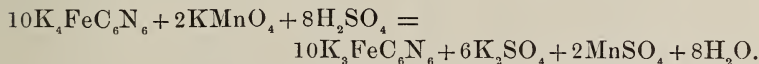
Estimation of Arsenic.

The essential procedure was to oxidize the arsenic by potassium ferricyanide in alkaline solution, and after making ammoniacal by the addition of ammonium sulphate, to precipitate the arsenic by magnesia mixture, filter off the ammonium magnesium arseniate, and titrate the filtrate with permanganate, after acidification with sulphuric acid.

For the work a solution of arsenious acid was prepared in the usual way by dissolving pure sublimed arsenious oxide in potassium hydroxide, neutralizing with sulphuric acid and adding sodium bicarbonate. The magnesia mixture used

[*] Zeitschr. f. Anal. Chem., xxxi, 1.
[†] This Journal, xxvi, 83.   [‡] This Journal, xxvii, 379.

was made up by dissolving 55 grams of the crystallized magnesium chloride and 29 grams of purified ammonium chloride in a liter of water, with the addition of about 5 cubic centimeters of concentrated ammonium hydroxide. The potassium ferricyanide used was purified by recrystallization, but even then, as in the previous work, it was necessary to apply a correction to the determinations for the number of cubic centimeters of permanganate required to give the pink coloration to the ferricyanide alone, generally amounting to about one-tenth of one cubic centimeter. A solution of potassium ferricyanide of convenient strength for use in the determination of all three elements contained 20 grams to 100 cubic centimeters.

In the preliminary experiments, recorded in Table I, low results were obtained, apparently due to the incomplete oxidation of the arsenic by the amounts of ferricyanide and potassium hydroxide used. If at least ten times the theoretical amount of ferricyanide, with a rather dilute solution of potassium hydroxide, is used, as in experiments (1) to (12) of Table II, the oxidation is complete; or, if a more concentrated solution of potassium hydroxide is used, as in experiments (13) and (14) of Table II, less ferricyanide is necessary. In any case, it is advantageous that the total volume of the solution be rather small, preferably less than 100 cubic centimeters, since, as shown by experiments (4), (5), and (6) of Table I, if the volume is greater than that, low results are obtained.

TABLE I.

	As_2O_3 taken grm.	$K_3FeC_6N_6$ grm.	KOH grm.	Vol. of sol. cm³.	As_2O_3 found grm.	Error grm.
(1)	0·0997	2	1·25	100	0·0966	—0.0031
(2)	0·0997	4	1·25	75	0·0987	—0·0010
(3)	0·1496	8	1·25	100	0·1486	—0·0010
(4)	0·0997	8	1·25	150	0·0982	—0·0015
(5)	0·0997	4	2·5	175	0·0978	—0·0019
(6)	0·1001	4	4·	150	0·0984	—0·0017

The procedure to be recommended, therefore, is as follows: To the solution containing the arsenic in the arsenious condition is added an amount of potassium ferricyanide equal to at least five times the amount theoretically required to oxidize the arsenic to the higher condition of oxidation, and about 25 cubic centimeters of a 20 per cent solution of potassium hydroxide, keeping the volume of the solution less than 100 cubic centimeters. After standing a few minutes, the solution is made ammoniacal by dissolving in it about 10 grams of ammonium sulphate, which acts on the potassium hydroxide, set-

TABLE II.

	As₂O₃ taken grm.	K₃FeC₆N₆ grm.	KOH grm.	Vol. of sol. cm₃.	As₂O₃ found grm.	Error grm.
(1)	0·0499	8	1·25	100	0·0502	+ 0·0003
(2)	0·0499	4	1·25	75	0·0499	± 0·0000
(3)	0·0499	3	1·25	75	0·0501	+ 0·0002
(4)	0·0501	4	1·25	75	0·0500	− 0·0001
(5)	0·0997	8	1·25	100	0·0999	+ 0·0002
(6)	0·0997	6	1·25	90	0·0993	− 0·0004
(7)	0·0997	6	1·25	90	0·0993	− 0·0004
(8)	0·1001	8	1·25	100	0·0998	− 0·0003
(9)	0·1496	9	1·25	110	0·1492	− 0·0004
(10)	0·1496	10	1·25	110	0·1496	± 0·0000
(11)	0·1502	10	1·25	110	0·1502	± 0·0000
(12)	0·1994	12	1·25	125	0·1994	± 0·0000
(13)	0·1001	4	4·	75	0·0998	− 0·0003
(14)	0·1001	3	4·	75	0·0998	− 0·0003

ting free ammonia, and about 100 cubic centimeters of the magnesia mixture are added. After settling, the ammonium magnesium arseniate is filtered off on asbestos, and washed with faintly ammoniacal water. The filtrate is strongly acidified with dilute sulphuric acid, and titrated with permanganate.

As Grützner* has shown, during the titration of large amounts of ferrocyanide by permanganate, a precipitate of $K_2MnFeC_6N_6$ often forms by the action of the manganese sulphate, which is formed by reduction of the permanganate, on the unchanged ferrocyanide. This precipitate slowly clears up as more permanganate is added, clearing up entirely as the end point is reached, but it tends to cause high results, on account of the difficulty in noting the end point exactly. It was found, in connection with the present work, that by titrating in the presence of a large amount of sulphuric acid, the formation of this precipitate is prevented. The titration may safely be made in the cold in the presence of ten per cent of sulphuric acid, and this amount will generally be sufficient to prevent the formation of the precipitate.

Determination of Antimony.

A solution of antimony trichloride was made up by dissolving pure antimony trioxide in hydrochloric acid, and diluting to a definite volume with the addition of sufficient hydrochloric acid to prevent the formation of the basic salt; the standard of this solution was determined by titrating with standard iodine.

* Chem. Centralblatt, 1902, I, 500.

The procedure was, in general, the same as in the determination of arsenic, except that it was found unnecessary to remove the antimony before titrating with permanganate. At least five times as much potassium ferricyanide as theoretically necessary was added in solution, and about 25 cubic centimeters of a 20 per cent solution of potassium hydroxide. After standing a few minutes, the solution was strongly acidified with dilute sulphuric acid and titrated with permanganate. The results are given in Table III.

<div align="center">Table III.</div>

	Sb_2O_3 taken grm.	$K_3FeC_6N_6$ grm.	KOH grm.	Vol. of sol. cm³.	Sb_2O_3 found grm.	Error grm.
(1)	0·0986	8	4	100	0·0989	+ 0·0003
(2)	0·0986	4	4	75	0·0984	− 0·0002
(3)	0 0986	2	4	75	0·0984	− 0·0002
(4)	0·0986	4	4	150	0·0984	− 0·0002
(5)	0·0986	4	4	75	0·0984	− 0·0002
(6)	0·0493	4	4	75	0·0495	+ 0·0002
(7)	0·0493	4	4	75	0·0497	+ 0·0004
(8)	0·0493	4	4	75	0·0495	+ 0·0002
(9)	0·1479	4	4	75	0·1482	+ 0·0003
(10)	0·1479	4	4	75	0·1477	− 0·0002
(11)	0·1479	4 ·	4	75	0·1476	− 0·0003
(12)	0·1971	8	8	125	0·1972	+ 0·0001

Determination of Tin

Definite portions of metallic tin were accurately weighed out and dissolved in concentrated hydrochloric acid; it was found necessary to perform this operation in the cold, and to keep an atmosphere of hydrogen over the liquid during solution of the tin, as under other conditions results lower than the theoretical were obtained, indicating that the stannous salt had been partially oxidized by the air or by dissolved oxygen. When the tin was completely dissolved, a solution containing at least five times as much potassium ferricyanide as theoretically necessary was added, and enough of a solution of potassium hydroxide to completely dissolve the precipitated stannic acid, the two solutions of ferricyanide and potassium hydroxide having been previously mixed. The stannic salt was removed by the addition of about ten grams of ammonium sulphate, and warming to 50° or 60°, under which conditions the tin was completely precipitated. After it had settled, the precipitate was filtered off on asbestos, under gentle pressure, and washed with a 10 per cent solution of ammonium sulphate. The filtrate was strongly acidified with sulphuric acid, and titrated with permanganate

in the usual manner. The results of the determinations are recorded in Table IV.

TABLE IV.

	Sn taken grm.	$K_3FeC_6N_6$ grm.	KOH grm.	Vol. of sol. cm³	Sn found grm.	Error grm.
(1)	0·1032	2·5	6	65	0·1033	+0·0001
(2)	0·1022	2·5	6	65	0·1016	−0·0006
(3)	0·1029	3·	7	60	0·1030	+0·0001
(4)	0·1009	5·	6	85	0·1011	+0·0002
(5)	0·1005	5·	5	60	0·1010	+0·0005
(6)	0·1011	10·	5	85	0·1015	+0·0004
(7)	0·0995	10·	5	85	0·1004	+0·0009
(8)	0·2020	4·	6	80	0·2019	−0·0001
(9)	0·2003	5·	6	90	0·1998	−0·0005
(10)	0·2021	10·	5	85	0·2027	+0·0006

ART. XXXV.—*A New Cystid from the Clinton Formation of Ontario—Lepadocystis clintonensis;* by WILLIAM ARTHUR PARKS.

IN 1873, F. B. Meek described a peculiar Cystid from the upper part of the Cincinnati formation at Richmond, Ind., under the name of *Lepocrinites moorei.** This form, according to Meek, differs from all other examples of *Lepocrinites* by the possession of four instead of three pectinirhombs and five instead of four arms. P. H. Carpenter† regards these peculiarities as of generic value, and proposes to establish the genus *Lepadocystis* for the reception of Meek's species. Jaekel, in 1899, suggests *Meekocystis* as the generic name, but

FIG. 1.
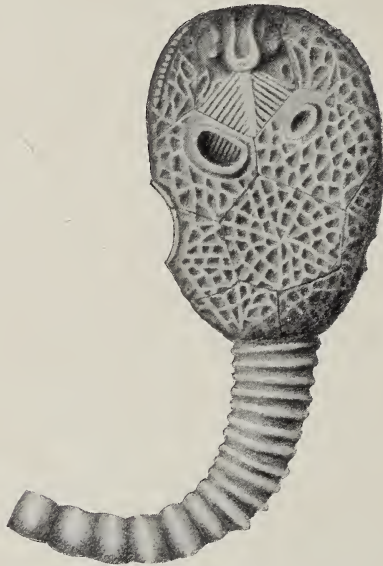
Lepadocystis clintonensis, sp. nov.

FIG 1.   Viewed from the right postero-lateral aspect. × 3

Bather gives precedence to Carpenter's name and recognizes the genus as a distinct member of the sub-family *Callocystinæ* of the *Glyptocystidæ.*‡

So far as I am aware, no other example of the genus has hitherto been described, so that its discovery at a higher hori-

* Geol. Sur. Ohio, Paleontology, vol. i, pp. 39–41, pl. iii, figs. 4a and 4b.
† Jour. Linn. Soc. Zool., vol. xxiv, p. 10.
‡ A Treatise on Zoölogy, E. Ray Lancaster, vol. iii, the Echinoderma, p. 61.

zon, the Clinton, is worthy of note. This formation is possessed of a very meagre Echinoderm fauna, the exposures in Ontario having yielded only a few fragmentary Crinoids. The present example lay for a long time in our collection as an unidentifiable specimen. Recently, however, an attempt to clean it was made with unexpectedly satisfactory results. By sawing the specimen out and treating it with caustic potash the organism was entirely freed from the matrix, so that it now shows the chief anatomical peculiarities in an excellent manner.

Adopting the method of numbering the plates proposed by Forbes,[*] we have, in the lower circlet, four plates, of which 1 and 2 are regularly pentagonal. Plate 4 is irregularly pentagonal, and 3 is hexagonal with its upper edge curved inwards. Of the second circlet, plates 5 and 6 are irregularly hexagonal:

Fig. 2.
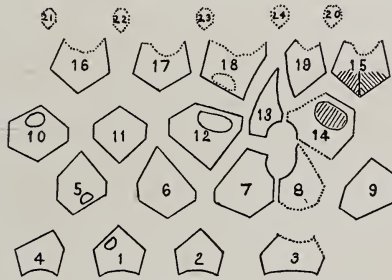
FIG. 2. Dissection of cup.

7 is also hexagonal, but it has an heptagonal appearance owing to the encroachment of the anal orifice on its upper, right-hand angle. Plate 8 is smaller than 7 and is likewise deeply cut by the anus on its upper left-hand corner ; its lower side is curved to fit into plate 3. Plate 9 is irregularly hexagonal. Of the third circlet, plates 10, 11 and 12 are hexagonal, but 12 is larger and more irregular than the other two. Plate 13 is narrower and reaches farther up the cup than any other plate of the ring : it is five-sided or six-sided if the deep anal excavation on its lower right-hand angle is included. Plate 14 is large and hexagonal, with the anal notch in the lower left-hand corner. The five plates of the fourth circlet (16, 17, 18, 19, 15) are pentagonal with the upper margin deeply notched for the ambulacral furrows. The plates of the fifth circlet (21, 22, 23, 24, 20) are small and almost indistinguishable in the specimen.

All the plates of the cup are ornamented with polygonal ridges, separated by shallow depressions. On the first two

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[*] Memoirs of the Geol. Survey of Great Britain, vol. ii, pt. ii, p. 488.

circlets of plates these ridges are radially arranged, but on the upper plates this regularity is lacking.

Pectinirhombs appear across the sutures between plates 1 and 5, 12 and 18, 14 and 15, and 10 and 18. Pectinirhomb 1–5 presents two small, oval discrete halves without apparent stereom folds. Pectinirhomb 12–18 is larger: the half on plate 12 shows indistinct stereom folds, but that on 18 is almost destroyed. Pectinirhomb 14–15 has a large oval half on 14, presenting eight folds of stereom and lip-like margins. The half on 15 is triangular in shape, with stereom folds reaching to the suture and not confined by a lip. Pectinirhomb 10–15 has a small, oval, lipped, discrete half on 10. The portion on 15 is exactly the same as the other half-rhomb belonging to that plate.

The anus is large and is situated at the angle between plates 7, 8, 13 and 14. These plates are deeply excavated by the anal margin, which is raised into an oval or circular ridge.

Except for distinct evidence of their original presence on the median line of each plate of the fourth circlet, the ambulacral furrows are not perceptible.

The column is round and tapers distally. The first ten segments show a sharp median crest and occupy a space of about 7^{mm}. They show a gradually increasing thickness distally. Beyond the tenth segment, the median crest is less defined, the segments gradually becoming barrel-shaped. The 17th segment is 2^{mm} long and of about the same width.

The present example differs from Meek's species in its larger size, being 15^{mm} high by 10^{mm} wide, while the genotype is $11 \cdot 5^{mm}$ by 9^{mm}. The column, at its proximal end, is 4^{mm} thick as compared with $3 \cdot 5^{mm}$ in Meek's species. The sculpturing of the plates is different, as *L. moorei* shows only "thread-like, radiating costæ, one of which, passing from the middle to each side of each plate, is usually slightly larger than the others between." The shape and arrangement of the plates of the cup are strikingly alike in the two species.

Horizon—Clinton.
Locality—Forks of the Credit River, Ontario.
Collector—Mr. Joseph Townsend.
Specimen number—University of Toronto Museum, No. 372 C1.

Art. XXXVI.—*A New Petrographic Microscope;* by Fred.
Eugene Wright.

Experience has shown that the so-called universal instru-
ments are as a rule unsatisfactory, and often do not accomplish
in a thoroughly competent manner any one of the several
purposes for which they are intended. To fulfill a given set
of conditions adequately, it is usually necessary that a special
instrument be designed for the purpose. Thus, a small calibre
rifle may be admirably suited for small game, but for
larger game it is totally inadequate and might even be of more
harm than service in an emergency; and vice versa, a large
calibre rifle is of little value in hunting small game.

The same principle of adaptability applies equally to micro-
scopes and scientific apparatus in general. The ordinary
microscope, which is designed to aid in the examination of thin
sections of rocks and minerals, is satisfactory and convenient
for such purposes, but is less so for use in the investigation of
artificial preparations which are usually very fine-grained, the
diameter of the individual grains averaging often not more
than $\cdot 01^{mm}$. To determine satisfactorily and with fair accuracy
the optical constants of substances in such minute grains, special
methods of attack are required, and these in turn postulate
certain new conditions to be fulfilled by the petrographic
microscope. It was with this end in view, to construct a
microscope better adapted than the microscopes now available
for the examination and determination of fine-grained artificial
silicate preparations, that the present microscope was designed
and constructed in the workshop of the Geophysical Laboratory.
Several of its features appear to be of general application, and
a brief description of its essential parts is therefore justified.

In the construction of the present instrument (fig. 1), a
Zeiss microscope No. 1 C for photomicrography served as base,
and on it extensive changes were introduced so that the result-
ing microscope resembles the original only slightly. This
particular model was chosen chiefly because of its wide upper
barrel, which was well adapted for the introduction of
diaphragms and the movable Bertrand lens. The changes which
have been introduced are essentially as follows.*

(1) The nicols are revolvable simultaneously about the optic
axis of the microscope. They are connected rigidly by the
bar T of fig. 1, and their angle of revolution can be read off
directly by the vernier on the stage. This method obviates
the errors introduced by the usual system of gear-wheels with
accompanying lost motion in the moving parts. The details of

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* A still further change, made recently and not shown in fig. 1, is the intro-
duction of a block just below the upper tube support. The distance between
the stage and the upper tube is thereby increased and the use of the univer-
sal stage facilitated.

Fig. 1.
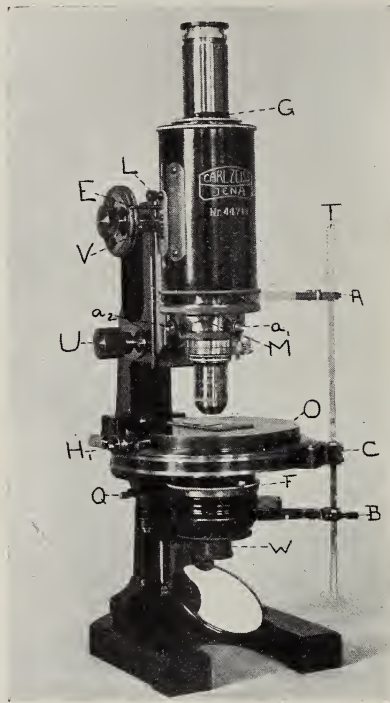
Fig. 1. New petrographic miscroscope. T, rigid bar connecting two nicols and effecting simultaneous revolution of the same ; A, arm connecting upper nicol carriage with T ; C, part supporting bar T and revolving about stage : B, arm from lower nicol carriage connecting with bar T ; by means of the screw and cross plate at B, this arm can be instantly released from T and the lower nicol either revolved by itself or, after a release by a snap spring not shown in the figure, thrown out of the field altogether.   The total angle of simultaneous revolution of both nicols by this device is 190°. O, new mechanical stage, simple in design and construction and fairly dust-proof. H_1, stage screw with divisions on head reading to ·01^{mm} motion of stage plate.   Q, sensitive-tint plate inserted above lower nicol, W, and revolvable about microscope axis by means of containing carriage, F. M, combination wedge above objective ; a_1 a_2, fine adjustment screws above objective ; U, screw of fine adjustment device of upper microscope tube ; V, iris diaphragm below Bertrand lens, diaphragm opened and closed by turning head V, which is connected with iris diaphragm by pin and ratchet movement; E, pin for insertion of Bertrand lens which moves in an accurately fitting carriage, supporting iris diaphragm V, Bertrand lens E and auxiliary lens L, which swings on an arm indicated in fig. 1a and is of such focal length that together with ocular, it forms a small microscope used in focusing the image from the objective in the plane of the iris diaphragm, V.   The supporting carriage of V, E, and L, can be moved up and down in the microscope tube and the amount of movement read off on the adjacent scale, thus obtaining different magnifications (6·5 to 15·2 diameters) of the interference figure.   G, upper iris diaphragm directly beneath ocular.

FIGS. 1a, 2, 3.
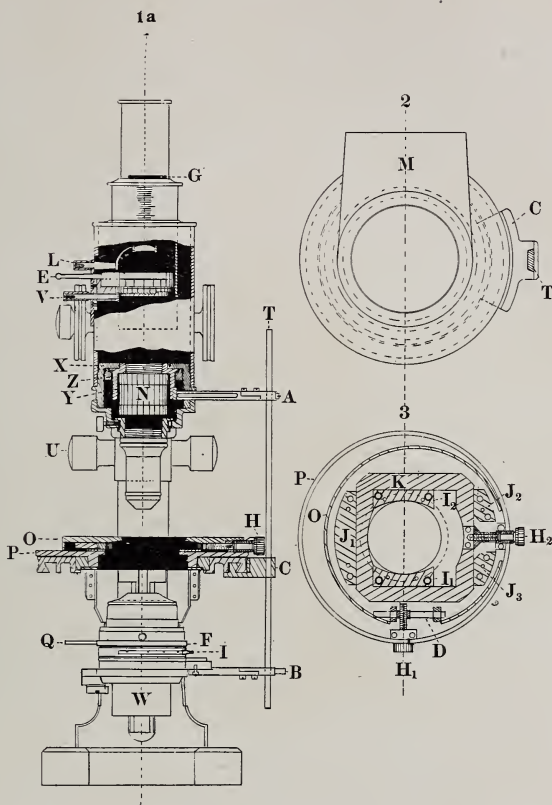
FIG. 1a. Section through microscope of fig. 1, showing working parts. The letters T, A, B, C, H, W, Q, F, O, U, V, E, L, and G, refer to the same parts as in fig. 1. I = lower iris diaphragm ; N, upper nicol ; X, Y, Z, brass parts effecting revolution of upper nicol ; P, revolving stage supporting movable plate, O.

FIG. 2. Section showing stage P and microscope plate supporting stage and other revolving parts and support for revolving nicol device, C ; T, cross section of bar connecting two nicols ; this bar slides accurately in the arms A and B of fig. 1a.

FIG. 3. Cross section through mechanical plate 1 of stage. I_1, I_2, brass plates screwed to revolving stage P and with wedge-shape sides in which rectangular plate K can move in an east-west direction, the movement being effected by the screw H_2. J_1, J_2 and J_3, three plates attached to under side of stage plate, O, and forming grooves for plate K, permitting stage plate O to move only in north-south direction, the movement being accomplished by screw, H_1, which in turn fits in a sliding block attached to the upper plate O, and traveling in the pin, D.

construction are shown in fig. 1a. By means of the screw and cross bar at B the connecting rod T can be instantly released and the lower nicol withdrawn or revolved by itself

independently of the upper nicol. The total angle through which both nicols can be revolved by this device is 190°.*

(2) A mechanical stage of new design† (fig. 3). This stage is practically dust-proof and mechanically simple in construction. In fig. 3. the vertical edge or rim of the cap, O, of the stage plate is indicated by the shaded broken circle, the upper surface of this plate being considered removed and the working parts as seen from above thus exposed to view. The small plates I_1 and I_2 are attached to the lower stage and are so constructed that wedge-shaped edges allow the rectangular plate K to move only in an east-west direction. This movement is effected by means of the screw H_2. The plates J_1, J_2 and J_3 of fig. 3, on the other hand, are attached to the upper movable plate O, and their wedge-shaped edges are so adjusted that they allow the upper plate to move only in a north-south direction with reference to the rectangular piece K. The screw H, which terminates in a block attached to the upper plate and running in a sliding pin D, accomplishes these north-south movements. The heads of both screws H_1 and H_2 have divisions reading to ·01^{mm} movement. Springs not indicated in the figure have been introduced and oppose the forward motion of the screws H_1 and H_2 and thus obviate errors due to lost motion in the screws. The total movement of the stage plate in any direction is 24^{mm}. Mechanically, it is of simple construction and consists of few parts.

(3) The metal part containing iris diaphragm and polarizer can be withdrawn from the optic axis of the microscope by means of a release spring not shown in fig. 1. This part is also revolvable by itself about the axis. This arrangement was adopted in preference to the usual method of inserting and withdrawing the upper nicol because of the disturbing effect which the introduction of the upper nicol causes, both on the focus and position of the field. With the present disposition, the upper nicol ‡ remains permanently in the upper tube and the optical system, objective, nicol, and ocular, is not disturbed in passing from ordinary to polarized light. In certain microscopes the effect of the upper nicol on change of focus is compensated by means of a small lens of weak magnifying power, but even after the introduction of this device some shifting of the field may still be experienced on inserting the upper nicol.

* Fuess & Company have recently constructed, at the writer's suggestion, a simplified model of microscope on this principle of a rigid bar connection between the two nicols, so that the two can be revolved simultaneously. (Price 300 mks.)

† This stage was designed by Mr. Chamberlin of this laboratory, and constructed by Mr. Semple.

‡ For certain positions of the reflector and on certain days the light from the reflector is polarized to such an extent that faint polarization colors are observed on minerals in the thin section even after the polarizer has been withdrawn. For this reason it would be an improvement if the upper nicol also could be withdrawn readily, whenever desirable. This is the case on the model constructed by Fuess & Co., noted above.

(4) An Abbe condenser is used, and with it a large nicol prism, or an Ahrens prism, 15^{mm} edge, after the manner of the Fuess microscope No. 1a. With this arrangement the entire condenser lens system remains in position and its upper lens need not be removed when low-power objectives are used. This does away with the devices which have been employed for throwing the upper part of the condenser combination out of the axis of the optic system and which complicate the construction considerably.

(5) The selenite, or quartz, plate of sensitive tint is inserted in a metal case at Q (fig. 1), just below the condenser. It is revolvable in the carriage F about the optic axis of the microscope, an arrangement which often facilitates the determination of the ellipsoidal axis of a particular section because the abrupt rise or fall of interference colors on insertion and rapid revolution of the plate appears more clearly than if the slower moving stage itself were revolved. At M a combination wedge is introduced as in ordinary microscopes.

(6) The Bertrand lens E, fig. 1, is mounted on a sliding arrangement which, in connection with the sliding ocular tube, permits of different magnifications of the interference figure, an arrangement already adopted on several well-known microscopes. In the present microscope the focal length of the Bertrand lens (55^{mm}) has been so calculated that the initial magnification of the interference figures can be varied from ·81 diameters to 1·90 diameters. The ocular itself magnifies this image in turn eight-fold, so that the resulting magnifications range from about 6·5 to 15·2 diameters. The fact that the upper nicol intervenes between the objective and Bertrand lens limits very materially the range of magnifications possible by the Bertrand lens. An iris diaphragm is introduced directly below the Bertrand lens and slides up and down simultaneously with it. This diaphragm is opened and closed by means of the pin, V, fig. 1a, which is connected with the diaphragm itself by means of pin and ratchet movement.

(7) A second iris diaphragm is introduced at G, fig. 1, directly below the ocular, and is used in connection with the observation of interference figures by the Lasaulx method without the Bertrand lens. To be of service in this connection, the iris diaphragm should be located precisely in the image plane from the objective, as was emphasized especially by Czapski in 1891,[*] for in that plane alone can light be excluded from adjacent minerals in the thin section. To realize satisfactorily this condition, the writer has heretofore used the cap stop indicated by fig. 4, with two sets of slides, S$_1$ and S$_2$, at right

[*] Neues Jahrbuch, Beilage Band vii, 506, 1891.

angles to each other.   This cap fits the microscope tube and is inserted in place of the ocular.   By means of the lens " a " the field is focused in the plane of the slides and any portion singled out for examination. Because of diffraction phenomena the aperture should not be made less than $\cdot5^{mm}$ in diameter, but even with this restriction, and with the ordinary objectives, 3 or 4^{mm} focal length, grains not over $\cdot01^{mm}$ furnish good interference figures which ordinarily would be completely overshadowed and not discernible if adjacent light were not excluded.
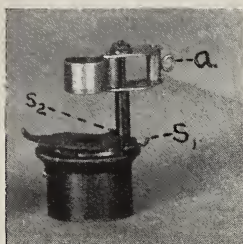
FIG. 4.

FIG. 4.   Device for cutting down the field when interference figures from small grains are being observed as they form in the objective itself (Lasaulx method).   Two sets, S_1 and S_2, of two plates at right angles and sliding in grooves permit the observer to cut off the light from any part of the field.   Before observing the interference figure, the image from the objective is first brought to coincidence with the plane of the iris diaphragm by means of the field lens " a."

Experience has shown that the effects are still clearly recognizable if the diaphragm is at a distance of not over 5^{cm} from the eye, and for convenience sake, therefore, this diaphragm was inserted just below the ocular.   The usual round disks with small aperture supplied with microscopes serve the same purpose but are less convenient.

Before stopping down the field by the diaphragm V just below the Bertrand lens, the image plane from the objective should on the same principle be brought to coincide with the plane of this diaphragm and the desired mineral section isolated by shutting off light from the adjacent grains.   To accomplish this readily, a small lens, L, fig. 1a (19^{mm} focal length) has been introduced in the present microscope above the Bertrand lens, and in conjunction with the ocular serves the purpose of bringing to sharp focus the image picture in the plane of the Bertrand lens iris diaphragm, in accord with the principle noted above.   In place of this small auxiliary lens, the writer has heretofore used a lens of long focal length and viewed the Bertrand lens diaphragm directly from the top of the tube.   The new arrangement is more convenient, however, and obviates the necessity of removing the ocular before viewing the interference figure.   The lens L swings on an axis and can be instantly thrown out of the field.   A small spring with pointer automatically indicates the correct position of the lens when thrown into the field. The Bertrand lens diaphragm ordinarily supplied with microscopes is of little value in the observation of interference

figures by the Lasaulx method without the use of the Bertrand lens, chiefly because of the disturbing effects of diffraction from the small apertures required and the distance of the aperture from the eye of the observer.

In designing this instrument, special attention has been paid to adjustment facilities and arrangements by which adjustments can be readily accomplished by the observer himself. In scientific instruments in general, too much reliance is often placed on the adjustment by the maker and the assumption " once in adjustment always in adjustment" notwithstanding jars and jolts of transportation, and the gradual relief of stress in any complicated mechanical system. Fortunately, the principle, which some manufacturers have adopted, of making all parts rigid and eliminating adjustment facilities, cannot be carried out in the construction of the microscope. In this instrument the axis of both the upper tube and the condenser holder on the microscope must coincide precisely with that of the revolving stage, in order that in every position the optical system remain centered. Since the ocular and the condenser remain automatically centered with respect to the revolving stage, while the objective changes its position slightly on each insertion, it is necessary that centering screws (a_1, a_2, fig. 1) be introduced for the objective itself and the direction of motion of centering should be parallel with the cross hairs of the ocular, as the eye estimates much more readily coördinate directions than diagonal directions. The principle sometimes adopted of placing the centering screws with directions of movement along the diagonals is therefore less favorable than along the cross hairs, and places a burden on the microscopist which might easily be avoided. The practice of placing the adjustment screws on the revolving stage instead of above the objective is wrong. The part of the optic system which is not in adjustment is the objective, not the stage. The axis of revolution of the stage should form the starting point for the adjustment of the whole instrument and should always remain fixed in its position. To this axis the ocular, condenser, and objective should be adjusted, and since the ocular and condenser remain practically stationary while the objectives are changed constantly, the only logical point of adjustment, to obtain satisfactory results, is above the objective.

To summarize briefly, the most important changes introduced on the present microscope are: (1) Both nicols revolve simultaneously, the connection between the two being a rigid bar, thus eliminating the errors due to lost motion in the gearwheels of the systems ordinarily employed for this purpose. Since adopting the above device, the writer has learned that the scheme of revolving the nicols by a rigid connecting bar

was used over thirty years ago by Dick in London, but was applied only to the revolution of a cap nicol above the ocular in conjunction with the polarizer. It was, therefore, slightly different from the present disposition. (2) The upper nicol always remains in the tube and the substage nicol is inserted or withdrawn on passing from ordinary light to crossed nicols. This device eliminates the annoying change of focus and shift of field ordinarily experienced when the nicol is inserted in the upper tube. (3) The sensitive plate is inserted just below the condenser and fits in a carrying device which is revolvable about the axis of the optical system. This disposition has been found convenient in determining the relative ellipsoidal axes in a plate, since the plate can be revolved more quickly and easily than the microscope stage or the two nicols together. (4) It has a new mechanical stage of novel design and simple but effective mechanical construction. The stage is practically dust-proof, has a free upper plate and a movement of 24^{mm} in any direction. (5) The Bertrand lens is fitted in a sliding device such that the magnification of the interference figure can be varied from 6·5 to 15·2 diameters. Immediately below the Bertrand lens, the iris diaphragm is introduced, while above this lens a second lens of short focal length can be thrown into the field which, together with the ocular, serves the purpose of focusing the image picture sharply in the iris diaphragm. (6) The second iris diaphragm at G, immediately below the ocular, is intended for use when observing interference figures directly by the Lasaulx method without the ocular and Bertrand lens. This iris diaphragm is a substitute for the device indicated in fig. 4, and the round cap plates usually furnished with microscopes, and although theoretically less satisfactory, practically it answers the purpose sufficiently well. (7) A large Abbe condenser is used, together with an Ahrens prism of 15^{mm} edge, or large nicol in place of the usual nicol and condenser with removable upper lens. This arrangement, first introduced on the Fuess microscope 1a, is a marked improvement over the usual arrangement and does away with the more or less complicated devices for removing the upper condenser lens from the optic axis of the microscope.

Art. XXXVII.—*A New Ocular for Use with the Petro-graphic Microscope ;* by Fred. Eugene Wright.

Minerals in the thin section are determined and recognized chiefly by the effects they produce on transmitted light and the relation of these effects to observed crystallographic features, such as cleavage, crystal form, etc. The usual optical properties which are thus made use of in determinative work are : crystal habit, cleavage, character of elongation, color, pleochroism and absorption, refractive indices, birefringence, extinction angles, optic axial angle, optical character, and rarely, dispersion of the optic axes.

These characters can be divided into two classes based on the methods of their determination. Those of the first-class (crystal habit, color, pleochroism and absorption, optical character of elongation, optical character of the mineral, and dispersion of the optic axes) are ascertained by direct observation without measurement, while for the second class (cleavage angles, extinction angles, optical axial angles, refractive indices and birefringence) numerical values obtained by actual measurement are required.

The ordinary petrographic microscope is adequate and satisfactory for the determination of the features included in the first class, but not for the second, if accurate data are desired. The result is that in petrographic determinative work and description these data are often only very roughly measured and are then expressed in general terms, such as "optic axial angle large," "birefringence strong," etc., without giving actual numerical data. The importance of quantitative measurements in all scientific work is obvious. The chief reason for the absence of the quantitative element in the major part of petrographic descriptions must, therefore, be sought in the cumbersome methods now available for the purpose. Thus a Babinet compensator, or other special device, is required for the measurement of the birefringence ; a double screw micrometer ocular or Becke drawing stage for the measurement of the optic axial angle, etc. Believing that these various requirements can be met with sufficient accuracy by the use of a single ocular, which can be made to fit any ordinary microscope, the writer has had the present ocular constructed, which has proved satisfactory and convenient in actual use.[*] The ideas involved in this ocular are not new,[†] but the assembling of the different

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[*] This ocular was constructed by Fuess & Co. of Steglitz, Germany, (cost 200 mks.) and the writer desires to express his appreciation of the care taken by that firm in carrying out his suggestions.

[†] Compare F. E. Wright, this Journal (4) xxiv, 317–369, 1907; xxvi, 349–399, 1908; Journal of Geology, x, 33–35, 1902; Tscherm. Min. Petr. Mitteil., xx, 275, 1901. J. W. Evans, Min. Mag., xiv, 87–92, 1905.

attachments into one ocular is novel and of sufficient general interest to warrant brief description.

The ocular is represented in fig. 1, and consists essentially of a metal holder, which is inserted in the microscope tube in place of the ordinary ocular and into which in turn a positive Ramsden ocular* is introduced at A and certain plates mounted in metal carriages, *a*, *b*, *c*, are inserted at B. Cross hairs are attached to the base of the tube A and are practically in the same plane with the upper surfaces of the sliding plates *a*, *b*, *c*, with the result that on focusing the Ramsden ocular on the cross hairs, the divisions marked on the plates *a*, *b*, *c*, are also in focus and their relative movements can be read off directly. With the above arrangement the optical constants required can be measured directly by means of the three plates.

FIG. 1.
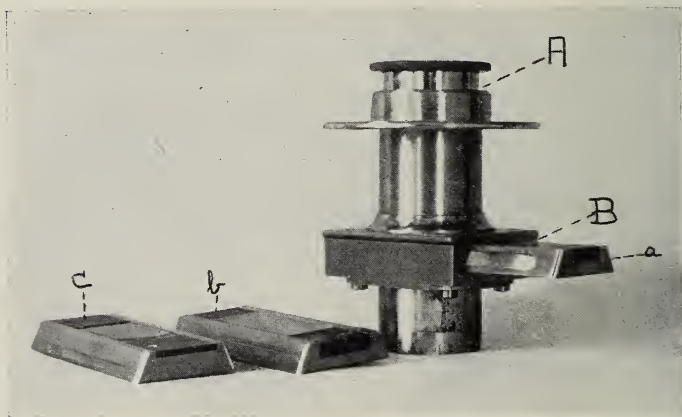
FIG. 1. New ocular with accompanying plates *a*, *b*, *c*, to be used in measuring the birefringence, the optic axial angle, and extinction angles of minerals in the thin section or in powder form.

Plate *a* (fig. 1, fig. 2a, b) is a combination quartz wedge† 35.3^{mm} long and 10^{mm} wide, and consists (fig. 2*a*) of a quartz wedge cut parallel with the principal axis (direction of elongation$=c$) $.5^{mm}$ thick at the thin end and $.89^{mm}$ at the thick end, its pitch being, therefore, about $6°$ $16'$; and (2) of a quartz plate with direction of elongation a of same length and width and $.56^{mm}$ thick. If these

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* An ordinary Huyghens ocular can also be used, provided the plates be inserted in the focal plane of the aplanatic eye lens.

† Compare F. E. Wright, Tscherm. Min. Petr. Mitteil., xx, 275, 1901; Jour. Geol., x, 33-35, 1902.

dimensions be followed exactly, 1/10 millimeter divisions ruled on the upper surface of the wedge (fig. 2*b*) will give directly the difference in distance in $\mu\mu$ between emergent light waves at a particular point. Thus, for sodium light the distance between successive interference bands will be 5·89^{mm}. The zero line of the scale must coincide precisely with the black line of exact compensation between wedge and superimposed plate. In the present wedge this is the case ; the slope of the wedge, however, is not exactly correct, and a slight correction must be applied to the readings obtained

Fig. 2a.
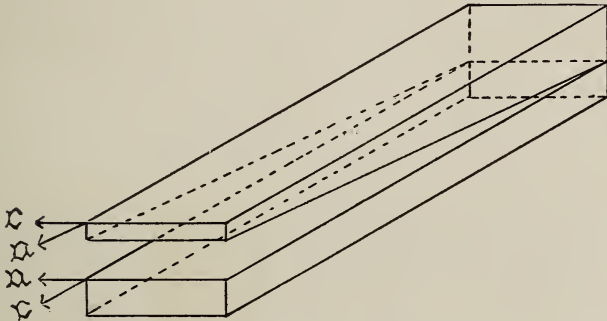
Fig. 2a. Combination wedge. Upper part of combination quartz wedge with direction of elongation=a, while lower part is a quartz plate, direction of elongation=c.

since 22^{mm} on the wedge is equivalent to 22·62 $\mu\mu$. For interference colors of the first and second order this error (nearly 3 per cent) is very slight and can practically be neglected, but

Fig. 2b.
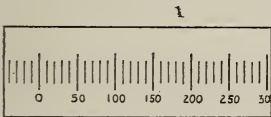
Fig. 2b. Top view of combination wedge showing divisions and position of dark line of exact compensation of wedge and plate. The 0·1^{mm} divisions on the scale are not represented in the figure.

for higher orders it must be taken into account and the readings multiplied by a factor of proportion. In actual work a table of equivalent values can be prepared or an inclined line of proper slope can be added to the color chart and the correct value equivalent to any observed value read off directly. With proper care, however, it is possible to grind these wedges correctly, so that the 1/10 millimeter divisions read directly in terms of differences in wave length ($\mu\mu$).

In practice, the determination of the birefringence of a crystal plate in the thin section requires the determination of two distinct factors—the thickness of the crystal plate and the

path difference between the emergent light waves. The thickness of the plate can be measured either by direct contact by micrometer screw or spherometer or by means of the fine adjustment screw of the microscope, or indirectly by means of the interference color or path difference of an adjacent mineral, properly cut and of known birefringence. Of these different methods the second is most convenient, although possibly less accurate. The usual method consists in bringing to sharp focus the upper surface of the plate and then the lower surface as seen through the plate itself, or if the plate be free along one side, to focus on the object plate on which the section is resting. In the first case, the apparent thickness must be multiplied by the refractive index of the mineral to obtain the true thickness. Since the average thickness of minerals in the thin section is about $\cdot030^{mm}$, an error of $\cdot001^{mm}$ in setting the micrometer screw will produce an error of 3 per cent in the thickness determination. In ordinary microscopes this error may frequently amount to $\cdot002$ or $\cdot003$, and the resulting error in thickness to 10 per cent.

Suppose the extreme limits of error be $\cdot003^{mm}$ or $\cdot0015^{mm}$ on either side of the true value, then an error of 5 per cent in the actual thickness determination may be considered probable. If this probable error be increased to 8 per cent to allow for multiplication by the refractive index and to introduce a safety factor, it can safely be assumed that the thickness of favorable crystal plates in thin sections, ranging from $\cdot03$ to $\cdot05^{mm}$ in thickness, can be determined readily by this method within 8 per cent of the true value. For minerals in powder form, the thickness of the individual grains may be much greater and the thickness determination correspondingly more accurate.

On the wedge whose scale divisions correspond to 10 $\mu\mu$ path difference of light waves, the error of determination is not over one division on the scale ($\cdot1^{mm}$), which is less than 2 per cent.

The total probable error of the determination of the birefringence of a mineral plate in the thin section in an unfavorable instance may amount, therefore, to 10 per cent. As the birefringence of the ordinary rock-making minerals ranges from about $\cdot005$ to $\cdot050$, an error of 10 per cent is confined to the third decimal place.[*]

In determining the birefringences $(\gamma-a)$ or $(\gamma-\beta)$ or $(\beta-a)$ of a mineral the position of the mineral plate (under examination)

[*] An average of the birefringences of the 118 minerals listed under birefringence on page 292–295 of Rosenbusch-Wülfing, Micros. Phys. I, 1, gives $\cdot040$ as the mean value, while the value of the members midway between the two limits is $\cdot020$–$\cdot025$. This value represents more nearly the mean value of the birefringence of rock-making minerals than the arithmetical mean, $\cdot040$.

Fig. 3.
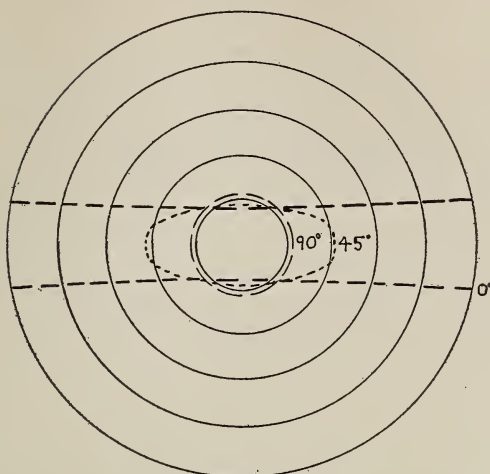
Fig. 3. In this stereographic projection plat (circles 10° apart) the positions of the directions in a biaxial crystal whose birefringence ($\gamma'-a'$) is 2 per cent less than that of the optic normal ($\gamma-a$) are indicated for the optic axial angles 2 V$=0°$, 45° and 90°. The optic normal coincides with the central point of the figure.

Fig. 4.
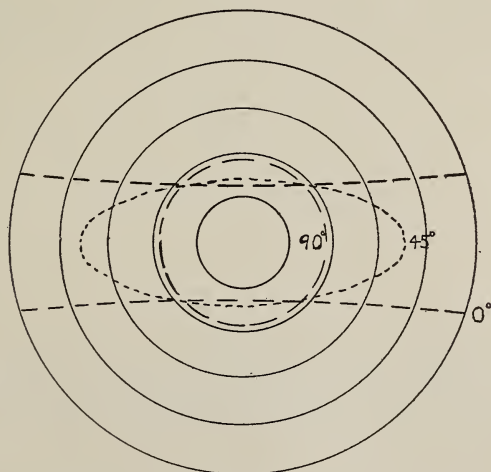
Fig. 4. Stereographic projection plat showing positions of the directions for which the birefringence ($\gamma'-a'$) is 5 per cent less than that of the optic normal ($\gamma-a$) which coincides with the center of the concentric 10° circles. These curves are drawn corresponding to the optic axial angles 2 V$=0°$, 45°, and 90°.

FIG. 5.
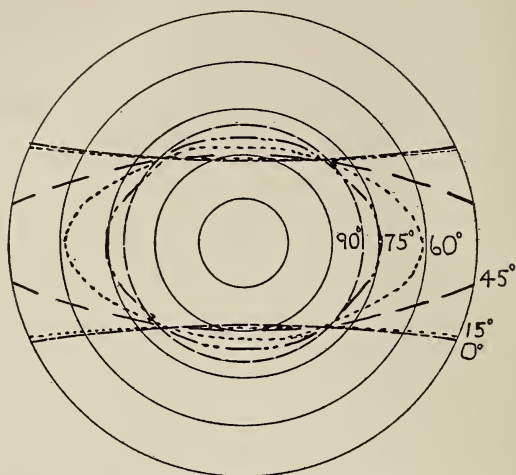
FIG. 5. Like fig. 4, except that the directions are indicated whose bire-fringence is 10 per cent less than that of the optic normal located at the center of the projection plat. The positions of the curves corresponding to optic axial angles 2 V=0°, 15°, 45°, 60°, 75°, 90°, are indicated in the figure.

FIG. 6.
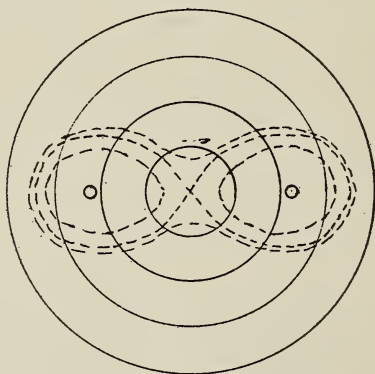
FIG. 6. In this figure the directions whose birefringence is 10 per cent less or greater than that of the acute bisectrix (optic axial angle 2 V=45°) are shown by the dotted curves. In this figure the dotted curve which passes through the center point (acute bisectrix) marks the directions whose birefringence is equal to that of the acute bisectrix $(\gamma-\beta)$ or $(\beta-\alpha)$ as the case may be.

is ascertained by means of convergent polarized light. In actual work it is not always easy to find a plate cut precisely normal either to the optic normal or to one of the bisectrices, and it is of interest to know the percentage error caused by

Fig. 7.
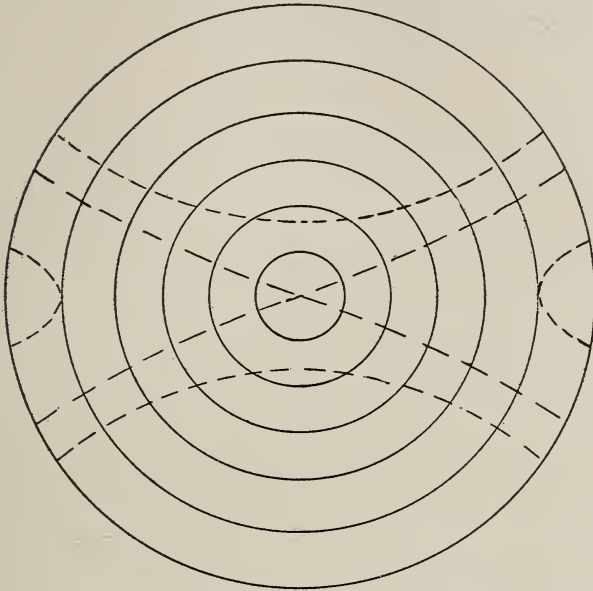
Fig. 7. Similar to fig. 6, except that the center of the projection plat is the obtuse bisectrix (2 V=45°). As in fig. 6, the directions whose birefringence is 10 per cent greater or less than that of the obtuse bisectrix are indicated.

Fig. 8.
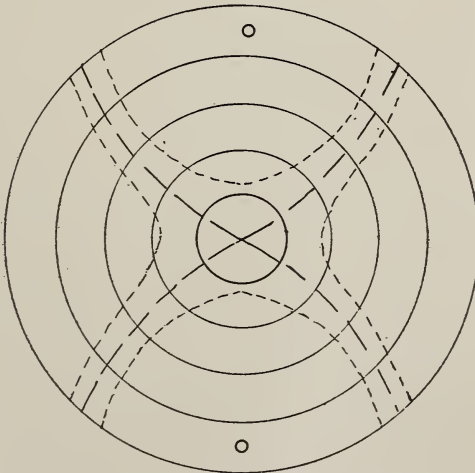
Fig. 8. Similar to fig. 6, except that the optic axial angle is 2 V=90°. The dotted curves again represent the directions for which the birefringence is 10 per cent greater or less than that of the bisectrix at the center of the projection plat. In this stereographic plat, as in all preceding, the concentric circles are 10° apart.

using sections inclined at low angles with the correct directions. For a given plate the birefringence can be calculated approximately from the usual formula,

$$\frac{\gamma'-a'}{\gamma-a}= \sin \text{ I}' \sin \text{ I}$$

in which I and I' are the angles which the normal to the plate makes with the two optic axes (or optic binormals) respectively.

In figs. 3–8 these relations are shown graphically in stereographic projection. In each figure the angular distance between any two successive concentric circles is 10°. Thus in fig. 3 are indicated the positions of the sections whose birefringence is 2 per cent less than the true birefringence $(\gamma-a)$ exhibited by a properly cut plate exactly perpendicular to the optic normal. The position of these lines of equal birefringence is different for different optic axial angles as indicated by the lines for 2 V=0°, 45° and 90°, but it is evident from the figures that an inclination of 10° with the true optic normal section will cause an error not over 2 per cent less than the true value $(\gamma-a)$ and often much less. In fig. 4 lines of equal birefringence 5 per cent less than the correct value $(\gamma-a)$ are drawn for different optic axial angles and show that inclinations of 15° produce errors of 5 per cent and less in the true value $(\gamma-a)$, while inclinations of 20° (fig. 5) produce errors of 10 per cent and less of the total birefringence. Similarly, for sections normal to a bisectrix, fig. 6 indicates that for an optic axial angle 2 V=45°, a plate cut at an angle of 7° with the bisectrix may produce a positive or negative error of 10 per cent or less in the birefringence $(\gamma-\beta)$ or $(\beta-a)$. But in this case the birefringence $(\gamma-\beta)$ or $(\beta-a)$ is only about 14 per cent of the total birefringence, and an error of 10 per cent, therefore, usually applies only to the fourth decimal place. In fig. 7 the directions for which the birefringence is 10 per cent greater or less than $(\beta-a)$ or $(\gamma-\beta)$, here about 85 per cent of $(\gamma-a)$ for 2 V=145° (obtuse bisectrix), approach within 18° of the bisectrix. In this figure, the curve indicating an increase of 10 per cent birefringence is 50° and over from the obtuse bisectrix. Plates making an angle of less than 20° with the bisectrix can, therefore, be safely assumed to furnish values of $(\beta-a)$ or $(\gamma-\beta)$, which are not over 10 per cent in error. An inclination of 8° would produce an error of about 2 per cent in $(\beta-a)$ or $(\gamma-\beta)$. In fig. 8, the rate of change of birefringence for sections at different angles with the bisectrix is indicated on the assumption that 2 V=90°; there an inclination of 12° and over is required to effect a negative error of 10 per cent in the birefringence $(\gamma-\beta)$ or $(\beta-a)$, and 18° or more to effect an equal, positive error.—Assembling these data, it may be assumed in general

that the birefringence of a plate, inclined at an angle of 5–10° with the true direction (optic normal or bisectrix), will be in error about 2 per cent of the true value $(\gamma{-}a)$, $(\gamma{-}\beta)$ or $(\beta{-}a)$; an inclination of 10–15°, about 5 per cent, while for 15°–20° inclination the error may be as much as 10 per cent of the true value desired. By means of the optic axial angle grating device described below, the angular inclination of the section can be ascertained and the probable error due to this cause thus eliminated.

In actual practice, therefore, the method of procedure in the determination of the birefringence of a mineral plate in the thin section or a mineral grain is to measure first the thickness by one of the methods noted above and then to insert the wedge "a" and determine under crossed nicols and in homogeneous (e. g. sodium) light, the path difference between the interfering light waves. For less accurate work the direct determination of the interference color and equivalent path difference indicated on standard color charts like that of Michel Levy is sufficient.—The actual error of such a determination should not exceed 10 per cent of the true value of the birefringence of the section. The probability of finding a section making an angle within 10° of a particular direction (optic normal) is about 1 in 66; and a section within 20° about 1 in 16. Since wedge "a" is merely a refined combination wedge, it can be used for all purposes for which the latter serves.

FIG. 9.
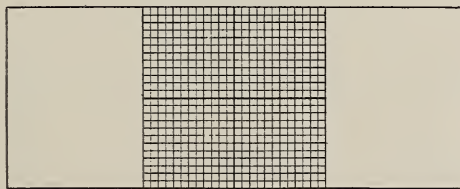
FIG. 9. Top view showing cross grating ruling on plate *b* used in the measurement of optic axial angles of mineral plates in the thin section. In this figure, the 0·5^{mm} divisions are indicated but not the 0·1^{mm}.

(b) Plate *b* (fig. 1 and fig. 9) and the measurement of the optic axial angle.—By the use of this device, which is simply a thin glass plate 1·5^{mm} wide, on which fine coördinate lines 0·1^{mm} apart have been ruled, the optic axial angle of a mineral can be measured, provided one or both optic axes appear within the field of vision. The principles on which the method is based are considered in detail in a former paper.*

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* The Measurement of the Optic Axial Angle of Minerals in the Thin Section, this Journal (4) xxiv, 317-369, 1907; also, Das Doppel-Schrauben-Mikrometer-Okular und seine Anwendung zur Messung des Winkels der optischen Achsen von Kristalldurchschnitten unter dem Mikroskop, Tscherm. Min. Petr. Mitteil., xxvii, 293-314, 1908.

There the different methods for measuring the optic axial angle are treated at length, especially those of Mallard, Becke and Fedorow, together with a new method which requires for its application a double screw micrometer ocular or a cross grating ocular like plate b (fig. 9). The method of procedure for both double screw micrometer ocular and cross grating ocular is the same,—the observed coördinates being first reduced to equivalent angular values, and these in turn,

Fig. 10a.
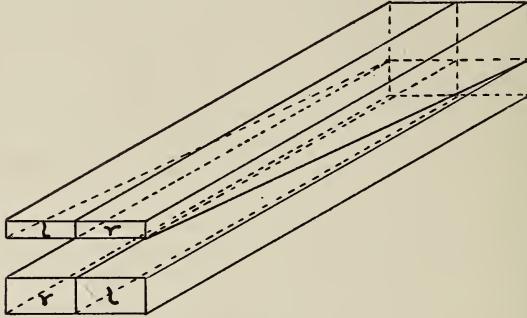
Fig. 10a.   View of bi-quartz wedge plate showing relative positions of right and left-handed wedges and underlying left and right-handed quartz plates, all normal to the optic axis, and in combination forming the most sensitive device for the determination of the exact position of total extinction of minerals in the thin section.   To be used also in adjusting the nicols in the petrographic microscope.

Fig. 10b.
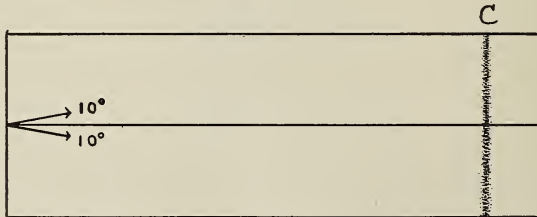
Fig. 10b.   Top view of bi-quartz wedge plate.   The position of dark line of zero rotation or exact compensation is indicated at C.

after reduction to values obtaining within the crystal, plotted in stereographic projection in order that the axial angle values may be found graphically.   In the article mentioned the different steps requisite for this method are described at length and need not be repeated here.   By means of this ocular, with ruled cross section slip, the optic axial angle of a favorable section on which both optic axes are visible can be determined within

1-2°. If only one optic axis appears within the field, an error of ±3° is possible on even a favorable section.

(c) Plate *c* (fig. 1 and fig. 10a and b), bi-quartz wedge plate for the accurate determination of extinction angles.—The principles and methods for determining extinction angles are presented at length in another paper,[*] where it is shown that for general purposes with variable light conditions and varying sensitiveness of the eye, a satisfactory general method should possess an element of adjustable sensibility in order to meet best the different conditions. This was found to be realized most satisfactorily in the bi-quartz wedge plate. The present plate was made after the following specifications: (fig. 10a) Wedge of right-handed quartz, length $35 \cdot 3^{mm}$, width 6^{mm}, thickness at thin end 35^{mm}, at thick end $\cdot 85^{mm}$; plate of left-handed quartz, length $35 \cdot 3^{mm}$, width 6^{mm}, thickness $\cdot 4^{mm}$; thin plate to be cemented on the wedge to a combination plate wedge which gives zero extinction at a distance $3 \cdot 5^{mm}$ from the thin end. The same specifications to be followed with a wedge of left-handed quartz and a plate of right-handed quartz, likewise superimposed and cemented side by side as indicated in the figure and in such a way that the line of total extinction in the first combination is the extension of the line of zero extinction in the second (C in fig. 10b). This wedge in sodium light gives at the extreme end symmetrical extinction of about ±10° (fig. 10b), while at the thin end it is ±1°.

The position of darkness between crossed nicols for any plate is tested by simply inserting the bi-quartz wedge plate and observing the effect on the adjacent halves of the plate. If the position of total extinction coincides precisely with the planes of the nicols, both sides of the wedge will show the same intensity of illumination on insertion. If this is not the case, the observed plate must be revolved again and the test repeated. With this method on favorable sections the position of total extinction can be determined on a single trial within 10′.

The determination of an extinction angle on a mineral plate involves two distinct steps—the location of the exact position of total extinction and the angular relation (optical system, accurately centered) of this direction to some observed crystallographic direction, as crystal edge or cleavage line. The error of the latter determination is not great since the eye is sensitive to errors in parallelism of adjacent lines as cross hair line and cleavage line. The measurement of the extinction angle by simply revolving the stage and thus determining the position of total extinction, is sufficiently accurate for ordinary purposes, if the average of a number of determinations be

[*] On the Measurement of Extinction Angles in the Thin Section, this Journal (4), xxvi, 349–390, 1908.

taken, and for ordinary petrographic work the expensive bi-quartz wedge might possibly be omitted altogether. The time saved, however, by its use in accurate work is a factor which would soon offset the expense involved.

For the adjustment of the petrographic microscope the bi-quartz wedge plate is also well adapted. *

With the three plates, *a*, *b*, *c* (fig. 1), accompanying this ocular, it is therefore possible to determine with sufficient accuracy the birefringence, the optic axial angle and extinction angles of mineral plates in the thin section. There remains still the determination of the refractive indices, and no satisfactory method has yet been devised for the accurate determination of these on plates in the covered thin section. On the polished thin sections the refractometer attachment of of Wallerant has proved satisfactory, while for minerals in fine grains or powdered sections the immersion method in liquids of known refractive index is best adapted. By this method, the refractive indices can readily be obtained on favorable sections with a probable error of about ±·002.† By such direct refractive index measurement, birefringence determinations and optic axial angle measurement can be checked and possible errors eliminated.

Summary.

With the ocular pictured in fig. 1, three fundamental optic properties of minerals in the thin section can be measured. (1) With the combination wedge "a" the birefringence; (2) with the ruled plate "b" (cross section ruling interval ·1^{mm}) the optic axial angle, provided one or both optic axes appear within the field of vision; (3) with the bi-quartz wedge plate "c" the extinction angle. These three features, and particularly the first two, are usually estimated only roughly and not measured accurately in petrographic work, chiefly because of the complicated apparatus now required for the purpose. The present ocular was constructed to serve as a simple but effective substitute for such apparatus, and thus to facilitate the actual measurement of these important properties. In the same holder other wedges and plates can be introduced which may serve for the determination of the above and other optical properties of a crystal plate.

Geophysical Laboratory,
    Carnegie Institution of Washington,
        Washington, D. C., January 31, 1910.

    * F. E. Wright, this Journal (4), xxvi, 386–388, 1908.
    † Compare O. Maschke, Pogg. Ann., cxlv, 568, 1872 ; Wiedemann's Ann., ii, 722–734, 1880 ; J. Thoulet, Bull. Soc. Min., Fr., iii, 62–68, 1880 ; J. L. C. Schroeder van der Kolk, Zeitschr. f. Wiss. Mikroskr., viii, 458, 1892; F. E. Wright, this Journal (4), xxvii, 385–387, 1907; Tscherm. Min. Petr. Mitteil., xx, 239, 1901.

Art. XXXVIII.—*On the Behavior of Crystals in Light Parallel to an Optic Axis;*[*] by Charles Travis, Ph.D.

If a section of a biaxial crystal be cut normal to an optic axis, and this section examined in parallel light between crossed nicols, it appears uniformly bright in all positions when rotated about the axis. This is commonly ascribed to interior conical refraction, the explanation given by various authorities[†] being the equivalent of the following :

When a ray of light, the wave-front of which is normal to the optic axis, enters the section, it is broken up into a cone of rays, each element of which is polarized in a different plane. Hence the light on emerging is polarized in all azimuths. This is equally true if the entering ray is plane polarized, for its vibration will have a component parallel to the vibration direction of each elementary ray of the cone. No matter how the analyzing nicol is placed with respect to the polarizer, then, it will fail to extinguish all the light that comes from the crystal. Following out this line of reasoning, it appears that the intensity of the light passing the upper nicol will be one-half of that from the lower.

Certain important factors are neglected in reaching this conclusion, which is untenable when these are considered. It is, therefore, the object of this paper to present a discussion of the behavior of crystals in light that is approximately parallel to an optic axis, and to explain the observed differences between uniaxial and biaxial crystals under these conditions.

§ 1. In any pencil of light that it is possible to obtain in practice, there are rays having all directions within certain limits. The energy of those rays that are strictly parallel to a given direction (e. g., the optic axis) is infinitesimal compared to the total energy of the pencil. An example will make this clear. Suppose our source of light is a circular area of radius, r, at the focus of a collimating lens of focal length, f. The angular radius of the pencil is then equal to the angle whose

tangent is $\dfrac{r}{f}$. A line drawn through the optical center of the

lens, parallel to the optic axis, will intersect the source in a point, p, and from this point *only* do we obtain rays that are

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[*] This paper was suggested by the work of W. Voigt (referred to below), who shows that interior conical refraction has no practical existence. The writer's chief object is to point out the correct explanation of a phenomenon that is well known to crystallographers.

[†] For example, cf. Groth, P., Physikalische Krystallographie, Leipzig, 1905, p. 109.

parallel to the axis.   The area of the point p is obviously zero compared to the total area of the source, no matter how small we may make the latter.

It appears from this that interior conical refraction is a purely mathematical ideal, never attained in practice. Yet it is a well-known fact that a small source of light (a pin hole), viewed along the optic axis of a biaxial crystal, appears not as a double image, but as a luminous ring.   Voigt[*] has shown that what is observed in this case is not interior conical refraction, but simply an approximation to it.   His reasoning may be summarized as follows :

A hollow cone of rays, of very small angular radius a, and surrounding the axis, traverses the crystal in two hollow cones of radius, $\dfrac{\phi_i}{2} \pm a$, where ϕ_i is the angle of the cone of interior refraction.   A solid cone of rays, of the same angular radius, will traverse the crystal under the same conditions in the annular space included between the two cones of radius $\dfrac{\phi_i}{2} \pm a$.   If, however, we consider not the summation of the effects produced upon a cone of rays, but the effect upon any individual ray, we see that this ray undergoes simple double refraction, and traverses the crystal in two definite rays.   In other words, there is no essential difference between the behavior of rays near the axis and that of those at an appreciable distance from it.

§ 2.   Plane polarized light is split up, by passage through a biaxial crystal, into two sets of rays, vibrating at right angles. The components of these vibrations, in any one plane (obtained by placing the analyzing nicol above the crystal), produce certain definite interference effects.   From the foregoing, light in the neighborhood of the optic axis forms no exception to this ; but as the divergence of the two complementary rays is often a maximum near the optic axis, it is well to consider the effect produced by having the source of light at a finite distance from the section.

A ray SA (figure 1), from a source S, is divided, upon entering the crystal, into the rays AB and AC, which vibrate at right angles.   From the same source, another ray, SD, may be found, which will divide into DC and DE ; C is then the common point of emergence of one ray from each of the points A and D.   These rays are polarized at right angles.   If the crystal is between crossed nicols, interference takes place between the components of AC and AD, parallel to the plane of the upper nicol.   The effect produced is dependent upon

[*] Voigt, W., Ann. Phys., xviii, 1905, p. 645.

the difference in phase at C, and this is due to the difference in the optical length of the paths SAC and SDC.

Let us assume that the wave-front of the two rays is essentially normal to the optic axis, so that the *front* velocity (not *ray* velocity) is the same for each, and is equal to $\frac{1}{\beta}$; let MN be the direction of the wave-front in the crystal and M′N′ that outside the crystal; also let SA be very large compared to AD. In the crystal, the path difference is β. AD . sin MNN′, AC having the longer path. Outside the crystal, the path differ

FIG. 1.   FIG. 2.
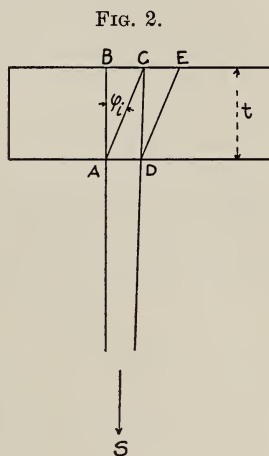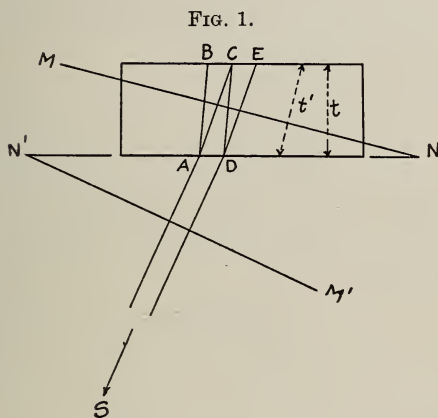
ence is AD . sin M′N′N, SD having the larger path. But sin M′N′N = β. sin MNN′; therefore SAC is optically equivalent to SDC.

If, then, S is at a great distance, the two rays at C will be in phase; their vibrations will give a resultant which is parallel to the plane of the lower nicol, and this resultant will be extinguished by the upper nicol.

In discussing the case in which the source is at a finite distance, the condition that the section be taken normal to the axis is assumed temporarily. (Figure 2.) The maximum phase difference is that between the two rays that lie in the plane of the optic axes; in the figure, this plane is taken as the plane of the paper.

Let $\Delta\gamma$ = the path difference, SD − SA. (AC and DC are optically the same.)

   D = the distance of the source, SA.

   ϕ_i = the angle of the cone of interior conical refraction.

$$\text{Then } \Delta\lambda = \frac{\overline{\text{AD}}^2}{2\text{D}} = \frac{(t \tan \phi_i)^2}{2\text{D}}.$$

$$\therefore \quad \Delta = \frac{(t \tan \phi_i)^2}{2\text{D}\lambda}.$$

For other pairs of rays in the plane of the axes, the relative lengths of SA and SD are changed, but the phase difference Δ at the point of interference is constant if the rays are so nearly parallel to the axis that their front velocity in the crystal may be considered constant. The reason for this is evident upon reference to fig. 1 and the accompanying discussion.

When the section is not cut normal to the optic axis (as in figure 1), it can be shown that the above results hold if t', the thickness parallel to the axis, be substituted for t.

For equally thick sections, with the source of light at a constant distance, the maximum phase difference Δ, due to the cause considered above, depends upon $\tan \phi_i$. The value of ϕ_i for aragonite is $1° 50'$, which is exceeded in very few other substances; the greatest known value is that for sulphur, for which $\phi_i = 7°$ approximately. Approximate values of Δ for sections of sulphur and aragonite, with D assumed as one meter, and λ as $0\cdot0005^{\text{mm}}$, are as follows:

Sulphur		Aragonite	
t (mm.)	Δ	t (mm.)	Δ
10	1·0	10	0·1
5	0·25	5	0·025
1	0·01	1	0·001

We may conclude from this, that with the source of light at distances commonly used when working with the polarizing microscope, Δ becomes practically zero in the very great majority of cases. (This assumes that the condensing system is removed from the polarizer.) Any illumination that is observed between crossed nicols is, therefore, due to the fact that the direction of the light is so inclined to the optic axis that one ray is appreciably retarded with respect to the other, in traversing the crystal. In other words, *the behavior of the crystal in light that is approximately parallel to an optic axis, must be referred to interference effects of exactly the same nature as those observed in any general section, with the light falling at any inclination to the axis.*

§ 3. The relative amount of light that a crystal section will transmit, when examined between crossed nicols, may be determined by means of the interference figure given by the same section in convergent light. This figure is virtually a spherical projection, in which each point represents a ray direction: if a is the angle between a given direction and the line

of collimation of the instrument, the point that represents this direction will lie at a distance from the center of the figure proportionate to sin a. The pencil of light that falls upon the section consists of rays having all directions within certain limits; if in any given pencil the maximum divergence between rays is $2a$, a circle drawn upon the interference figure, with radius proportionate to sin a, will represent the limits of the pencil. The average intensity of that portion of the figure lying within the circle is obviously equal to the relative amount of light transmitted by the section, when this is illuminated by the pencil under consideration.

The intensity at any point of the interference figure may be found from the following equations :[*]

$$I = \sin^2 2\theta \cdot \sin^2 \pi\Delta \qquad (1)$$

$$\left. \begin{array}{l} \Delta\lambda = F\rho \sin \phi_1 \sin \phi_2 \\[2mm] F = \dfrac{\dfrac{1}{2}\left(\dfrac{1}{a^2} - \dfrac{1}{\gamma^2}\right)}{\left[\dfrac{\dfrac{1}{a^2} + \dfrac{1}{\gamma^2}}{2}\right]^{\frac{3}{2}}} \end{array} \right\} \text{(For biaxial crystals.)} \qquad (2)$$

$$\left. \begin{array}{l} \Delta\lambda = F\rho \sin^2 \phi, \\[2mm] F = \pm \dfrac{\dfrac{1}{2}\left(\dfrac{1}{\omega^2} - \dfrac{1}{\epsilon^2}\right)}{\dfrac{1}{\omega^3}} \end{array} \right\} \text{(For uniaxial crystals.)} \qquad (3)$$

Equation (1) gives the relative intensity I at any point of the figure, in terms of the phase difference Δ between the two sets of interfering rays projected in that point, and the angle θ that the vibration planes of these rays make with the planes of the nicols. In equations (2) and (3), which give us Δ, ρ is the thickness of the section measured along the wave-front normal of the rays, ϕ_1 and ϕ_2 the angles that this normal makes with the two optic axes in a biaxial crystal, and ϕ the angle that it makes with the single axis in a uniaxial crystal. In both cases F is a function of the principal indices of refraction; if $(\gamma - a)$ for a biaxial crystal is equal to $\pm (\omega - \epsilon)$ for a uniaxial one, F will not be very different in the two cases.

Near the optic axis, (2) may be written

$$\Delta = \frac{F\rho}{\lambda} \cdot \phi_1 \sin 2V$$

[*] Liebisch, Th., Grundriss der physikalischen Krystallographie, Leipzig, 1896, p. 273, 336, 375. The above forms for the equations are somewhat different from those given by Liebisch.

or, dropping the subscript,

$$\phi = \frac{k\Delta}{\sin 2V} \qquad (4)$$

2V being the angle between the optic axes, and k a small constant. Under the same conditions, (3) may be written

$$\phi = \sqrt{k\Delta} \qquad (5)$$

Hence in the figure given by either kind of crystal, the loci of points of equal phase difference Δ are concentric circles. When Δ is an integer, the factor $\sin^2\pi\Delta$ in (1) vanishes; when Δ is an odd number of times one-half, $\sin^2\pi\Delta$ attains its maximum value, which is unity. The dark circles around the axis are the loci of points for which Δ is equal to n, and the bright ones those of points for which Δ is equal to $n-\frac{1}{2}$, n being an integer.

It is evident that the average intensity of the portion of the figure included in a circle whose center is the axis, increases with the size of the circle until this coincides with the first ring of maximum brightness; after this the average intensity fluctuates, but undergoes no great change. If, then, a crystal section is illuminated by a pencil of angular radius r, the intensity of the light transmitted is zero when r is zero, increases with r until r is equal to the radius of the first bright ring, and is approximately constant as r increases beyond this.

The only important difference between biaxial and uniaxial crystals, in this regard, lies in the difference between the radii of the first bright rings in the two cases. If the birefringence and the thickness of section are the same for both, k (equations (4) and (5)) has roughly the same value for either kind of crystal. But the radius of the first bright ring for the biaxial crystal is

$$\phi_b = \frac{\frac{1}{2}k}{\sin 2V}$$

whereas for the uniaxial crystal it is

$$\phi_u = \sqrt{\tfrac{1}{2}k}$$

and if k is very small (as it commonly is), ϕ_u is much larger than ϕ_b.

This is well shown by comparing sections 1^{mm} thick of aragonite and calcite. It is to be noted that while calcite has the greater birefringence, the first bright ring for this substance is six times as large as that for aragonite. In the calculation,* sodium light is assumed, for which $\lambda = \cdot000589^{mm}$.

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* The radii of the circles of maximum and minimum intensity are calculated as they appear after refraction from the crystal into the air.

	Aragonite		Calcite
	$\alpha = 1\cdot5301$		$\omega = 1\cdot6585$
	$\beta = 1\cdot6816$		$\epsilon = 1\cdot4863$
	$\gamma = 1\cdot6859$		$(\omega-\epsilon) = 0\cdot1722$
	$2\mathrm{V} = 17°50'$		$\log k = 7\cdot46201$
	$(\gamma-\alpha) = 0\cdot1558$		
	$\log k = 7\cdot58012$		

Radii of bright rings	Radii of dark rings	Radii of bright rings	Radii of dark rings
0° 36'		3° 37'	
	1° 12'		5° 07'
1 48		6 17	
	2 24		7 15
3 00		8 07	
	3 36		8 54

§ 4. The maximum divergence of so-called parallel light is often considerable, as a simple calculation will show. The lowest power objective (No. 0) that is furnished with the Fuess No. 3 microscope has a focal length of about 42^{mm}; its working distance was found to be $38\cdot2^{mm}$, its aperture, $6\cdot8^{mm}$, and its field, $4\cdot8^{mm}$ in diameter. From this, its angular aperture is 17° 30' approximately, and when the low power lens that is furnished with the polarizer is in place, the objective works at this full angle. By removing this condensing lens, the effective aperture is considerably diminished, becoming approximately 7° 30'; this may be reduced to 6° 30' by the substage diaphragm. Only by decreasing the size of the source of light, or by increasing its distance, can we obtain light that has less divergence than this. A source 1^{cm} in diameter, at a distance of 1 meter, for example, gives with the above objective a pencil whose angle is roughly 1°.

By comparing these values with the diameter of the first bright ring for aragonite, the reason is apparent for the brightness of a section of this substance, cut normal to an axis, of appreciable thickness. It is evident that a basal section of uniaxial calcite, 1^{mm} thick, should also be bright when examined with the above objective, even without the substage condensing lens; experiment verifies this.

The dark brushes of the interference figure, that mark the points for which the factor $\sin^2 2\theta$ (in (1)) approaches zero, widen out as the distance from the axis increases. At an appreciable distance from the axis, a small circle, centrally located in a brush, has an average intensity that is practically zero. This is the reason why a biaxial crystal, placed so that its axial plane coincides with the plane of one of the nicols, and rotated in this plane, is dark except in those positions in which an axis is approximately vertical.

In the above discussion, the light in every case is assumed to be monochromatic. When white light is used, we must consider two additional factors.

(1). The size of the rings in the interference figure increases with the wave length of the light; the average intensity for a pencil concentric about the axis is therefore dependent upon wave length. If the pencil is small, we may say that with light of a *greater* wave length, *less* is transmitted.

(2). In biaxial crystals, the dispersion of the optic axes renders it impossible to center a pencil about the axis for light of more than one wave length.

The total result of these two factors is that the intensity of the illumination varies with its color, and the crystal in white light, which is approximately parallel to an optic axis, shows impure interference colors.

Summary.

In regard to the observed fact that a section of a biaxial crystal, cut normal to an optic axis, is uniformly bright between crossed nicols, we may conclude that :—

(1). Interior conical refraction, in a strict sense, plays no part whatever as a cause of the phenomenon.

(2). The cause is to be found in the fact that so-called parallel light has commonly a considerable divergence.

(3). In any given case, the observed intensity of illumination is equal to the average intensity of that portion of the interference figure bounded by the limits of the pencil of light used. The general configuration of the interference figure is dependent upon the optical constants of the crystal, and upon the thickness of section; these, as well as the amount of divergence of the light, are the determining factors.

(4). The reason why the same phenomenon is not commonly observed in uniaxial crystals, is that in the uniaxial figure the first bright ring about the axis is in general much larger than that in the biaxial figure. Under proper conditions, however, the phenomenon may be also shown by a uniaxial crystal.

University of Pennsylvania, January, 1910.

ART. XXXIX.—*Some Simple Improvements for a Petrographical Microscope ;* by ALBERT JOHANNSEN.

1. A rotating upper nicol in which the annoying reflection of light from the surface is overcome.—In examining, between crossed nicols, minerals which are rather dark, a small amount of light falling upon the upper surface of the nicol produces a hazy appearance of the image. Figure 1 represents a light-

FIG. 1.
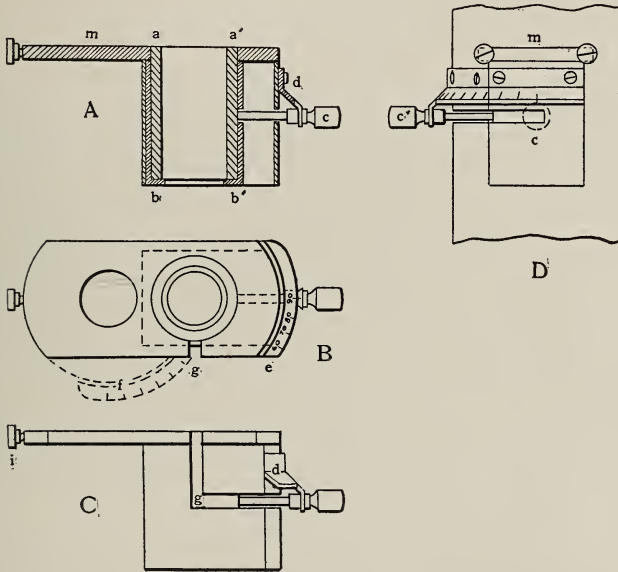
tight modification of the upper nicol of the Fuess III–*a* microscope. A vertical section through the carriage is shown at A. A rotating collar (*a a'*) is moved by the lever *c* and is supported by the flanges *b b'* of the outer tube in which it rotates. A part of the scale (*d*) is attached to the box and is divided into degrees, although only the 10° divisions are shown at B.

B and C are respectively the horizontal and the vertical projection. The separation of the scale into two parts, which was made necessary by its lowered position, is shown at *e* and *f*. The slot *g*, which is also shown in figure 1–C, is for the easy removal of the nicol from the carriage. The prism is rotated 90° and is lifted out, after the entire carriage is taken from the tube of the microscope, by the removal of the screw *i*. Figure 1–D is an end view showing how the plate *m*

entirely closes the upper part of the opening in the tube and prevents all reflection from the surface of the nicol. The lever c is shown at c', rotated through 90°.

2. *A permanently attached combination wedge.*—A great deal of time is ordinarily lost in picking up the accessories to the microscope and in hunting for the slot into which they are to be inserted. The simple contrivance shown in figure 2

FIG. 2.
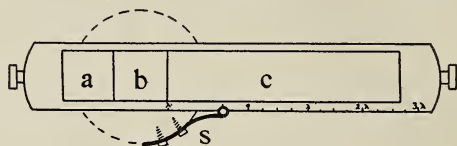
has been found to overcome all this. A carriage, exactly fitting the slot above the objective, is inserted in the tube of the microscope and is kept in place by two end screws like those holding the Bertrand lens bar. At one end is a square of gypsum (*a*) giving red of the first order; *b* is an opening; and *c* is a quartz wedge underlain by a mica plate, the two minerals having their c directions at right angles to each other, and similar in construction to a Wright quartz gypsum-wedge. The thickness of the underlying mica plate is so chosen that it exactly compensates the front end of the quartz wedge, consequently the colors of the combination wedge begin at darkness and gradually increase to the fourth order as the wedge is shoved forward. A spring (S) attached to the side of the microscope tube presses against the carriage and produces enough friction to hold it wherever it is placed. When the opening *b* is centered, the spring drops into a rounded notch as shown. Upon the upper side of the carriage a scale is engraved and the end of the spring shows the order of the color at that time beneath the cross hairs of the microscope.

3. *A rotating lower nicol for observing very slight pleochroism.*—In the ordinary petrographical microscope, such as the Fuess III–*a*, which is the one generally used, the arrangement for rotating the lower nicol is extremely crude, and the force necessary to overcome the friction by which it is retained in place makes smooth rotation impossible. In order to observe very slight pleochroism, it is often desirable to turn the nicol instead of the stage; the movement of the mineral in the latter case causes confusion and makes it impossible to observe very slight changes of color. Nor is it possible to obtain the same results by removing the lower nicol and rotating the upper nicol in its place, for a distortion of the image results and consequently, also, a movement of the lines. For this

reason the arrangement described below has been found very effective.

A brass collar was turned to fit the lower part of the nicol tube and was soldered on as shown in figure 3. A section through the collar is shown at A, figure 3; the nicol tube being here

FIG. 3.
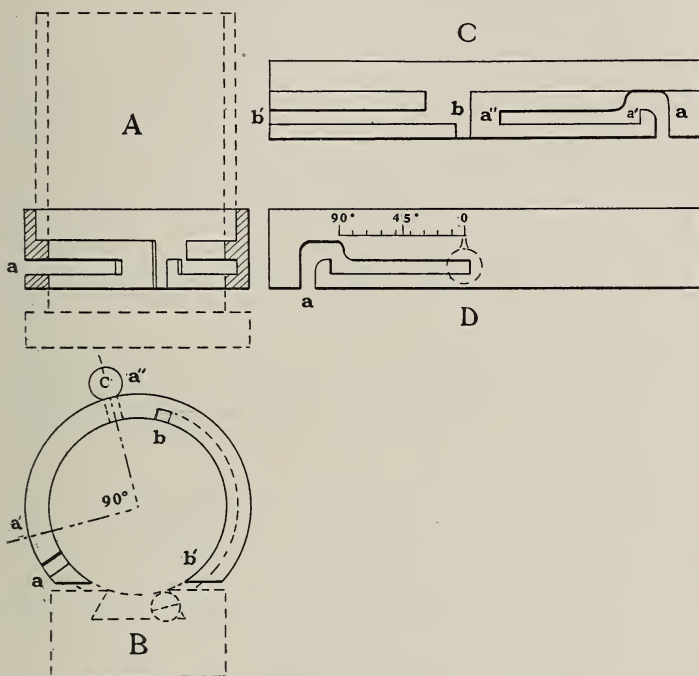
indicated by dotted lines. B is a view from below; C, a view of the inside of the collar as it would appear if straightened out; and D, the outside of the collar similarly unrolled. A groove is cut on the inside to receive the head of a screw projecting from the side of the nicol tube (*b b'*, fig. 3, B and C). On the opposite side of the tube, a lever (*c*) moves in the slot *a a''* (fig. 3, B), which is of such length that the distance between centers of the lever, in the positions *a' a''*, is just 90°. The screw head and the lever bar thus form the bearings to carry the nicol tube. As the lever is moved from *a'* to *a''*, the screw head *b* slides in the groove from *b* to *b'*. (As a matter of fact this groove was turned the entire circumference of the collar, for convenience of construction, though it is not so shown in the diagrams.) The nicol tube may be removed or inserted easily by slightly raising and rotating the tube until the lever bar passes over the projection at *a* (fig. 3, D).

In the microscope as purchased, the nicol is held in place by the pressure of a part of the tube between two saw cuts. Before attaching the collar, this pressure arm is cut off just above where the upper edge of the collar is to come, and the upper part is bent outward until only enough friction remains to hold the nicol in any position to which it may be turned. It is necessary to saw off the lower part of this section in order that the upper part may later, if necessary, be bent more or less to produce the proper amount of friction.   On a new instrument the cut would be made only above.   The collar is soldered on the tube so that the nicols are approximately crossed when the lever is set at 0°.   Accurate adjustment may later be made by rotating the prism within the tube.

In the Fuess microscope with rotating upper nicol, the vibration plane is at right angles to the direction of the lever, and the indicator points to 90° on the scale.   Consequently, the upper and lower scales have readings differing by 90° when the nicols are crossed, and have the same readings when they are parallel.

In using certain accessories it is sometimes necessary to place the ocular so that the cross hairs form angles of 45° with the vibration directions of the nicols.   With a microscope fitted as above, both nicols may be rotated to 45° and the ocular left in its normal position.

4. Additions to the Hirschwald stage.—Figure 4 shows two scales engraved upon the two parts of the Hirschwald stage. A mark on the sliding portion indicates the distance through which the plate has been moved.   Horizontal movement is

Fig. 4.

registered by a small scratch made with a diamond point on the lower margin of the thin section.   Any mineral, whose position is once registered, may again be located by resetting the stage to the former reading.   By reading first the vertical and then the horizontal scale, the stage setting shown in the diagram is indicated by the figures "1·5-2·0" (if the scratch on the slide is at the letter *a*).

The stage, as made at present, does not permit a high power objective to be brought close to a slide of normal thickness when the mineral is near either of the clamping bars (*b, b'*).   The bars should be beveled slightly at *a* and *a'*.   In a corresponding position on the under side, enough of the sliding stage should be cut away to permit the condensing lens to be carried against the slide at its edges as well as at the center.

The University of Chicago, February, 1910.
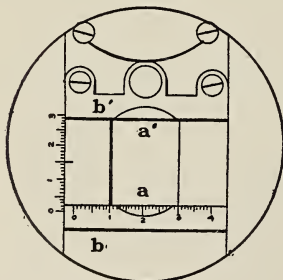
Art. XL. — *A Natural Naphtha from the Province of Santa Clara, Cuba;* by Clifford Richardson and Kenneth Gerard Mackenzie.

The occurrence of colorless naphtha as a natural product in Santa Clara is not new. It was first encountered August 18, 1881, in the western part of the Province near the town of San Jose de los Ramos, at a depth of 300 feet. Its special characteristics were, according to Salterain* : "It is colorless, transparent as the clearest water, easily inflammable, and leaves no sensible residue after its complete combustion; its density is 0·754; it boils at a temperature of 85°, dissolves asphaltum and resinous matter, and possesses the characteristics of naphtha." Sr. Manuel Cueto, the discoverer, reports that it was used with good success in the engine of a steam launch and as motive power for automobiles. About 20,000 gallons were obtained, but disasters, breaking of drills, etc., caused the enterprise to be abandoned, and the buildings were destroyed during the war. The wells were visited in 1902 by a Canadian driller. He reported that they were not producing, but that considerable gas was being evolved. Oil was found 300 feet down, which had a gravity of 61·6°B. The rock, through which the wells were drilled, was a limestone mixed with a black quartz. About 180 feet below the surface, a rock resembling serpentine was encountered.

The oil described in this paper comes from the same general locality, at a depth of 1560 feet. The overlying strata as shown by the drilling records were as follows:

Depth		Kind of Rock
18	feet	Red soil.
44	"	Yellow clay.
50	"	Hard black rock.
52	"	Flint, gravel and pyrite.
58	"	Loose bowlders.
80	"	Bowlders and gravel.
85	"	Pyrite.
88	"	Pyrite and sand.
94	"	White quartz.
96	"	Coral rock.
101	"	Sand.
108	"	Hard dark sand.
118	"	Pyrite.
124–128	"	Sand.
128–134	"	White limestone.

* U.S. Consular Report, vol. x, p. 75, 1883, cited by Wood, Civil Report of Military Gov. Cuba, Jan. 1, May 20, 1902, vol. v, pt. iii, p. 82.

Depth		Kind of Rock
134–154 feet		Black slate and white limestone.
166–176	"	*Green serpentine.*
176–194	"	Limestone and slate.
208–242	"	Black slate.
302	"	Soapstone.
347	"	Green serpentine.
425	"	Green serpentine and soapstone.
550	"	Dark slate.
565	"	Hard black "shells" and soapstone.
590	"	Soapstone and green serpentine.
670	"	Slate and soapstone.
680	"	Green serpentine, soapstone.
835	"	Slate and serpentine.
1109	"	Hard black slate and serpentine.
1187	"	Black "shells."
1560	"	

The rock is strikingly similar to that described by the Canadian driller. He found serpentine at 180 feet, in this well it first occurs at 166 feet. Furthermore in another well (No. 2) 45 feet N.E., serpentine was found at 183 feet. Likewise the black "shells" so often mentioned must be the black quartz referred to. Well No. 2 was carried only to 700 feet. Two gallons of naphtha were obtained at 580 feet but no more. The well described above gave a little gas at 467 feet, half a pint of naphtha at 700 feet, but no more till 1560 feet was reached.

Much water is obtained with the naphtha, the relative proportions being (average of 17 drawings).

$$\text{Oil} \ldots \ldots \ldots \ldots \ 72 \cdot 5\% \text{ by volume.}$$
$$\text{Water} \ldots \ldots \ldots \ 27 \cdot 5\%$$

The oil figure includes a substance which the driller spoke of as "paraffin," and which will be referred to later as "emulsion."

The naphtha was of a very pale yellow color, and deposited on long standing, a slight, light brown sediment. It had :

$$\text{Specific gravity, Westphal} \ldots \ldots 15 \cdot 6° \qquad 0 \cdot 732$$
$$N_D 25° \ldots \ldots \ldots \ldots 1 \cdot 4092$$

It gave a fire test below 0°.

An Engler distillation gave :

TABLE I.

Engler Distillation, Cuban Oil.

Temperature	% Wt.	Sp. gr. 15·6°	Sp. gr. 20°/20°	$N_D 25°$
−75°	3·5	----	----	1·3900
75°–100°	18·9	0·72	----	1·4002
100°–125°	51·3	0·739	0·7372	1·4094
125°–150°	18·4	0·75	0·7497	1·4166
150°–160°	1·2	----	----	1·4242
Residue	2·1	----	----	1·4492

By way of comparison, two naphtha distillates from California petroleum, and samples of 62° and 88° naphtha obtained in open market, were distilled.

TABLE II.

Engler Distillation of California Naphtha Distillate.

Marked "64·7°"

Sp. gr. Westphal _____ 15·6°   0·722
N$_D$25° _____ 1·4062

Temperature	% Wt.	Sp. gr. 15·6°	N$_D$25°
−50°	1·5	----	1·3750
50°−75°	19·4	0·660	1·3814
75°−100°	23·2	0·716	1·3987
100°−125°	24·9	0·756	1·4139
125°−150°	9·8	0·774	1·4261
Residue	6·0	0·808	1·4480

TABLE III.

Engler Distillation of California Naphtha Distillate.

Marked " 64·5° "

Sp. gr. Westphal _____ 15·6°   0·732
N$_D$25° _____ 1·4141

Temperature	% Wt.	Sp. gr. 15·6°	N$_D$25°
−50°	0·5	----	1·3752
50°−75°	13·5	0·678	1·3818
75°−100°	32·8	0·716	1·3987
100°−125°	24·6	0·740	1·4141
125°−150°	12·3	0·768	1·4270
Residue	5·9	0·810	1·4500

TABLE IV.

Engler Distillation of Commercial 88° Naphtha.

Sp. gr. Westphal _____ 15·6°   0·651
N$_D$25° _____ 1·3695

Temperature	% Wt.	Sp. gr. 15·6°	N$_D$25°
−50°	47·7	0·609	1·3605
50°−75°	29·2	0·65	1·3756
75°−100°	6·8	0·70	1·3930
Residue	1·4	----	1·4061

TABLE V.

Engler Distillation of Commercial 62° Naphtha.

Sp. gr. Westphal _____ 15·6°   0·732
N$_D$25° _____ 1·4106

Temperature	% Wt.	Sp. gr. 20°/20°	$N_D25°$
−50°	----	----	----
50°–75°	1·2	----	1·3830
75°–100°	20·0	0·7029	1·3956
100°–125°	51·9	0·7286	1·4061
125°–150°	24·6	0·7462	1·4168
Residue	9·2	----	1·4282

Practically all of the Cuban oil comes over between 75°–150°, half between 100°–125°. The California naphthas boil somewhat lower, a much larger part coming over 50°–100°. The 88° naphtha boils, of course, very much lower, but the 62° naphtha shows almost an identical composition by distillation, the fraction 125°–150° alone being larger.

Of the original oils, California 64·5°, 62°, and the Cuban oil have the same gravities, though the California index of refraction is higher than the other two.

A comparison of the different fractions is interesting. The first found in all is 50°–75°. The Cuban oil has the highest refractive index. The two California naphthas and the 66° are close together, while the 88° naphtha is lowest. In the portion 75°–100°, the Californias are nearly equal to the Cuban, while 62° and 88° are respectively lower. The gravities do not differ materially, but are in the same order from Cuban to 88°. Fraction 100°–125° shows a slight variation. 62° and 88° indices are equal and lowest, Cuban is next, with California highest. The gravities do not reveal anything, running Cal.–Cuba–Cal.–62°. The highest fraction, 125°–150°, gives similar constants for the Cuban and 62° naphthas, higher for the California.

It is hard to make a general summary of these comparisons. The Cuban oil boils identically with 62° naphtha, but higher than the California naphtha. The indices of refraction and specific gravities of its fractions are nearest those of 62° naphtha, but not as high as California naphtha.

The action of reagents on the original oils was as follows:

	Removed by 10% NaOH	33% H_2SO_4	Conc. H_2SO_4	Fuming H_2SO_4
Cuban oil	----	----	0·76%	1·8%
" fraction 145°–	----	----	0·2 %	2·5%
Cal. naphtha "64·5°"	2·0%	2·9%	3·6 %	2·9%
62° naphtha	1·3%	----	1·3 %	2·5%

The refractive indices in each case were not materially changed.

The Cuban oil has practically no unsaturated compounds, even the 62° naphtha showing more action with acid, while the

California naphtha, besides 3 per cent nitrogen bases, has 6·5 per cent unsaturated hydrocarbons.

The California petroleums do not contain hydrocarbons of the series $C_n H_{2n+2}$.[*] The source of the 62° naphtha cannot be determined, but it in all probability contains both paraffins and naphthenes. The Cuban oil evidently is not composed entirely of naphthenes, which are characterized by higher gravity and index of refractions, nor yet of paraffins.

To further investigate its composition, a fractional distillation was made, with an 18-column Young dephlegmator condensing with an ice-salt mixture.

TABLE VI.

Fraction Distillation Cuban Oil.

Temperature	%	Specific gravity	$N_D 0°$	$N_D 25°$
−30°	1·6	0·589 0°/4 °	1·3706	----
30°–35°	0·5	----	1·3703	----
35°–50°	0·3	----	1·3772	...
50°–65°	1·0	----	1·3905	----
65°–75°	3·6	0·685	1·3975	1·3860
75°–85°	3·8	0·7266 20°/20°	1·4140	1·4020
85°–95°	6·8	0·7270	1·4155	1·4032
95°–105°	19·2	0·7308	1·4172	1·4061
105°–115°	7·2	0·7387	----	1·4112
115°–125°	17·2	0·7392	----	1·4121

Using a 4-bulb Hempel fractionator.

125°–135°	6·8	0·7477	----	1·4162
135°–145°	7·2	0·7517	----	1·4181
Residue	8·1	0·7768	----	1·4302

Fraction −30°. Sp. gr. 0·589 (0°/4°), $N_D 0°$ 1·3706. n-Butane boils at 1°, tetramethylmethane at 10°; dimethylethylmethane at 30°, with sp. gr. 0·6385 (14°). This fraction must be composed of paraffin hydrocarbons as must also

Fraction 30° − 35° $N_D 0°$ 1·3703
Fraction 35° − 50° $N_D 0°$ 1·3772 ; calc. $N_D 25°$ 1·365

n-Pentane boils at 38° and has a refractive index of 1·3649; trimethylethylmethane boils at 49·6° and $N_D 25·5° = 1·3602$. This fraction also, by its index, is composed only of paraffin hydrocarbons.

Fraction 50° − 65°. $N_D 0°$ 1·3905; calc. $N_D 25°$ 1·379. Di-iso-propyl boiling at 58° has $N_D 25° = 1·3648$. The index here is slightly high for pure paraffins.

Fraction 65° − 75°. Sp. gr. 0·685 (0°/4°), $N_D 25° = 1·3860$.

[*] Richardson, VI International Congress of Applied Chemistry, iv-a, 243.

n-Hexane boils at 71°,[*] sp. gr. 0·6630 (17°) $N_D20°$ 1·3734; methylpentamethylene[†] boils at 71°, sp. gr. 0·7474 (21°/4°), $N_D20°$ 1·4101. This fraction consists almost entirely of n-hexane with a small amount of methylpentamethylene.

Fraction 75°−85°. Sp. gr. 0·7266 (20°), $N_D25°$ 1·4020. Here, also, we probably find n-hexane and methylpentamethylene and also hexamethylene boiling at 81°,[‡] sp. gr. 0·7771 (15°)[§] $N_D18°$ 1·42897.[||]

Fraction 85°−95°. Sp. gr. 0·7270, $N_D25°$ 1·4032. Ethylisoamyl[¶] boils at 90·5°, sp. gr. 0·6819 (17·5); 1, 3, dimethylcyclopentane[**] boils at 91°, sp. gr. 0·7410 (24°/4°), $N_D18°$ 1·4253. Evidently contains both paraffins and naphthenes.

Fraction 95°−105°. Sp. gr. 0·7308 (20°), $N_D25°$ 1·4061. n-Heptane boils 98·4°,[††] sp. gr. 0·6886 (15°),[‡‡] $N_D20°$ 1·3854;[§§] methylcyclohexane[||||] boils 103°, sp. gr. 0·7662 (18·5°/4°), $N_D19°$ 1·4243.[¶¶] Paraffins and naphthenes both are present.

Fraction 105°−115°. Sp. gr. 0·7387 (20°), $N_D25°$ 1·4112.

Fraction 115°−125°. Sp. gr. 0·7392 (20°), $N_D25°$ 1·4121. n-Octane boils 125·5°,[***] sp. gr. 0·7020 (20°),[†††] N_D 1·3943;[‡‡‡] two unknown octanes described by Mabery and Hudson[§§§] boil at 119·5° and 124°−125°, and have gravities (20°) of 0·7243 and 0·7134; octonaphthene[||||||] boils at 119°, sp. gr. 0·7503 (18°) $N_D20°$ 1·4234;[¶¶¶] isooctonaphthene[****] boils at 124°, and has sp. gr. 0·7637 (17·5°). The percentage of naphthenes in each fraction seems to increase with the temperature. In this fraction, nearly equal amounts of paraffins and naphthenes are present.

Fraction 125°−135°. Sp. gr. 0·7477 (20°), $N_D25°$ 1·4162. β−Nonane[††††] boils 129·5°, sp. gr. 0·725 (24·7°); nonanaphthene[‡‡‡‡] boils 135°−136°, sp. gr. 0·7667 (20°/0°). Here also is a mixture of the two classes of hydrocarbons.

Fraction 135°−145°. Sp. gr. 0·7517 (20°), $N_D25°$ 1·4181. a−Nonane[§§§§] boils 135°−137° and has sp. gr. 0·742 (12·4°).

From these constants we can see that the lower boiling hydrocarbons are of the paraffin series while those coming over

[*] Engler and Routala, Ber. xlii, 4615.   [†] Engler and Routala, loc. cit.
[‡] Fortey, J. Chem. Soc., lxxiii, 932.   [§] Fortey, loc. cit.
[||] Engler and Routala, loc. cit.   [¶] Schorlemer, Ann., cxxxvi, 259.
[**] Engler and Routala, loc. cit.
[††] Francis, Young, J. Chem. Soc., lxxiii, 921.
[‡‡] Thorpe, Ann., cxcviii, 364.   [§§] Engler and Routala, loc. cit.
[||||] Knoevenagel, Ann., ccxcvii, 159.   [¶¶] Zelinsky, Ber., xxviii, 1022.
[***] Thorpe, J. Chem. Soc., xxxvii, 217.   [†††] Engler and Routala, loc. cit.
[‡‡‡] Engler and Routala, loc. cit.   [§§§] Am. Chem. J., xix, 255.
[||||||] Engler and Routala, loc. cit.   [¶¶¶] Knoevenagel, loc. cit.
[****] Engler and Routala, loc. cit.
[††††] Lemoine, Bull. Soc. Chem., Paris, xli, 164.
[‡‡‡‡] Konowalow, J. Russ. Chem. Ges., xix, 255.
[§§§§] Lemoine.

at higher temperatures contain increasing percentages of naphthenes, approximately equal amounts being finally found.

It has already been mentioned that with the naphtha, a substance was obtained which was described by the driller as paraffin. It was a grey substance, somewhat gelatinous, and similar in appearance to an oil emulsion. Its composition was found to be :

Oil _____ 81%
Water _____ 14%
Clay _____ 5%

in the form of an emulsion.

The oil had a

Sp. gr. Westphal 15·6°_____ 0·738
$N_D25°$ _____ 1·4100

Distillation Engler.

Temperature	%	15°	Sp. gr. 20°/20°	$N_D25°$
−75°	0·4	----	----	1·4045
75°−100°	18·0	0·72	0·7217	1·4006
100°−125°	56·4	0·74	0·7372	1·4090
125°−150°	18·4	0·75	0·7500	1·4161
Residue	3·4	----	----	1·4499

This oil is practically identical with the clear naphtha, except for a slightly higher gravity. It was more deeply colored and had a larger amount of brown sediment.

Action with reagents. Oil from emulsion. Removed by

Soda _____ ·6%
Concentrated acid_____ 1·5%
Fuming acid _____ 0·0%

The water had 2·31 per cent total solids.

The clay, which was gray, lost 15·7 per cent on ignition, the iron being oxidized. It was submitted to the Office of Public Roads, Washington, D. C., and an examination by Dr. Lord showed that the indurated material consisted essentially of highly decomposed fragments of a ferruginous rhyolitic glass and rounded grains of bitumen cemented together by chalcedonic silica and an indefinite hydrated silicate. The clay is composed of the secondary products resulting from the decomposition of the rhyolite, with some bitumen grains and fragments of undecomposed glass.

The emulsion is of the greatest interest.

Gilpin and Cram have shown* that when petroleum is allowed to rise in a tube packed with fuller's earth, a fractionation

* Am. Chem. J., xl, 495. This property was first pointed out by Day, Proc. Am. Philos. Soc., xxxvi, 154.

results, the fraction at the top of the tube has a lighter gravity than that at the bottom, and that the saturated hydrocarbons come to the top while the unsaturated are lower. Also when water is added to the fuller's earth containing the petroleum, the oil is displaced, but about one-third of the oil remains in the earth.

Day and Gilpin* have carried this work further and have obtained similar results with clay. They have pointed out its application to the accumulation of petroleum in different places.

We have in this Cuban oil an exact confirmation of these experiments by nature. It will be remembered that from the oil well there was obtained naphtha, water and emulsion. The history of this naphtha may be very briefly told. At some depth, considerably below 1500 feet, a crude petroleum filtered up through this rhyolitic clay,† the upper part of the clay stratum by fractionation containing the lightest naphtha. Saline waters then came in contact with this upper clay layer, displacing two-thirds of the oil contained in it and forming with it the emulsion. In Trinidad asphalt, as shown by one of us,‡ we have an exactly similar case of a permanent emulsion of bitumen, water and mineral matter.

To summarize briefly, we have examined a naturally occurring white naphtha from the province of Santa Clara, Cuba. It occurs at a depth of 1560 feet in black quartz and green serpentine with water and an emulsion of oil, water and rhyolitic clay. It contains practically no unsaturated hydrocarbons, but a mixture of paraffins and naphthenes. Over 50 per cent distills between 100°–125°, and very little above 150°. It was undoubtedly formed by the upward filtration of a heavy petroleum through the clay stratum, similar to the fuller's earth filtrations of Gilpin and Cram, and the light naphtha in the upper part of the stratum was afterwards partly liberated by saline waters, the oil remaining in the clay forming with water the emulsion.

Our thanks are due to Mr. L. W. Page of the Office of Public Roads for the examination of the clay, and to the Cuban American Sugar Company, the owners, for permission to publish these results.

* Ind. Eng. Chem., i, 449.
† It may be stated that the drillers are confident of finding a heavy petroleum at greater depths.
‡ Richardson, Proc. Am. Soc. Test. Mat., vi, 509.

ART. XLI.—*Intrusive Granites and Associated Metamorphic Sediments in Southwestern Rhode Island;* by G. F. LOUGHLIN.

INTRODUCTION.

Studies in southeastern Connecticut and southwestern Rhode Island have convinced the writer that all the granites in this area are parts of one composite batholith, and that this batholith is not of pre-Cambrian age, but is intrusive into rocks that have been mapped as Carboniferous. A detailed report on the southeastern Connecticut portion was completed about two years ago, and is awaiting publication by the United States Geological Survey.[*]

The present paper expresses the results of reconnaissance work from the Connecticut–Rhode Island boundary eastward to the vicinity of Narragansett Basin and of more detailed study along the western border of the Basin—here designated the Kingstown area.

Bibliography.—The granites of the area studied have been mentioned in a few publications, but their ages and structural relations have seldom received close attention, especially at critical points. C. T. Jackson, in 1840, mapped the granite as "Primary"[†] and the sediments of the Narragansett Basin as "transition graywackes" derived from the Primary. In 1899, Shaler, Woodworth, and Foerste published "The Geology of the Narragansett Basin, R. I."[‡] Shaler and Foerste, who worked in the area under discussion, gave little attention to the granites bordering the Basin. They regarded them as Algonkian and distinct from the pegmatite dikes that cut the Carboniferous strata of the Basin. The latest geological map of North America[§] represents the granite as pre-Cambrian.

[*] Contributions to Geology of Eastern Connecticut.
[†] Geol. and Agricult. Surv. of the State of R. I., 1840.
[‡] U. S. Geol. Surv., Mon. XXXIII, 1899.
[§] Bailey Willis, Geol. Map of No. America, 1906.

B. K. Emerson and J. H. Perry * in 1907 described and mapped the formations along the western border of the Narragansett Basin. The southern end of their area overlaps the northeast corner of the area here discussed, but no contacts are there exposed. They also mapped the granite as pre-Cambrian (fig. 1 of this paper).

Résumé of Evidence in S. E. Connecticut.

As the writer's work here described has been essentially a continuation of his studies in southeastern Connecticut, a summarized statement of the character and relations of the granite and adjacent metamorphic sediments in that area is here given to serve as a basis for correlation.† A portion, also, of the map is copied (fig. 1, west of long. 71° 45′ and north of lat. 41° 25′).

The metamorphic sedimentaries shown in the map are a quartzite (Plainfield quartz-schist) and a more extensive quartz-biotite-schist, more or less feldspathic (part of the Putnam gneiss series). These, and closely related metamorphics not shown in the map are characterized by the general predominance of plagioclase wherever feldspar is present. The composition of the plagioclase ranges from Ab_3An_1 to Ab_1An_1. They are possibly of Carboniferous age.

The granite—Sterling granite series—mostly of pink color and gneissoid structure, includes three varieties : normal biotite-granite, porphyritic biotite-granite, and alaskite. The alaskite is known to cut the other two varieties, but all gradations in composition and texture appear. All the varieties are intrusive into the sedimentary series. Pegmatite and aplite, in sheets and dikes, cut the granite series, and are abundant in the metamorphic sediments. The granite series is characterized by a well-developed microline, in some cases microperthitic, white oligoclase, or albite, and some quartz.

The relation of the micro-textures of the granites to regional metamorphism has been treated at some length in the original paper, with the conclusion that the normal and porphyritic types were intruded and crystallized while the disturbing forces were most active, and that the alaskite became solid during the waning stage of regional movement. This relation, if the sedimentary series includes Carboniferous rocks, correlates the time of metamorphism and intrusion with that of the Appalachian Revolution. The question of age will be furthur considered towards the end of this paper.

* The Green Schists and Associated Granites and Porphyries of Rhode Island, U. S. G. S. Bull. 311, 1907.
† By permission of the Director of the U. S. Geol. Survey.

Evidence at Westerly and Niantic, R. I.

The writer during the past six years has made several visits to the Westerly, R. I., granite quarry district along the southern part of the Connecticut boundary, and one visit to the neighboring and similar district of Niantic, R. I. (fig. 1) He finds at these places the above summarized evidence duplicated and supplemented by a later intrusion—that of the Westerly granite. Metamorphic sediments here appear only as isolated inclusions in granite. Both the sediments and the Sterling granite series are cut by dikes of the fine-grained Westerly granite (quartz-monzonite according to Dale).* The latter rock has the same mineralogic characters as the Sterling granite, differing only in containing a higher percentage of plagioclase. Its contact phase and apophyses are medium-grained to pegmatitic, and cannot be distinguished in the specimen from the Sterling granite series. The contacts of the Westerly with the Sterling granite are sharp, but the close petrographic resemblance between the two rocks and the absence of any evidence indicative of widely different age favor the interpretation that the Westerly granite is not a type independent of the Sterling granite series, but the latest exposed phase of the same batholith.

Reconnaissance Eastward to the Kingstown Area.

Two reconnaissance traverses have been made across southwestern Rhode Island, one extending from the southeastern Connecticut area eastward to Wickford Junction, the other from Hope Valley southward to Niantic and thence eastward, in a zigzag course, to Wakefield (fig. 1). The outcrops visited are plotted on the map. Those along the first, or northern, traverse are identical in character with the normal gneissoid Sterling granite, save one outcrop of the porphyritic type a mile west of Millville. The normal type is disintegrated to a considerable extent, a characteristic feature in parts of southeastern Connecticut, and some outcrops are completely reduced to a coarsely granular soil to a depth of six feet or more.

Short veins of pegmatite and pegmatitic quartz, from less than an inch to one foot in width, are commonly present, most of them cutting across the schistosity of the granite. One small dike of fine-grained granite, similar to the Westerly type, was noted on the southward sloping ridge $1\frac{1}{4}$ miles east of Pine Hill. No inclusions of the metamorphic sediments were found.

A glance at the map will show that no outcrops were found along the eastern three miles of the traverse; but over 99 per

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* Dale, T. N., The Chief Commercial Granites of Mass., N. H. and R. I. Bull., U. S. G. S., No. 354, 1908, pp. 190 et seq. The reader is referred to this Bulletin for structural and petrographic details.

cent of the abundant bowlders in these three miles, and in fact along the whole traverse, are of the normal gneissoid Sterling granite, and it is the writer's experience that the majority of bowlders in southern New England are of strictly local origin. The granite therefore is believed to be continuous from the Connecticut boundary to the edge of the Narragansett Basin, $1\frac{1}{2}$ miles west of Wickford Junction, but the relations there between the granite and the rocks of the Basin are concealed by drift.

The eastern part of this traverse overlaps a small part of the area mapped by Emerson and Perry as a southward continuation of the pre-Cambrian Northbridge gneiss of Massachusetts. The thorough concealment of all contact relations renders it impossible at this point to choose between the conclusion of the authors cited and that of the writer. Evidence supporting the writer's views will be presented in the description of the Kingstown area.

Evidence along the southern traverse is not quite so inconclusive as that just presented. The granite outcrops are all of the Sterling types, chiefly the normal and to some extent the porphyritic. Two small dikes of the Westerly type were noted; one a mile south of Plainfield, the other on the summit of Shumunkanug Hill. No outcrops were found along the eastern six miles of the traverse, but here again practically all the bowlders are of the Sterling granite.

Exposed inclusions of the metamorphic sediments are very scarce and only one deserves mention. This one lies in the road on the hill a mile west of Worden's Pond (see map, fig. 1). Its texture is pseudo-porphyritic with flattened, lens-shaped pebbles of quartz-schist, but the matrix is identical in color and texture with the quartz-biotite schist exposed in southeastern Connecticut and at Westerly. It is also similar to the most severely metamorphosed conglomerate in the Kingstown area. It is cut by a narrow pegmatite dike of the Sterling (or Westerly) type. This evidence though limited proves that the age relations found in Connecticut and at Westerly exist as far east as Worden's Pond.

The Kingstown Area.

The limits of the Kingstown area are shown in fig. 2. It includes the west boundary of the Narragansett Basin sediments from Hamilton southward, and has yielded decisive evidence for determining the relative ages of the rocks in question. The area was studied and mapped in detail by Messrs. Y. S. Bonillas and V. M. Frey under the writer's direction.*   The

* MS. thesis No. 340, 1908, Min. Dept. Mass. Inst. Tech., Boston, Mass.

Fig. 1.

Fig. 1. Geologic map of S. W. Rhode Island and S. E. Connecticut. Detailed mapping is expressed only in the eastern and western portions of the area. Only outcrops seen by the writer are shown in the central portion, which is believed to consist essentially of the Sterling granite.

writer has not visited every outcrop in the area, but has studied the continuous exposures along the shore of the Bay, and all the exposed granite contacts, and has examined thin sections of the several rock types represented.

Granite.—The various granite exposures include types identical in texture, mineral composition, and structural relations with the several members of the Sterling series (including the Westerly granite). These types and their relations to one another are perfectly shown in the continuous granite ledge which extends along the shore of the Bay from Narragansett Pier for two miles southward. There is, in addition to the types previously mentioned, a pegmatitic muscovite granite which, as will be shown presently, is a contact phase of the Sterling batholith, and is transitional into those pegmatites which were previously interpreted as post-Carboniferous.[*] Muscovite variations are present in the areas previously described, but only in the Kingstown area are they conspicuous and important. The feldspars of the muscovite granite are the same in character and composition as those of the other types. Schist inclusions are found in all the granite types.

Normal and porphyritic Sterling granite, moderately to highly gneissoid, are the prevailing types in the Kingstown area. They comprise the body of the two-mile exposure along the shore, and are exposed to the north on Rose, McSparren, and Hammond Hills. Exposures are few at intervening points, but are of the same types of granite. Small pegmatite dikes, more or less muscovitic, are of common occurrence. The northern part of this area also overlaps the southern limits of the area previously mapped as pre-Cambrian (see p. 448); but here again, owing to the general lack of local evidence, it is impossible to choose between the differing interpretations. Weathered schist inclusions are found on McSparren Hill, but the presence of these alone is not convincing evidence.

Definite evidence, however, is afforded east of Wakefield, at the bend of Indian Run, in an exposed contact with quartz-biotite schist, the metamorphic sediments of the Narragansett Basin. The granite a short distance from the contact is red, distinctly gneissoid, and irregularly porphyritic. Both its megascopic and microscopic characters are identical with those of the Sterling granite types of Connecticut. As the contact is approached, the gneissoid character is obscure or absent, and pegmatitic segregations are numerous. Distinct dikes of pegmatite are also present, cutting the granite. The adjacent schist is penetrated by many pegmatitic apophyses, most of which follow the foliation plains.

A mile eastward, along the southeast slope of Tower Hill,

[*] U. S. G. S. Mon. XXXIII, p. 377.

Fig. 2.

Fig. 2. Detailed geologic map and sections of parts of North and South Kingstown, R. I., along the western border of the Narragansett Basin. Boundaries actually exposed or definitely located are represented by solid lines; indefinite boundaries by dotted lines. The dotted lines in the sections indicate the unexposed surfaces of bed rock.

are excellent exposures of granite apophyses following and cutting across the foliation of the schist. The apophyses are medium-grained to pegmatitic, slightly to highly muscovitic, and of red to white color. The white color is more pronounced in the more highly muscovitic rock. The pegmatitic and muscovitic characters are best developed in the large dikes (fig. 2), which cut approximately at right angles to the foliation of the schists. These dikes, or large apophyses, are exposed at intervals along Tower Hill towards Bridgetown.

Excavations in a graphitic bed of the schist, between one and two miles south of Bridgetown, have exposed pegmatite dikes and associated quartz veins. The graphitic rock is also cut by small, branching, fibrous veins composed chiefly of sillimanite, quartz, and muscovite. These veins are believed to be genetically associated with the pegmatite, but no careful study has yet been given them in connection with the problem under discussion.

Similar, and even more convincing, evidence is found along the shore of the Bay from Little Neck northward to Hazzard's quarry. The muscovitic granite with schist inclusions is the prevailing rock on Little and Boston Necks. It is increasingly muscovitic and pegmatitic as the contact with the schists is approached. At Watson's Pier schist, cut by many large dikes of the granite and pegmatite, is the prevailing rock. Large pegmatite dikes are numerous along the coast as far as the north end of the Bonnet, and outcrop at intervals as far north as Saunderstown. From this point northward, pegmatite dikes are scarce, and the northernmost exposure seen is at Hazard's quarry. Here is a small dike consisting chiefly of quartz with a little feldspar and practically no mica. A few quartz veins with rare feldspar crystals, exposed near the summit of Barber's Heights, are the northernmost pegmatitic exposures found. The evidence in the Kingstown area, therefore, appears conclusive that the granites bordering the metamorphosed Narragansett Basin sediments are members of the Sterling batholith and are intrusive into the schists. Petrographic study proves that the pegmatite dikes on Tower Hill and along the shore of the Bay are not independent intrusions, but apophyses from Sterling batholith, tending to grade into quartz veins as the distance from the batholith increases. Evidence in the whole area studied has proved that the granites of southwest Rhode Island, south of the Washington Co.– Kent Co. boundary (fig. 1) are not of pre-Cambrian age as previously supposed, but belong to the Sterling batholith, the youngest formation (including the Westerly granite dikes) of the area.

Time of Intrusion.—The details of metamorphism in the

Kingstown area have not been exhaustively studied, but it is very evident, from the field work done, that vertical dips and the most complete recrystallization of the sediments are found where granitic intrusions are most abundant. There seems, then, no reason for doubting that in the Kingstown area, as well as in southeastern Connecticut, the granite intrusion accompanied metamorphism and folding. As the Kingstown sediments have been determined to be of Carboniferous age,[*] the time of granite intrusion and folding may be correlated with the Appalachian Revolution.

The Kingstown Sediments.—As the Kingstown sediments have heretofore been regarded as resting uncomformably upon the granite, a study of their composition is necessary for a complete solution of the problem here considered, and as a check on the conclusions already reached. Detailed descriptions of outcrops have been made by Foerste,[†] and only petrographic evidence is considered here.

The sediments comprise chiefly an alternating series of light to dark gray arkose, conglomerate and phyllite beds, with at least one highly graphitic bed. Metamorphism effects are everywhere distinct, varying from moderate around Hamilton, the northernmost point studied, to extreme in close proximity to granite contacts. In the latter case traces of clastic structure are nearly, or quite, obliterated, and the rocks are typical gray gneisses and schists, penetrated by the reddish granite.

The pebbles of the less metamorphosed conglomerate comprise quartzite, quartz-sericite schist, black very fine-grained slaty schist, vein-quartz, felsite-porphyry, a fine even-grained granite. The granite pebbles, which do not resemble the Sterling or Westerly granite, will be separately described below. In the highly metamorphosed conglomerate, the pebbles appear as flattened lenses and even linear streaks. Only the less severely mashed are clearly recognizable. The arkose and the matrix of conglomerate consist of quartz, feldspar, biotite, and muscovite in varying amounts. The most metamorphosed exposures present the same general megascopic characters and variations as the quartz-biotite schist of southeastern Connecticut. Thin sections prove the feldspars to be mostly plagioclase with a few of poorly defined microperthite and, possibly, of orthoclase. Not a feldspar grain was noted with the well-developed microcline twinning so characteristic of the feldspar in the Sterling and Westerly granite, save in the one instance, $1\frac{1}{4}$ miles south of Narragansett Pier, of a schist inclusion which is thoroughly injected with dikelets and stringers from the granite.

[*] Mon. XXXIII, U. S. G. S., plate xxxi.
[†] Op. cit., pp. 215 et seq.

Granite Pebbles.—The granite pebbles in the conglomerate are light gray to pink, fine even-grained to sub-porphyritic, and consist of finely intergrown quartz and feldspar with a little biotite and muscovite. Three thin sections were studied; one of a pebble from an outcrop 1½ miles west of Wickford Junction (fig. 1), one from an outcrop ¼ mile southeast of Hamilton, and one from a bowlder south of McSparren Hill. The three thin sections present the same characters. The texture is conspicuously micrographic. The primary minerals are plagioclase and microperthite in about equal amounts, quartz, biotite, and the usual minor accessories; the chief secondary minerals are muscovite, replacing feldspars, and chlorite replacing biotite. The microperthite is the same type as that noted in the arkose and conglomerate matrix. The plagioclase mostly corresponds to oligoclase-andesine, though some grains appear more basic. These characters suffice to point out the decided lack of resemblance to the Sterling granite.

Derivation and Correlation of the Kingstown Sediments.— The composition of the Kingstown sediments thus verifies the conclusions already stated, and no evidence whatever remains to indicate that the Sterling granite is not the younger rock. The Kingstown sediments were derived from a series of quartzites and black slaty schists, felsite-porphyry, and igneous rocks containing considerable plagioclase. The plagioclase may come wholly or in part from the fine-grained granite and possibly in part from more basic igneous rocks, no pebbles of which have yet been found. None of these rocks are found within the area studied, but they may be represented in the Cambrian formations and the granite-porphyries to the north.*

The general similarity in mineral composition between the Kingstown sediments and the quartz-biotite schists of the southeastern Connecticut and the Westerly–Niantic, R. I., districts favors the correlation of these rocks as parts of one extensive formation. Fossil evidence in the areas studied is wholly lacking, but structural and petrographic evidence favors this provisional conclusion.

Summary.

The principal conclusions reached in this paper are as follows:

1. The Westerly granite is closely related to the Sterling granite in general character and mineral composition, and is considered the latest exposed phase of the Sterling batholith.

2. The Sterling granite batholith is continuous from eastern Connecticut to Narragansett Bay, R. I., and includes granite formerly thought to be pre-Cambrian. There are no

* Emerson and Perry, op. cit., pl. 1.

pre-Cambrian rocks in Rhode Island south of the Washington Co.–Kent Co. boundary.

3. The Sterling granite batholith is intrusive into all the sediments with which it is in contact, including the Kingstown sediments of the Narragansett Basin, and its intrusion accompanied metamorphism and folding.

4. Since the Kingstown sediments are said to be of Carboniferous age, the time of the granite intrusion, metamorphism and folding may be correlated with that of the Appalachian Revolution.

5. The Kingstown series were derived principally from metamorphic rocks of possible Cambrian age, from felsite-porphyry, fine-grained micrographic granite, and possibly more basic igneous rocks.

6. In the absence of fossil evidence, structural and petrographic data favor provisional correlation of the Kingstown sediments with the quartz-biotite schists found in southeastern Connecticut and at Westerly and Niantic, R. I.

Massachusetts Institute of Technology.

SCIENTIFIC INTELLIGENCE.

I. CHEMISTRY

1. *Metallic Zirconium.*—WEISS and NEUMANN have succeeded in preparing fused zirconium in a pure condition. The metal has been previously known only as an impure powder, or containing much carbon when fused. This difficult operation was performed, after many failures, by compressing the powder into pencils and passing an electric arc from the end of one pencil to another, either in a vacuum furnace containing hydrogen under very low pressure, or in the same apparatus containing an atmosphere of nitrogen or ammonia. The upper pencil, forming the positive pole, was fused and the metal dropped upon the lower electrode, forming a stalagmite-like mass which was sometimes 3 or 4^{mm} in diameter and 2 or 3^{cc} high. The light produced at the melting point was so intense that the eyes had to be protected by very dark glasses when the operation was watched through the window of the apparatus. The fused zirconium was somewhat tarnished, but the fracture was white and metallic like cast iron. It was slightly harder than quartz, and decidedly less hard than Moissan's product containing carbon. It was very brittle, with a specific gravity of 6·400. The specific heat was found to be 0·0804, a value considerably higher than any previous determi-

nation and giving an abnormal atomic heat, 7·316. It burns in air, and the average heat of combustion was found to be 1958·7 cal.—*Zeitschr. anorgan. Chem.*, lxv, 248.   H. L. W.

2. *The Gas-volumetric Determination of Hydrogen.*—Heretofore no liquid reagent has been known for the absorption of hydrogen in gas analysis, but PAAL and HARTMANN have found such a reagent which can be used with accuracy in technical gas analysis, and which can be employed also for removing hydrogen from certain gases in preparative work. The reagent is a solution of colloidal palladium and sodium picrate. The metallic palladium first absorbs the hydrogen, then immediately acts as a catalytic agent by transferring the hydrogen to the sodium picrate and reducing the latter to triamidophenol :

$$C_6H_2(NO_2)_3OH + 18H = C_6H_2(NH_2)_3OH + 6H_2O.$$
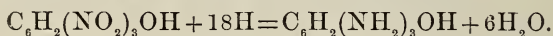
The absorption requires a little time, depending upon the amount of palladium present in the liquid. Experiments with various mixtures showed that accurate results could be obtained by the method. Since the reagent effects the combination of hydrogen with oxygen if both are present, and as it also causes the combination of hydrogen with unsaturated hydrocarbons, the procedure required in ordinary gas analysis is the application of the reagent after the carbon dioxide, unsaturated hydrocarbons, oxygen and carbon monoxide have been removed by the usual methods.— *Berichte*, xliv, 243.   H. L. W.

3. *Theoretical Principles of the Methods of Analytical Chemistry ;* by M. G. CHESNEAU, translated by A. T. Lincoln and D. H. Carnahan. 8vo, pp. 184. New York, 1910 (The Macmillan Company).—In its general object this book is similar to Ostwald's well-known work on the subject, but instead of advocating the theory of ions, the present author employs what he calls a calorimetric method for explaining certain reactions. He admits that Ostwald's plan is certainly more attractive *à priori* than the calorimetric method, but he objects to the electrolytic theory, and gives an extensive discussion of the objections, based chiefly on the work of Kahlenberg. Teachers of analytical chemistry, as well as advanced students, will doubtless find much that is suggestive and interesting in the book, particularly if they prefer the mathematical form of discussion.   H. L. W.

4. *Analyse Volumétrique ;* par LOUIS DUPARC et MARIO BASA- DONNA. 8vo, pp. 170. Geneva and Paris, 1910 (Kündig, Geneva; Felix Alcan, Paris).—This theoretical and practical manual of volumetric analysis has been prepared particularly for the purposes of laboratory instruction, but it is intended to be useful also to the practical analyst. It contains concise and clear descriptions of many of the best known and most frequently employed methods, including a number of special technical processes. Although it is not an exhaustive treatise on volumetric analysis, it will be found useful and suggestive in regard to some of the methods described. It has the fault of many French books in

lacking an alphabetical index, and since the subject matter is arranged according to general methods, and not according to the elements to be determined, it is not a convenient book for reference. H. L. W.

5. *Solid Bitumens,* by S. F. PECKHAM. 8vo, pp. 317. New York and Chicago, 1909 (The Myron C. Clark Publishing Co.). —This book is a treatise on the natural history, chemistry, physical properties, and technology of natural bitumens or asphalts. The author's extensive personal experience has been of much service in the preparation of the work, and much material from other sources is included. The uses of the solid forms of bitumen in the construction of pavements are very thoroughly discussed, and there is an interesting chapter on the oiled roads and streets of the Pacific Coast. H. L. W.

II. GEOLOGY.

1. *Iowa Geological Survey;* SAMUEL CALVIN, State Geologist ; JAMES H. LEES, Assistant State Geologist. Vol. XIX, Annual Report for 1908, with accompanying papers. Pp. xiii and 779, ills. 117.—The original coal supply of Iowa is estimated at 29,160,000,000 tons ; 141,608,792 tons have been mined up to and including 1908, which indicates that at the present rate of production the Iowa supply will last for 2550 years. The importance of the coal industry in Iowa justifies the publication of a number of papers dealing especially with this subject.

The first report by Henry Hinds on "The Coal Deposits of Iowa" (pp. 25–391) gives detailed descriptions of the geological relations, mode of occurrence of the Iowa coals and the present state of development of the coal industry for each township and district in the state. The Fuel Value of Iowa coal is discussed by Frank A. Wilder (pp. 401–497) and includes analyses by James H. Lees and A. W. Hixson, in which are given the results of the fuel tests at the plant established at St. Louis by the United States Geological Survey. The History of Coal Mining in Iowa by James H. Lees (pp. 521–597) is an interesting account of the successes and failures in coal mining from 1840 to 1908.

The chapter on the Carboniferous Section of Southwestern Iowa by George L. Smith (pp. 605–657) deals largely with the stratigraphy of the Missouri stage, and in this same report S. W. Beyer discusses the origin, distribution and commercial value of peat deposits in Iowa (pp. 693–725), and L. H. Pammell describes the flora of the northern Iowa peat bogs (pp. 739–776).

H. E. G.

2. *West Virginia Geological Survey ;* I. C. WHITE, State Geologist. County Reports and Maps, 1909. Marshal, Wetzel and Tyler Counties, by RAY V. HENNEN, Assistant Geologist. Pp. xvi and 654, maps 3, plates xii, figures 3.—This second vol-

ume of the series dealing with individual counties has been prepared in accordance with the plan announced some years ago of furnishing reports dealing with various parts of the state, the plan being to include in one volume all the important geological matter pertaining to a given section.

From an economic standpoint, little criticism can be made of these reports since they discuss not only coal, gas, oil, building stone and clay, but also soils ; but as general reading books dealing with the geology of the section, they are not so satisfactory. It is a legitimate part of the work of a State Survey to publish the results of geologic research in a form which may be of use to schools and to the average intelligent man. The publications of the Wisconsin, the Illinois and the Connecticut Surveys indicate how this may be done.

The maps published with this volume are especially good, and the idea of combining the county maps into one map for the whole district is to be commended. H. E. G.

3. *New Zealand Geological Survey ;* J. M. BELL, Director. Bulletin No. 8 (New Series). The Geology of the Whangaroa Subdivision, Hokianga Division, by J. M. BELL and E. DEC. CLARKE. Pp. v and 107, illustrations xvii, maps 8, geological sections 4.—Little geological work has previously been done in the area covered by this report, the northern edge of Auckland Island, although this part of New Zealand contained one of the earliest settlements and is widely known as a producer of kauri gum, which next to gold has contributed most to New Zealand revenues.

The rocks of this area include pre-Cretaceous, argillites, quartzites, and igneous rock; late Mesozoic and early Tertiary, the Kaeo series of sedimentaries ; Miocene, the Wairakau breccias, dikes and flows ; Miocene or post-Miocene, Kerikeri flows and underlying sediments ; post-Miocene lake beds, acid and basic volcanics. Since the deposition of the Wairakau series tectonic movements include little folding but extensive faulting. The surface as a whole is a faulted tableland deeply dissected and with volcanic cones rising above the level. The shore line is that of a typical depressed land surface. There are evidences of baseleveling on the surface of the Kaeo rock and renewed peneplanation occurred between Wairakau times and the extrusion of the Kerikeri volcanics. Rock benches are developed along the shore line, but they are believed not to represent planes of marine erosion, but rather to be due to the coöperation of subaërial weathering and marine transport. The freshwater lakes occupy basins due to damming by lava flows or explosion craters.

Chapters 4 and 5 of this report (pp. 41–79) are devoted to detailed descriptions of the stratified rocks with their fossils and the igneous rocks, including a number of analyses. In the chapter on economic geology (pp. 80–98), an interesting account is given of the occurrence of mercury, which seems to be directly associated with hot springs, as in the case of certain Nevada and California deposits, discussed by G. F. Becker. H. E. G.

4. *Certain Jurassic (Lias-Oolite) Strata of South Dorset; and their Correlation; Certain Jurassic ("Inferior Oolite") Species of Ammonites and Brachiopoda;* by S. S. BUCKMAN. Quart. Jour. Geol. Soc., London, lxvi, No. 261, February 1910, pp. 52–108, pls. ix–xii.—The author describes here in detail certain strata of the Jurassic of the Dorset coast and compares them with similar strata inland.

American geologists often doubt the ability of paleontologists to make correlations of zones having thicknesses from 10 to 50 feet, but Buckman here makes correlations of zones but a few inches in thickness! He states :

" The Inferior Oolite rocks are so remarkably prolific in species of Mollusca and Molluscoids—there is so great a number of species yet awaiting description—that there seems to be an idea among those who have not studied the rocks in the field, that they receive a kind of preferential treatment in this respect. Another explanation may be suggested—that our judgment as to the time occupied in the forming of the so-called 'Inferior Oolite' strata is warped owing to their tenuity—that they represent a time during which destruction of strata was particularly active, therefore the remaining deposits are only the fragmentary representatives of a whole.

" This is particularly the case in Dorset. A schoolboy once defined a net as a series of holes strung together, and the Dorset Inferior Oolite might be defined as a series of gaps united by thin bands of deposit. And one reason for the prolificness of the deposits is that the amount of deposit can be no indication of the amount of time, as shown by the changes in successive faunas ; and also that the deposits are so local—the deposits of one place correspond to the gaps of another. Therefore many localities have to be placed together to produce the full tale of the Inferior Oolite. The very local distribution of Inferior Oolite species often means that strata of particular dates have only been preserved in a few favoured localities.

" The beds of the 'Inferior Oolite,' in a restricted sense, have now been divided as deposits of about twenty-two successive dates or hemeræ. The total for the whole of the Jurassic would not be more than about eighty-five, or perhaps, on an extended scale, a hundred hemeræ. Therefore, according to this reckoning, the few feet of Inferior Oolite represent from about a quarter to a fifth of the total time occupied in the deposition of the entire Jurassic System.

" One can hardly view the few feet of Inferior Oolite limestone at Burton Bradstock, about 15 to 20 feet say, and imagine that it represents an interval of time equal to a quarter or a fifth of the whole Jurassic Period—a time during which thousands of feet of strata were laid down. But this is because we do not allow sufficiently for the gaps.

" If anything like this supposition be correct, then the Inferior Oolite prolificness is understandable ; it should represent in

species as many as would form from a quarter to a fifth of the total for the Jurassic System. At that rate, its tale is nothing like complete yet ; which all workers in its rocks know to be the case." (90–91.)

" The strata described are classified according to what may be called the multizonal or polyhemeral system—in the main, according to the scheme introduced for these strata in 1893 (Quart. Jour. Geol. Soc., vol. xlix, p. 481) ; but further divisions due to other investigators and to myself are dealt with.

" The strata described are arranged among thirty-six zonal (hemeral) divisions—a greater number of divisions than Oppel used in 1856 for all the Jurassic rocks, of which these beds form but a small part.

" The Upper Lias'part of the Junction Bed of Down Cliffs, Chideock (Lower or pre-*striatulus* Toarcian), is a very condensed, imperfect epitome in 20 inches of about 180 feet of strata on the Yorkshire coast, and of very much more when allowing for gaps.

" Between the *bifrons* layer and the *striatulus* layer of the Junction Bed there is occasionally a 2-inch layer which is all that represents some 250 feet of deposit in the Cotteswolds—so that about two feet of Junction Bed was formed while a thickness of some 550 feet was being deposited elsewhere." (89.)

" The President (Prof. Sollas) congratulated the author on the very interesting manner in which he had presented a highly technical subject. The correlation of thin seams with thick deposits was a matter of great importance, and called to mind Suess's remarks on the partings in the Trias. It might afford some hints as to the order of magnitude of the scale of time. If we assumed that one foot of sediment might accumulate in a century, in an area of maximum deposition, then in the case of the seam two inches thick which was represented by 250 feet in the Cotteswolds, the rate of formation would be less probably than one foot in 150,000 years.

" The Author, in reply, remarked that Jurassic zones were by no means the result of local observation only ; they had been followed widely, even the new ones ; the thinness of zones was no test of their importance or otherwise, being often only a local accident of alternating deposition and denudation. The net increase of deposit must have been much less than one foot in a century, as this seemed too rapid for the faunal changes involved." (109, 110.)   c. s.

5. *Palæontologia Universalis*, ser. II, fasc. IV, 1910.—This fasciculus contains 71 sheets redescribing 35 species of fossil echinoderma and mollusca, and completes the second series having 169 sheets. The entire set may be had for $8.00 of G. E. Stechert, 9 East 16th St., New York City.   c. s.

6. *Geologic Atlas of the United States. Folio 169, Watkins Glen–Catatonk, New York, 1909;* by H. S. Williams, R. S. Tarr, and E. M. Kindle.—The topography and the Quaternary deposits are described in detail by Tarr, the Upper Devonian

stratigraphy by Williams and the igneous rocks and historical geology by Kindle. The interfingering of the western Portage faunas into the eastern Hamilton-Chemung biotas is clearly described and is of much interest to stratigraphers.   c. s.

7. *Geology of the Auburn–Genoa Quadrangles ;* by D. D. LUTHER. Bulletin 137 N. Y. State Museum, 1910, 36 pages and geologic map.—An excellent description of the areal geology of the region of Cayuga and Owasco lakes. The formations range from the upper part of the Silurian to the close of the Devonian.
                                                                          c. s.

III. MISCELLANEOUS SCIENTIFIC INTELLIGENCE.

1. *National Academy of Sciences.*—The annual Spring meeting of the National Academy was held at Washington on April 19 to 21 ; some forty members were in attendance.

The following new members were elected : Douglas H. Campbell, Professor of Botany in Stanford University ; John Dewey, Professor of Philosophy in Columbia University ; Jacques Loeb, Professor of Physiology in the University of California ; Forest R. Moulton, Professor of Mathematics in the University of Chicago ; William A. Noyes, Professor of Chemistry in the University of Illinois ; Thomas B. Osborne, Chemist of the Connecticut Agricultural Experiment Station ; Charles Schuchert, Professor of Paleontology in Yale University. Professor Giovanni Schiaparelli, the astronomer, of Milan, Italy, was elected foreign associate.

The list of papers presented at the meeting is as follows :

E. C. PICKERING : The 16-inch Metcalf doublet.

GEORGE E. HALE : Solar magnetism. Some visual and photographic observations of Mars.

WILLIAM TRELEASE : The distribution of Agave in the West Indies.

JOHM M. COULTER : The vascular plate and cotyledons of Gymnosperms.

F. E. NIPHER : Some crucial experiments demonstrating the necessity of accepting the one-fluid theory in electricity.

W. J. HUMPHREYS : A probable indirect relation between solar disturbance and terrestrial temperatures.

E. A. HARRINGTON : Quantitative studies of tuning forks.

S. W. STRATTON : The Bureau of Standards.

ARTHUR L. DAY : The determination of temperature constants in mineral formations.

J. M. CRAFTS : A new form of gas thermometer and the boiling points of water and naphthalene.

H. N. MORSE : The temperature coefficient of osmotic pressure.

H. L. ABBOTT : Hydraulics of the Chagres river.

C. D. WALCOTT : The development of Olenellus.

E. W. HILGARD : A new development of mudlump activity at the mouth of the Mississippi river.

H. F. OSBORN : The correlation of the Pleistocene of Europe and North America. The epidermal covering of the trachodont Dinosaurs. Biographical memoir of Joseph Leidy.

W. B. SCOTT : Report of progress in the study of the Miocene Ungulates of Patagonia.

J. M. CLARKE : The austral Devonian.

W. M. Davis : Quandaries following from the theory of isostacy.

R. B. Dole : Composition of American river waters.

F. W. Clarke : A preliminary study of chemical denudation.

George F. Becker : Denudation evidence in relation to the age of the Earth.

Franz Boas : The influence of environment on human types.

A. G. Webster : A new method for the study of elastic hysteresis.

A. A. Noyes : The ionization relations of poly-ionic salts.

Theodore Gill : The structural characteristics and relations of the Apodals. Recent discoveries of the early history of the common eel.

Ira Remsen : Some studies in molecular rearrangement.

R. G. Aitken : The number of double stars as a function of the separation of the component.

W. W. Campbell and Sebastian Albrecht : On the spectrum of Mars as photographed with high dispersion.

W. W. Campbell : Second catalogue of spectroscopic binary stars.

2. *Ostwald's Klassiker der Exakten Wissenschaften.* Leipzig, 1909 (Wilhelm Engelmann).—The following are the latest additions to the valuable series of scientific classics :

Nr. 171. Über unendliche Reihen (1689–1704) ; von Jakob Bernoulli. Aus dem Lateinischen übersetzt und herausgegeben von Dr. G. Kowalewski. Pp. 141, with 12 figures.

Nr. 172. Abhandlungen Jean Rey's, Doktors der Medizin. Über die Ursache der Gewichtszunahme von Zinn und Blei beim Verkalken. Deutsch herausgegeben und mit Ammerkungen versehen von Ernst Ichenhäuser und Max Speter. Pp. 56, with 2 figures.

Nr. 173. Untersuchungen über die Affinitäten über Bildung und Zersetzung der Äther ; von Berthelot und L. Péau de Saint-Gilles. Annales de Chimie et de Physique (3), lxv, p. 385 ; lxvi, p. 5 ; lxviii, p. 225. Übersetzt und herausgegeben von Margarete und Albert Ladenburg. Pp. 242, with 2 tables.

Ektropismus oder die Physikalische Theorie des Lebens ; von Felix Auerbach. Pp. iv, 99. Leipzig (Wilhelm Engelmann), 1910.

Obituary.

Professor Alexander Agassiz of Harvard University, Cambridge, Mass., died on March 27, in the seventy-fifth year of his age ; a notice is deferred until a later number.

Professor Robert Parr Whitfield, curator in the American Museum of Natural History, New York, died on April 6, in his eighty-second year ; a notice will be published later.

Dr. Charles Reid Barnes, Professor of Plant Physiology in the University of Chicago, died on February 24, at the age of fifty-one years.

Professor Samuel Ward Loper, curator of the museum of Wesleyan University, died in March, in his seventy-fifth year. While he published little in geology, he did much to further paleontology in making extensive collections of fishes and plants from the Connecticut Triassic and in the older Paleozoic formations of Texas, Wyoming, and Nova Scotia.

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ART. XLII.—*An Experimental Investigation into the Flow of Rocks, by Frank D. Adams, assisted by Ernest G. Coker. First Paper—The Flow of Marble.* (With Plates II–IV.)

CONTENTS.

Introduction.

THAT the rocks of the earth's crust, under the stresses to which they are subjected, have been bent and twisted in the most complicated manner is a fact which was realized by the earlier geologists, and it needs but a glance at an accurate geological section through any highly contorted district of the earth's crust to see that during the folding of the rocks there

has often been a marked transfer or " flow " of material from one place to another within the fold.

While, however, these facts are undisputed, the precise nature of this folding and flowing has been a subject concerning which there has been much discussion and a wide divergence of opinion.

Some authorities—among whom Heim,[*] whose work in the Alps must command the admiration of all, may be mentioned —have held that while in the upper portions of the earth's crust, rocks when submitted to pressure will break, giving rise to faults and overthrusts—the same rocks in the deeper portions of the earth's crust are unable to break up in this way, owing to the great weight of the superincumbent strata. The lines of fracture they hold in this case become smaller and greatly increase in number, the various minerals constituting the rock thus breaking down into grains, which, however, move around and past one another, the adjacent grains always remaining within the sphere of mutual cohesion. The structure of the rock thus becomes cataclastic ; but the rock mass, while acting as a plastic body and flowing in the direction of least resistance, maintains its coherence while altering its shape.

Now according to Spring,[†] the property known as regelation is really due to a power which fragments of bodies have of uniting if brought within the range of the molecular forces, a property which, although possessed in a marked manner by ice, is also, as he has experimentally demonstrated, exhibited by many other bodies and would probably be displayed by all if the required conditions could be attained. The " flow of rocks " would, therefore, according to Heim's view, be a manifestation of regelation on an enormous scale.

Other writers on this subject have maintained that rocks are absolutely destitute of plasticity in any proper sense of the term. Pfaff[‡] has even held that in the depths of the earth great pressure will tend rather to prevent molecular movement and thus keep the rocks rigid. Those holding such views attribute the deformation of rocks either to crushing with subsequent recementation of the fragments by mineral matter deposited from percolating waters as the movements proceed or after they are completed,[§] or to a continuous process of solution and redeposition of the minerals which

[*] Der Mechanismus der Gebirgsbildung, p. 31, 1878 ; see also Van Hise, C. R., Metamorphism of Rocks and Rock Flowage, Bull. Geol. Soc. of America, vol. ix, 1898.
[†] Recherches sur la propriété que possèdent les corps de se souder sous l'action de la pression ; Revue Universelle des Mines, 1880.
[‡] Der Mechanismus der Gebirgsbildung, pp. 19–21.
[§] Stapff, Zur Mechanik der Schichtenfaltungen, Neues Jahrbuch für Mineralogie, 1879, p. 792 ; Reyer, Theoretische Geologie, p. 443.

make up the rock. The percolating waters, it is held, tend to dissolve material at those points where the pressure is greatest, and to redeposit it where the pressure is wholly or partially relieved ; the movements thus being accompanied by a more or less complete recrystallization of the whole rock. Moisture would thus be a necessary factor in all rock folding or contortion, and recrystallization the essential feature of the phenomenon. The deformation of a body of dry rock would be impossible.

An experimental study* of the subject was undertaken some years since, the rock selected being Carrara marble. The investigation showed that in the case of this rock plastic deformation could be brought about by the action of pressure alone, that heat made the rock more plastic, and that under the conditions of the experiments, the presence of water exerted little or no influence in this respect.

By this it is not meant to imply that when rocks are folded in the earth's crust solution and redisposition do not play a very important rôle. These processes undoubtedly are at work and are widespread in their action. It is quite possible that they are the most important agencies in the folding and flow of rocks.

The experimental study showed, however, that the presence of water was not an essential factor in the development of flow, in the case of marble at least, and that under the experimental conditions, that is to say with the deformation carried out in days, weeks, or at most in a few months, instead of being extended over long periods measured by years or centuries, the deformation of the marble took place quite independent of solution.

It showed furthermore that the structures displayed by highly contorted marbles in many parts of the earth's crust are identical with those produced under the experimental conditions and that they have been developed by the same agencies.

As the subject seemed to be one worthy of further study, the work was continued under a grant from the Carnegie Institution of Washington, and as the investigation went forward it was found to be necessary to follow out several separate lines of research.

The amount of cubic compression which rocks undergo when submitted to pressure from every side was first investigated, all rocks of course being subjected to such compression before deformation.†

* Adams, F. D., and Nicolson, J. T.—An Experimental Investigation into the Flow of Marble ; Phil. Trans. Royal Soc., London, Series A, vol. cxcv, pp. 363–401.

† Adams, Frank D., and Coker, Ernest G.—An Investigation into the Elastic Constants of Rocks, more especially with reference to Cubic Compressibility ; Publication of the Carnegie Institution of Washington, No. 46 (Résumé in this Journal, Aug. 1906.)

A further study was then made of the "flow of marble" under widely varied conditions of pressure, temperature and time; after which the investigation was extended to a number of fine-grained and more or less impure limestones ; to crystalline dolomites ; and then to a series of typical plutonic intrusives—diabase, essexite and granite.

A series of comparative experiments were then made for the purpose of accurately measuring the loads required for the deformation of standard columns of these and other rocks under precisely identical conditions of differential pressure and extremely slow movement.

In the present paper it is proposed to outline the methods employed in these investigations and to present the results obtained by the further study of the "Flow of Marble"; and in subsequent papers to set forth the results obtained in the case of some of the other and more resistant rocks. The results of the investigation as a whole when completed will appear, in extended form and fully illustrated, as a Publication of the Carnegie Institution of Washington.

Methods Employed.

In seeking to ascertain experimentally the action of differential pressure on rocks with a view to reproducing more or less accurately the conditions of pressure which obtain in the deeper parts of the earth's crust, it is manifestly quite useless to attempt to reproduce these conditions by simply submitting the rocks to compression in a testing machine, as is done in testing the strength of materials. There is certainly differential pressure in this case, but it is merely the ordinary atmospheric pressure on the sides of the test-piece, while the tremendous pressure of the testing machine acts in the vertical direction. It is necessary to increase the lateral pressure and make it in some degree at least approach the measure of that exerted in a vertical direction if the pressure conditions of the deeper parts of the earth's crust are to be reproduced. The material must be held in and supported laterally, so that it will not readily break or fracture as the vertical pressure is brought to bear upon it until at least the required conditions of differential pressure have been secured.

In the deformation of rocks within the earth's crust the pressure element which corresponds to this lateral resistance is furnished by the great weight of overlying strata forming the upper portion of the earth's crust, while the direct pressure exerted by the testing machine represents the tangential thrust which folds them.

To secure this lateral resistance, two methods have been proposed. The first is that suggested many years ago by

Kick, in which a stout copper case is prepared within which the specimen is placed, the intervening space being filled by alum, sulphur or some other more or less plastic material, poured in when in a fused condition and which solidifies on cooling. (Fig. 1.) The whole is then submitted to the action of a powerful press and squeezed down. Upon the completion of the experiment the embedding material is removed by heat or solution and the deformed specimen obtained. This method is easily carried out, but it has a number of defects. Thus, the experiments can be carried out only at the ordinary tem-

Fig. 1.
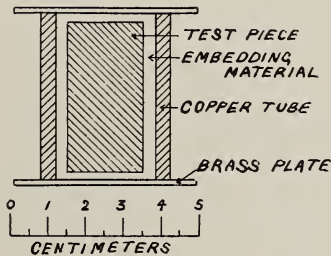
perature of the laboratory; the lateral resistance offered is not as great as is required in the case of the harder rocks, and it is furthermore impossible to determine the pressure to which the specimen has been subjected, seeing that the load has been divided between the box, the embedding material and the specimen itself.

A series of experiments on the deformation of various minerals and rocks were, however, carried out by this method, the results of which are detailed in another paper.*

The second method is that employed by Adams and Nicolson in their investigations on the Flow of Marble. In this a column of the rock is very accurately turned or ground in a lathe and fitted into a heavy tube of steel which has been bored out with equal accuracy to receive it. Pistons of hardened chromium-tungsten steel are then inserted into the ends of the tube, the pressure being transmitted through them to the column enclosed in the steel. By this method a much greater lateral resistance can be secured, which makes it possible to carry out the deformation under much higher

* Adams, F. D.—An Experimental Investigation into the action of Differential Pressure on certain minerals and rocks employing the process suggested by Professor Kick; Journal of Geol., 1910.

pressures. This resistance also may be varied as desired by altering the thickness of the walls of the enclosing tube, and the pressure under which the rock is being deformed can be accurately measured, seeing that the whole vertical pressure is brought to bear directly upon the specimen. The deformation may, furthermore, be carried on at temperatures approaching even to incipient redness and, if required, in the presence of water or steam.

The material employed in the construction of the enclosing tubes in our earlier experiments was wrought iron or a mild carbon steel, but in all later work a steel containing 4·10 to 5·18 per cent of nickel was employed. This steel has a considerably higher elastic limit than ordinary carbon steel, and our thanks are due to the Bethlehem Steel Company for several consignments of this steel which have been used in the investigation. For the construction of the pistons the chromium tungsten "Novo" steel was employed. This steel when heated to whiteness and plunged into fish oil develops extraordinary strength, a specimen having the dimensions of one of the pistons—namely ·815 inch in diameter and 1·56 inch long—when tested in compression having sustained a load of 215,000 lbs., equivalent to 411,880 pounds per square inch, with practically no alteration of shape. The pistons of this steel may, furthermore, be used under the great pressures employed at temperatures as high as 600° C.

In order that the conditions of differential pressure may be satisfactorily developed, it is necessary to make that portion of the enclosing nickel-steel tube immediately surrounding the central portion of the rock column thinner than it is elsewhere, while leaving the portions of the tube about the ends of the column thicker. This concentrates the flow or deformation of the rock, giving a symmetrical bulge developed within the column and between its extreme ends, and prevents the enclosing tube from opening up under the pressure and permitting the rock to force itself up between the pistons and the ends of the steel tube. As the result of a long series of experiments, too numerous to detail here, it was found that a tube of the dimensions shown in the accompanying drawing (fig. 2) was the most suitable, the thickness of the wall immediately around the central part of the specimen being increased from 25 millimeters to a centimeter according to the amount of lateral pressure or resistance which it is desired to develop, all the other dimensions of the tube remaining the same. The pistons at either end were inserted into heavy steel castings by which the load was transmitted from the press.

The rock columns upon which the experiments were carried out were in most cases about 2^{cm} (·814 inch) in diameter and

about 4^{cm} (1·56 inch) long. In the earlier experiments the rock was first ground into rough columns 6^{cm} long and 2·5^{cm} in diameter on a rubbing bed. Subsequently a small diamond drill was installed having a hollow bit, which proved an excellent device for readily securing a rough column of any rock which it was desired to use for experimental work. This was then cut into lengths and turned into columns of the required size in a lathe. The final very accurate shaping of the columns was given to them by grinding with an emery or corundum wheel while in the lathe. In this way the little columns were turned to the desired shape with extreme accuracy. They were not as a general rule made exactly cylindrical in shape, but in order to secure a very accurate fit were usually made slightly conical with a taper of 1/1000 of an inch in their length.

Fig. 2.

In the same way the steel tube was first turned in a lathe in the usual manner, the inner surface was then ground to secure greater accuracy of shape, and the tube was finally finished by the employment of a reamer. In this way a taper identical with that given to the column was secured, the column, however, being slightly larger than that portion of the tube which was to enclose it. The tube was then heated by placing a red hot iron ring about it and when thus expanded the rock was gently shoved into it to the required position, and the tube being allowed to cool, a mechanically perfect fit of the tube to the column was secured.

When it is desired to carry out the deformation at temperatures above that of the laboratory and up to 600° C. or more,
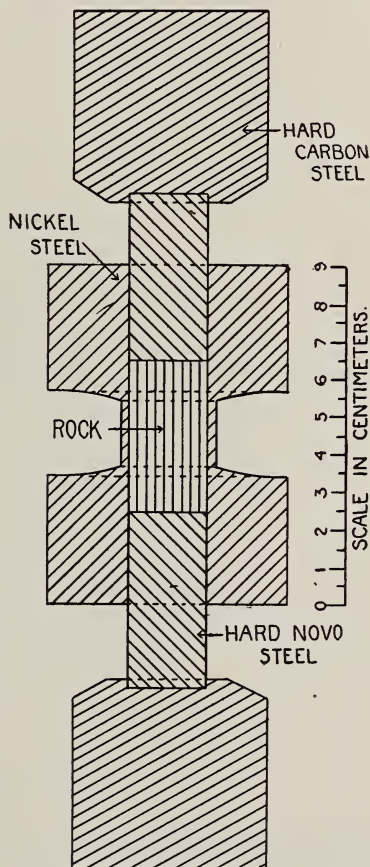
the rock with its tube is enclosed in a small stove of special construction heated by a gas blast, the air being supplied by a Reichhelm blower driven by a 2 h.p. electric motor.

In experimental work formerly carried out on the Flow of Marble at temperatures up to 400° C., a small cast-iron stove was used. As in these later experiments much higher temperatures —up to 1000° C.—have been employed, it was found that in many cases it was extremely difficult to remove the steel tube

Fig. 3.
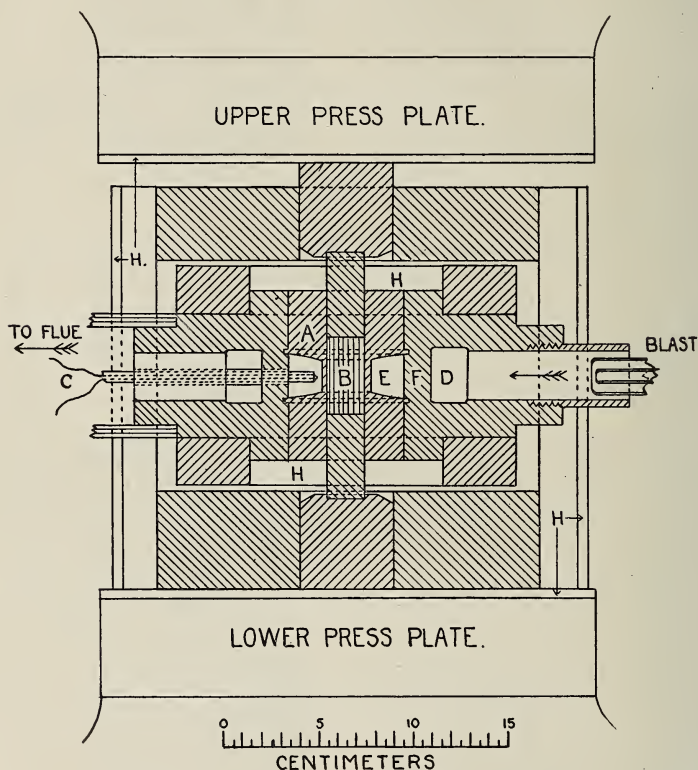
enclosing the rock from the stove at the conclusion of the experiment, the two having become partially welded together. A stove of cast steel has, therefore, been substituted, made in two parts which are firmly held together by heavy steel collars during the experiment, which collars can be removed at the conclusion of the experiment, allowing the stove to fall apart and access to the enclosed tube to be thus easily obtained. This form of stove has proved very satisfactory. A section of it is shown in fig. 3.

The casting is so arranged that hot gases circulate in an annular channel (D) within it, and outside of the wrought iron cylinder (A), the rock (B) being thus kept at a high temperature while the pressure is applied. The casting is as massive as possible and a very uniform temperature is thus maintained during the whole time of the experiment. The temperature of the enclosed rock is ascertained by means of a platinum—platinum rhodium couple (C), provided with properly calibrated resistance boxes, etc. This lies in the air space (E) by the side of the tube which incloses the specimen. The hot gases are excluded from this space by the wall (F). The whole is well lagged with asbestos, asbestos millboards (H) being also inserted between the bases of the pistons and the plates of the press.

When it is desired to deform the rock at high pressures and temperatures in the presence of water, a modified form of the stove was adopted. The apparatus employed for the purpose has been described in the former paper, to which reference has been made.

Upon the conclusion of the experiment the deformed tube with its enclosed rock was placed in a lathe and the steel tube was carefully turned off until a mere film of metal remained. This was carefully filed through along one line and the enclosed rock was thus obtained intact.

In experiments where very accurate measurement of the pressures employed was required, the large 100-ton Wickstead testing machine set up in the testing laboratory in the Engineering Building of McGill University was employed. In other experiments a series of three hydraulic presses, provided with suitable intensifiers and necessary accessory appliances, were employed. These were calibrated from time to time by direct comparison with the Emery testing machine in the testing laboratory, and the accuracy of their reading thus maintained. The most powerful of these presses, which was the one usually employed, has a capacity of 120 tons.

The Flow of Marble.

In a former paper, as has been mentioned, it has been shown that under conditions of differential pressure marble flows as a plastic body. In the present contribution the results of further experimental work, carried out with the view of obtaining a more complete and thorough knowledge of the behavior of marble under varying conditions of differential pressure, are presented.

1. *Deformation of the dry rock at ordinary temperatures.*

(*a*) *Deformation at comparatively low pressures. Structure of the deformed marble.*

The pressures employed ranged from 120,000 to 130,000 lbs. to the square inch. A series of experiments was first made in which the marble was enclosed in wrought iron tubes. The walls of these tubes immediately surrounding the marble had a thickness varying from 1/8 to 1/4 of an inch, and the load was slowly applied until deformation, indicated by the bulging of the tube, had commenced. So soon as movement ceased the load was increased slightly and the movement was thus resumed, and in this manner the deformation was carried on at a rate which was kept as nearly as possible constant.

The experiments were arranged so that in some cases the deformation went forward rapidly and in other cases very slowly, the time occupied being from ten minutes to sixty-four days.

In later experiments, as has been mentioned, the wrought-iron tubes were replaced by tubes of steel. These latter had the advantage of offering a higher resistance and also of being more easily prepared and more uniform in strength than those of wrought iron. This latter quality was of especial importance in cases where experiments were carried on in series under identical conditions for purposes of comparison. Plate IV shows such a tube with the enclosed marble column, cut open after deformation.

The deformed marble was uniform and compact and seemed to break with equal ease in all directions. It differed somewhat in appearance from the original rock in possessing a dead white color, the glistening cleavage surfaces of the calcite being no longer visible, and the contrast being well brought out when the deformed column is split or cut through vertically, owing to the fact that a portion of the original marble often remained unaltered and unaffected by the pressure. This, when present, had the form of two cones of obtuse angle whose bases are the original ends of the column resting against the faces of the steel pistons, while the apices extend into the deformed marble and point toward one another. These cones, or rather parabolas of rotation, are also developed, as is well known, where cubes of rock, cement or cast-iron are crushed in a testing machine in the ordinary manner. In the present experiments they sometimes constitute a considerable proportion of the whole mass; in other cases they are absent or but faintly indicated; but there is always in immediate contact with the ends of the steel pistons at least a thin cake of marble possessing the character of the ordinary rock.

Thin sections of the deformed column passing vertically through the unaltered cone and deformed portion of the rock were readily made and when examined under the microscope clearly showed the nature of the movement which had taken place. Under the microscope the deformed portion of the rock can be distinguished at once by a turbid appearance differing in a marked manner from the clear, transparent mosaic of the unaltered cone. In that portion of the rock which has suffered deformation the calcite individuals have been squeezed against one another in such a manner that a distinct flattening of the grains has resulted. The individuals are not only flattened, but in some cases distinctly twisted, these movements being effected by the development in the calcite, first of marked strain shadows, and then, where the movement is more intense, by the appearance in each calcite grain of a series of fine parallel lines or very narrow bands giving to it a fibrous appearance, which bands become more numerous as the distortion of the grain becomes more pronounced, the calcite as these bands increase in number displaying a progressive decrease in transparency. When highly magnified, these lines are seen to be due to an extremely minute polysynthetic twinning. The chalky aspect of the deformed rock on the surface of fracture is chiefly due to the destruction by this repeated twinning of the continuity of the even cleavage surfaces of the calcite individuals, thus making the reflecting surfaces much smaller.

By this twinning the calcite individuals are enabled under pressure to alter their shape somewhat, while the flattening of the grains is evidently due to movements along the gliding planes of the crystals.

In the paper by Adams and Nicolson describing the results formerly obtained in the deformation of marble at ordinary temperatures, it was stated that a microscopic examination of the deformed rock revealed the presence of an " anastomozing meshwork of curved and branching lines " of minutely granulated calcite running through the rock, these being lines of cataclastic structure similar to those obtained when marble is deformed by Kick's process. In our more recent experiments, however, this cataclastic structure is seldom found and in many cases is entirely absent. This is probably due to the fact that in this latter work the grinding and fitting of the columns to the tubes has been carried out with the utmost accuracy, while in the former experiments mechanical work was less perfect and the column probably did not in all cases fit its tube perfectly. It is probable that the little lines along which cataclastic structure is developed may have been largely due to a slight shearing of the column before perfect adjustment of the tube had been effected by the pressure to which it was subjected.

A faint but distinct cataclastic structure is, however, found in some cases even when the support offered to the marble by its steel tube is perfect, and along planes of greatest movement the calcite individuals can in some cases be seen to have been apparently slightly torn.

(b) *Deformation at very high pressures—Structure of the deformed marble.*

In order to ascertain whether under a greater load the cataclastic structure would entirely disappear, another series of experiments were carried out employing much higher pressures and at the same time carrying the deformation as far as possible. This was secured by increasing the thickness of the wall of the tube which enclosed the marble. A tube of wrought iron built up in the same manner as a gun barrel and having a wall thickness of ·5 inch (12·7^{mm}) for a length of ·625 of an inch (15·875^{mm}) along the central portion of the tube about the enclosed marble column was employed. Steel pistons were then inserted and the pressure applied in the usual way. The tube commenced to bulge when the pressure reached 35,000 lbs. (15,870 kilos.), and the maximum load applied to the marble was 154,000 lbs. (169,750 kilos.), that is to say, a pressure of 296,725 lbs. per square inch (20,875 kilos. per square cent.), the deformation being carried on slowly and occupying forty-one hours. This is equivalent to a depth of 46 miles below the surface of the earth. A photograph of the tube upon the completion of the experiment is shown in Plate II (a). Under this tremendous pressure the upper steel piston failed, four radial cracks developing on its face in contact with the marble, thus dividing the piston face into four nearly equal quadrants. These cracks extended up into the piston for approximately half an inch (12·7^{mm}), the largest of them being one one-hundredth of an inch (·254^{mm}) in width at its widest part, and the marble was forced up into these very narrow cracks. Notwithstanding the great thickness of the ends of the tube, moreover, a small amount of the marble under this enormous pressure passed up between the piston and the inner surface of the tube, in a form which while coherent was sufficiently soft to yield to the finger nail with ease. The marble was removed from the bulged tube by turning off the latter in a lathe. That portion of the rock which had not been forced up around the pistons, constituting of course almost the entire mass, was obtained in the form of a slaty cake ·682 inch (17·3^{mm}) in height and 1·135 inch (28·81^{mm}) wide at its widest part, and in form somewhat barrel-shaped. This is shown in Plate II *b* with a column of its original dimensions placed beside it for purposes of comparison. On the

a
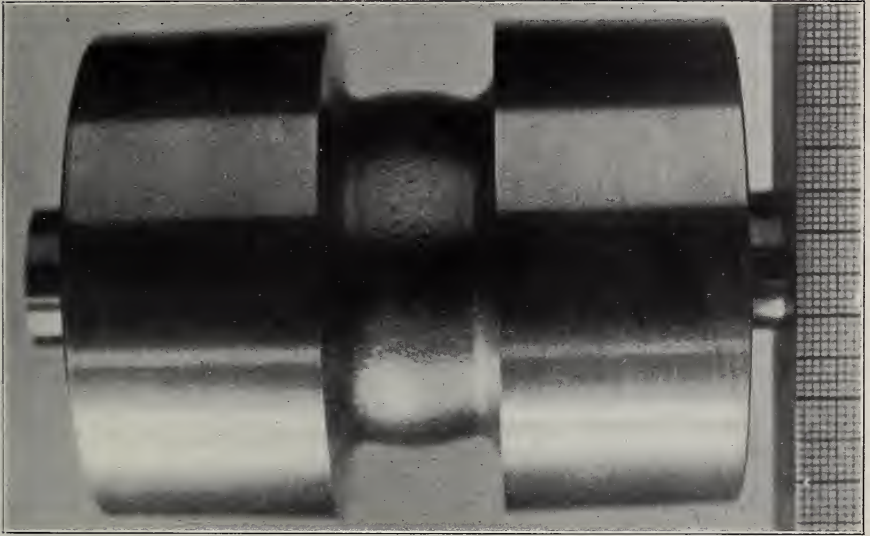
Wrought iron tube enclosing marble column after compression (see below).

b
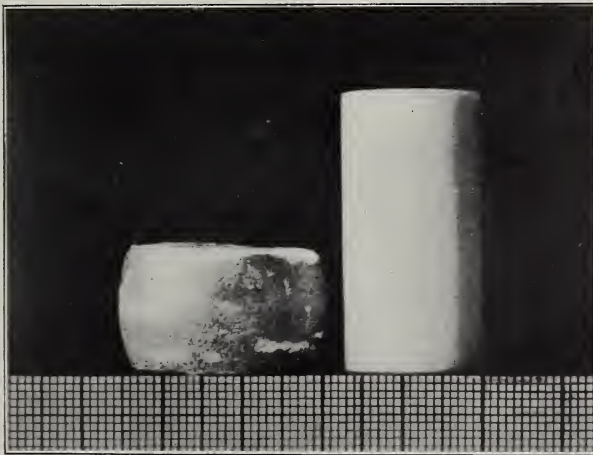
Column of marble before and after compression under a load of 296,725 pounds per square inch (20,875 kilos. per square cent.). The finer lines of the scale are one millimeter apart.

a
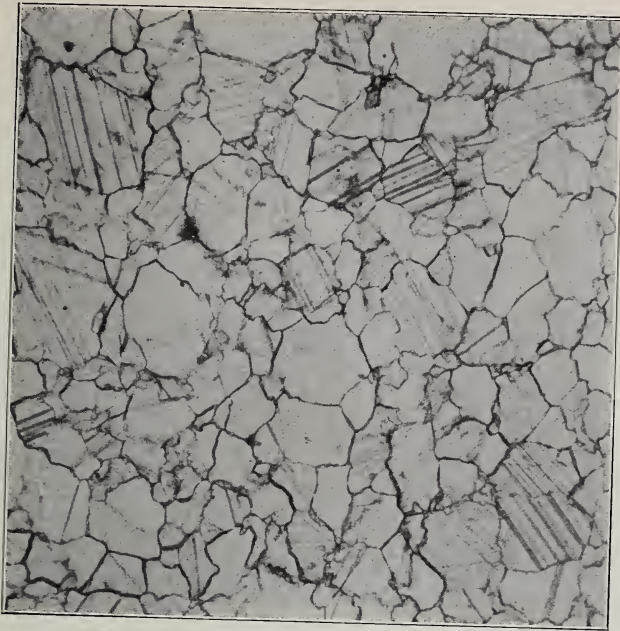
Carrara marble – original.   (× 60 diam.)

b
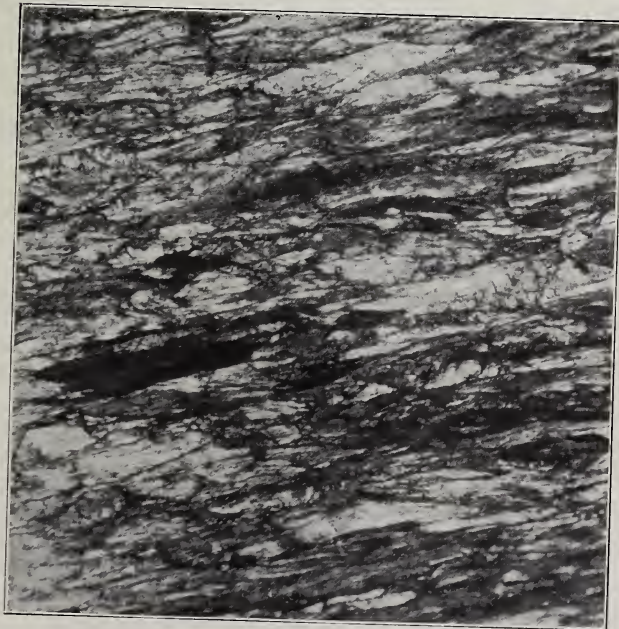
Carrara marble—caused to flow under pressure of 296,725 lbs. per square inch.   (× 40 diam.)
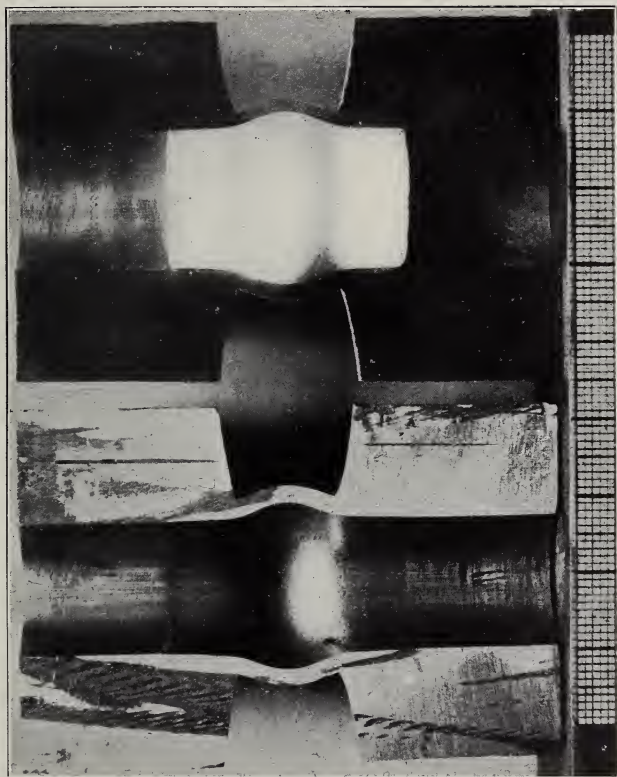
Tube with its enclosed column of Carrara marble—cut open after deformation. The finer lines in the scale are one millimeter apart.

surface of this cake no reticulating (Luder's) lines such as those observed when marble is deformed in Kick's experiment are seen.

A series of thin sections of the deformed marble was then prepared. When examined under the microscope these sections show that the marble has had developed in it a most striking and beautiful foliated structure due to the arrangement of individuals of calcite, each of which has been flattened out so that in a section passing vertically through the deformed column it presents the appearance of a ribbon drawn to a point at either end and from eight to ten times as long as it is wide. These elongated calcite individuals are perfectly moulded upon one another, coming together along sharp and gently sinuous lines. A microphotograph of this deformed rock, together with one of the original marble, is shown in Plate III. While many of them possess a very fine polysynthetic twinning, causing them to maintain a generally uniform illumination as they are revolved between crossed nicols, the movement has evidently been chiefly of the nature of a translation or slipping on gliding planes without the development of pronounced twinning, so that the elasticity axes of the various individuals lie nearly parallel to one another, and the whole rock section thus becomes light and dark four times during a revolution between crossed nicols, the periods of extinction being reached when the longer axes of the crystals (i. e., the foliation of the rock) coincide with the vibration planes of the nicols. In sections parallel to the foliation, the flattened individuals are seen to have a rudely polygonal form, often presenting somewhat rhombic outlines, some showing strain shadows which in many cases can be seen to result from a polysynthetic twinning of almost ultra-microscopic minuteness. This is of especial interest, as it is precisely this movement of individual lamellæ of measurable width over one another that gives rise to the phenomenon of the "flow" of metals. Calcite, however, is apparently much more prone to twin during this deformation than metals are, although the greater difficulty of recognizing twinning in metals—the latter being opaque—may have led to the frequency of this phenomenon in their case being underestimated.

The marble shows no trace of granulation and the movement set up in it is an example of perfect plastic flow.

The rock has a distinct foliated structure and the plane of foliation is transverse to the vertical axis of the deformed column, that is to say, at right angles to the direction of pressure in that part of the column between the piston faces, but immediately about the sides of the highly deformed and flattened column the foliation bends up until it runs approximately par-

allel to the walls, thus following the direction of movement which would be developed in any plastic mass when flowing away from between the advancing pistons in a confined space such as that afforded by the deformation of the enclosing tube. A microphotograph of this deformed marble is shown in Plate III *b*.

Another experiment similar to that just described was carried out with a column of marble of the same size enclosed in a nickel-steel tube with a wall thickness at the thinnest part of ·19 inch (·5^{cm}). This required a pressure of 221,160 lbs. per square inch, which increased the diameter of the column to 36·7 per cent. In this the same structure was developed in the marble as in the case of the experiment just described, but the deformation being smaller, the foliation developed in the rock was not quite so marked.

(c) *Strength of the marble after deformation at ordinary temperatures.*

A series of columns of Carrara marble of the size regularly employed, namely 1·575 inch (4^{cm}) long and about ·814 inch (2^{cm}) in diameter, with a slight taper, were prepared and were put into a series of tubes made of a mild carbon steel. The walls of the tube were ·592 inch (1·5^{cm}) thick, except in the central portion of the marble, where for a length of ·688 inch (1·75^{cm}) the wall was thinned away to ·13 inch (·33^{cm}) so as to localize the bulging here. The pistons were then put into the tubes in the usual way and the marble deformed so as to give the column a barrel-shaped form having a diametral enlargement of as nearly as possible ·2 inch (·508^{cm}), or 24·5 per cent. This deformation was produced in one minute, a 100 ton Buckton testing machine being employed. The maximum load required to complete the deformation at this rate of speed averaged about 56,000 lbs. (25,390 kilos.). This very rapid deformation severely tested the steel tubes, a number of them splitting before the required deformation was secured and being therefore rejected. Eighteen such experiments were made, eleven of which were successful, the tube remaining unruptured. The steel tubes were turned off as soon as possible after the conclusion of the experiment and the bulged columns of marble thus set free. Of these the first two having been carefully measured were at once tested in compression to ascertain their strength. In each case the load at which the first splitting of the marble took place was noted and then the load under which the column finally broke down.

The next three columns were allowed to stand for 100 days (or 2400 hours) and were then tested in the same manner. Four others, after having been freed from the enclosing steel

Time of deformation	Number of experiment	Maximum bulge of steel tube (inches)	Maximum bulge of marble (inches)	Time after deformation when tested (hours)	Special treatment	Load at which specimen first split (lbs.)	Load at which specimen broke down (lbs.)	Average load at which specimens broke down (lbs.)	Percentage of original strength	Pounds per square inch
1 minute	108	·228	·242	24	none	3200	4150	4175	60·6	7910
"	115	·174	·211	4	none	3300	4200			
"	111	·196	about ·2	2400	Rest for 100 days	3700	4750	4517	65·7	8558
"	112	·172	"	2400		3600	4160			
"	113	·174	"	2400		4300·	4640			
"	116	·176	·193	21	Heated to 100° C for 20 hours	2400	3470	3822	55·5	7241
"	117	·214	·225	21		3100	3920			
"	163	·159	·189	77		2550	4000			
"	121	·176	·205	31			3900			
"	119	·175	·213	77	Heated to 350° C for 20 hours	2650	3900	4150	60·3	7863
"	164	·163	·201	77		3520	4400			
30 days	337		·182	2 years	Left in collar		7150	5830	84·7	11,050
"	338		·183	"	"		4920			
"	339		·189	"	"		5420			
Original Marble	177b		·21		Break down suddenly		6780	6886		13,046
"	178		·21				6180			
"	179		·21				7475			
"	180		·24				6140			
"	181		·24				7290			
"	182		·21				7660			
"	183		·21				6460			
"	184		·22				7100			

tube, were heated in a water bath for 24 hours and then tested. The last two, after being freed from the steel tube, were maintained at a temperature of 350° C. for 20 hours and then tested as before.

Eight columns of the original marble, cut to the same barrel-shaped form and having the same average dimensions as those resulting from the one minute squeezes just described, were then prepared, and these also were tested in compression to ascertain their strength. It was found that these, instead of first splitting and then breaking down as in the case of the columns of deformed rock, showed no signs of preliminary rupture, but gave way suddenly and completely.

The results obtained, together with certain others to be referred to later, are given in the table on page 479.

It will be seen that when the marble is deformed in the manner described, the deformation being accomplished in one minute and tested so soon as the enclosing tube can be removed, it retains 60·6 per cent of its original strength.

In order to ascertain whether the deformed marble would be stronger if the deformation were carried out at a higher pressure, a column of the Carrara marble having the same dimensions as those above described was deformed in a heavy tube of nickel steel having a wall thickness of ·197 inch (·5^{cm}) at the thinnest part. The deformation was carried out a little more slowly than in the case of the experiments above described, occupying 100 minutes, and the load required to effect the deformation was 115,000 lbs. Upon the completion of the experiment the deformed column, having been freed from its enclosing tube, was tested in compression and was compared with a column of the original marble cut to the same dimensions. The deformed column measured 1·07 inch (2·72^{cm}) in diameter, which represents a diametral enlargement of 31·4 per cent. The loads required to crush the two specimens respectively were as follows:

> Original marble_____ 6525 lbs. (2954 kilos.)
> Deformed marble _____ 5470   "   (2479   ")

The deformed marble thus retains 83·8 per cent of its original strength. The experiment was then repeated with three other columns and almost identical results obtained.

It will thus be seen that the increased pressure (accompanied by a somewhat slower rate of deformation) led to a greatly increased strength in the case of the deformed marble, the strength increasing from 60·6 per cent to 83·8 per cent.

In three other experiments an attempt was made to ascertain whether, if the marble were deformed under a still higher pressure, a still further increase in strength might be secured.

The thickness of the tube walls was accordingly increased to 1^{cm}, that is to say, the thickness was doubled. It was found, however, that with a wall of this thickness it was impossible to confine the bulging of the marble to the thinner portion of the tube and thus secure a symmetrical barrel-shaped mass of deformed rock. The pressure required for this deformation was 387,000 lbs. to the square inch (273,000 kilos. per square cm.), and was so great that when subjected to it the marble forced its way up between the pistons and the walls of the tube, and the thin, wedge-shaped ridges so produced broke away and crumbled to powder as the steel tube was being turned off in a lathe.

Attempts were then made, by increasing the length of the marble column and altering the dimensions of the enclosing tube, to prevent the rock forcing its way up between the pistons and the thicker ends of the tube. These attempts, however, were unsuccessful, and it was evident from them that the result could only be accomplished by greatly increasing the thickness of that portion of the walls which enclosed the pistons, which would in its turn necessitate the employment of a much higher pressure to deform the rock, and this would result in the destruction of the pistons themselves. In the case of these experiments under very high pressure, furthermore, it was found that the deformed marble could not be obtained as a solid mass, for so soon as the last thin remnant of the steel tube which was left by the lathe was filed through, the marble developed cracks running across the column at right angles to its vertical axis. In some cases the deformed limestone at once broke in two along one of these cracks. In other cases it was obtained in what was apparently a solid mass, but upon standing a few minutes little transverse cracks, running partially or completely across the specimen, made their appearance. This phenomenon is apparently due to the expansion of the mass upon its relief from the tremendous pressure consequent upon the removal of the enclosing tube and is not confined to marble deformed under very high pressures, but is met with, as will be mentioned, in the case of the various impure limestones and dolomites whose deformation will be described later.

It was, therefore, found to be impossible to test the strength of the marble when deformed at these highest pressures owing to the fact that these transverse cracks invariably developed, thus destroying the continuity of the rock.

(*d*) *Influence of rest and of heat on the strength of the deformed marble.*

It has long been known that iron which has been overstrained, that is to say strained beyond its elastic limit, pos-

sesses very different elastic properties from the same iron in its original condition.   The iron so treated assumes a more plastic character and a bar thus stretched will on the application of small additional loads undergo a further elongation or creeping, producing a permanent set.   It is a well-known fact moreover that iron when thus over-strained will, if allowed to rest for a sufficiently long time, revert to its former state of normal elasticity, and Muir* has shown that this recovery is greatly hastened by raising the temperature of the bar even a few degrees, and if the temperature be raised to 100° C., the reversion to the state of normal elasticity is very rapid, being accomplished in a few minutes instead of requiring several days.

As has been shown, the movement set up in marble under the conditions of deformation secured in these experiments is essentially of the same character as that which takes place in iron or other metals when they are deformed, for while there is in marble, when deformed at ordinary temperatures and at comparatively low pressures, a certain amount of granulation, this is very subordinate to the movement of the calcite on its gliding places or by twinning, as before described.   It was therefore conjectured that if the marble was rapidly deformed, thus giving rise to a comparatively weak product, this deformed rock might, following the analogy of the metals, become stronger if allowed to rest for a certain time.   If the analogy to metals holds, it might still further be expected that the application of heat would bring about a more rapid recovery of strength on the part of the deformed rock than mere rest alone.

The results of three experiments in which the strength of the deformed column was tested after a rest of 100 days, as well as the results of four other experiments in which the marble after deformation was heated to 100° C. for 20 hours, and two experiments in which the marble after deformation was heated to 350° C. for 20 hours, are given in the table on page 479.   As will be seen from an examination of the figures, the marble became distinctly stronger as the result of a rest of 100 days, but the application of heat, whether it be 100° C. or 350° C., does not noticeably accelerate the recovery of strength as it does in the case of the iron.   In fact, the figures seem to show that the heating of rock to 100° C. for 20 hours rather weakens it and that it recovers this loss at a higher temperature.

Another series of three experiments was then made in which columns of marble and steel tubes of the same dimensions were

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* On the Recovery of Iron from Over-strain, Phil. Trans. Royal Soc., series A, vol. xciii, pp. 1–46.

employed, but in which the deformation was carried on very slowly, being extended over a period of 30 days, and in which the marble after deformation was allowed to remain in its enclosing steel tube for two years, after which time the steel tube was turned off in the usual way and the marble tested in compression to determine its strength. As will be seen by consulting the table on page 479, under these conditions of slow deformation and long, subsequent rest, the deformed marble is but little weaker than the original rock, its strength being on an average 84·7 per cent of that which it originally possessed, while one of the deformed columns in this series showed a strength greater than the average strength possessed by the columns of the original rock.

Another series of three experiments, the results of which were published in a former paper, show that slow deformation alone conduces to increase of strength. In these experiments the deformation was carried on in wrought iron tubes, and at the conclusion of the experiments the tubes, instead of being placed in a lathe and turned off from the enclosing marble, were sawn in two vertically and the half columns of marble thus obtained. These when tested in compression gave the following results :

	Original height	Original diameter	Greatest diameter after deformation	Time of deformation	Crushing load for deformed marble, lbs. per square inch
Experiment A	1·594	1·000	1·407	64 days	5350
" O	1·594	1·000	1·203	1½ hours	4000
" P	1·505	1·000	1·388	10 minutes	2776

These values cannot be used for comparison with those of the former table owing to the fact that the shapes of the test pieces in the two series of experiments were quite different, but compared with one another we see clearly that slow deformation conduces greatly to the preservation of strength.

2. *Deformation of the dry marble when heated to temperatures of 300° C. and 400° C.*

In a former paper an account has been given of the deformation of the marble at these temperatures. Debray* has shown that calcite when heated in closed vessels to a temperature of 350° C. suffers no decomposition, that at 440° C. the decomposition is "insensible," while at 860° C. the disassociation of the molecule of carbonate of lime is marked. In the experiments carried out at 400° C., therefore, it would seem that the marble was deformed at the highest temperature which could be employed without danger of decomposition under atmospheric conditions of pressure.

* Comptes Rendus, 1867, p. 603.

In these experiments, as in the case of those on page 479, the deformation was carried out at comparatively low pressures. The marble after deformation was hard and solid. Tested in compression it was found to be nearly as strong as the original marble. When sliced and examined under the microscope, the rock showed no trace of cataclastic structure, but the grains were seen to be distinctly flattened, giving to the rock a foliation which in some places was very pronounced. The calcite individuals showed the very narrow polysynthetic twinning producing the fibrous appearance before described. The twin lamellæ were in some cases twisted, the twisting being accompanied by strain shadows, which phenomenon, however, in this rock was neither very common nor very striking. The individual grains had to all appearance acted as plastic bodies. A very pronounced movement along gliding planes, coinciding in direction with the course of twin lamellæ, is undoubted. This movement, induced by comparatively low pressures at this elevated temperature, is identical in character with that produced by very high pressures at the ordinary temperatures. In both the movement is due to translation and twinning; breaking or cataclastic structure is absent.

The increased temperature evidently gives the calcite a freer movement on its planes of translation and twinning,—the rise in temperature increases its plasticity. In the case of ice crystals, as is well known, a rise in temperature develops similarly a greater ease of movement along the gliding planes.

3. *Deformation of the marble when heated to 300 C. in the presence of water.*

In the series of experiments formerly made, in addition to heat and pressure a third factor, viz., the presence of moisture, was introduced. A column of Carrara marble enclosed in its iron tube was slowly deformed while at a temperature of 300° C., but in the presence of water vapor under a pressure of 460 lbs. to the square inch (32·33 kilos. per square cm.). The apparatus used for the purpose of this deformation is described in the paper to which reference has already been made. This deformation was carried on very slowly, and at as uniform a rate as possible, the experiment extending over a period of 54 days or nearly two months. Tested in compression, the rock after deformation was slightly stronger than the original rock. Its structure was found to be identical in character with that seen in the case of the marble which had been deformed at 300° C. or 400° C. while dry. A distinct foliation was induced, some of the calcite individuals being three or even four times as long as they were wide. Some few of these flattened grains displayed strain shadows, but no twinning, while the grains in their immediate vicinity showed well-

defined twinning, giving rise to the fibrous appearance before described. In some cases a grain showed strain shadows at one end which passed over into a very narrow polysynthetic twinning at the other. The twin lamellæ in many cases are so narrow that even when magnified 1050 diameters they are not very clearly resolved. The individual lamellæ in several sets which were measured were found to have an average width of between ·0005 and ·0006 of a millimeter (·00001968 inch and ·00002361 inch), and some were even narrower.

While the rock was deformed without loss of strength, the presence of water, so far as could be ascertained, did not influence the character of the deformation. It is just possible, however, that there may have been a deposition of infinitesimal amounts of calcium carbonate along very minute cracks or fissures, thus contributing to maintain the strength of the rock. No signs of such deposition, however, were visible.

4. *Specific gravity of the marble after deformation.*

In order to determine whether as a result of deformation under high differential pressures, the specific gravity of the marble was in any way altered, the specific gravity of two specimens of deformed marble was taken as well as the specific gravity of two specimens of the original rock.

The first specimen of deformed marble, " A," had been deformed at ordinary temperatures in a tube of nickel steel 1^{cm} thick, the experiment being carried out in 100 minutes, the pressure required to effect its deformation being 340,000 lbs. to the square inch. The second specimen of deformed marble, " B," had been deformed in a steel tube at a temperature of 400° C. in eight and a half hours at a pressure of 63,000 lbs. to the square inch. Both specimens of the deformed marble when placed in water showed at once that they were traversed by minute fissures, as a considerable amount of air was discharged in the form of minute bubbles. Specimen " A " was allowed to soak in the water until no further bubbles appeared. The rock when so treated was found to have a specific gravity of 2·65. The rock was then placed under water in an air pump. When the pump was worked additional air bubbles appeared, and the rock was allowed to remain under the vacuum until no further air was given off. After this treatment the rock was found to have the specific gravity stated in the accompanying table. In the case of specimen " B," the deformed rock was evidently more solid and compact, as less air was given off. This gives a partial explanation at least for its greater strength, it being evidently freer from minute cracks and fissures.

The following table shows the specific gravity obtained in the case of the various specimens:

Original marble—1st specimen.

<div style="text-align:right">Specific
gravity</div>

    Specific gravity after the rock had been placed in water under a vacuum of $28\frac{1}{2}$ inches of mercury for 24 hours _____ ___   2·722

Original marble—2d specimen.

    After treatment in a similar manner _____   2·722

<div style="text-align:right">Average_____   2·722</div>

Deformed marble—specimen "A," 1st fragment.

    After having been placed in water under a vacuum of 28 inches of mercury until no further air was given off _____   2·712

Deformed marble— specimen "A," 2d fragment.

    Treated in vacuo in the same manner for 24 hours, no further air bubbles being given off _____   2·717

Deformed marble—Specimen " B."

    After having been placed under water in vacuo for 24 hours, until no further air was given off_____   2·713

<div style="text-align:right">Average_____   2·714</div>

The comparison thus stands :

    Original marble _____   2·722

    Marble after deformation _____   2·714

<div style="text-align:right">Difference _____   ·008</div>

This may be taken to mean that the marble remains unchanged in specific gravity by deformation, but that in the deformed marble some of the little cracks or crevices developed in the rock on relief of pressure still remain, into which the water can not penetrate, and which give rise to the slightly lower specific gravity of the deformed rock. In this connection it is to be noted that specimen " A " could not be tested for strength on account of the minute fissures by which it was traversed and which were developed upon the relief of pressure incident to the removal of the steel tube in which it was enclosed during deformation, while specimen " B," which gave off comparatively few air bubbles, had the appearance of being much more solid.

    In connection with these results it is interesting to note the results of the investigations carried out by Spring[*] on the specific gravity of the sharply folded limestones in the Alps. In these he found that the specific gravity of the limestone on the concave side of a sharp fold, where the pressure of course is greatest, was slightly higher (·003 to ·023) than on the convex side of the same fold. This he at first interpreted as

[*] Note sur la véritable origine de la différence des densités d'une couche de calcaire dans les parties concaves et les parties convexes d'un meme pli ; Ann. Soc. Géol. de Belgique, xl, p. 4, 1883-4.

meaning that there had actually been a permanent condensation of the calcite by the greater pressure to which it had been subjected in folding. Further investigation, however, showed that the slightly lower specific gravity of the rock on the outer side of the fold was due to the presence in it of minute rifts or pores which were wanting in the rock on the more highly compressed inner side, the limestone itself really being of the same specific gravity throughout.

Conclusions.

1. Marble when deformed at ordinary temperatures will flow readily by distortion of the original calcite grains, accompanied, if the differential resistance be low, with the development of a certain amount of cataclastic structure.

2. The marble when deformed at ordinary temperatures will increase in strength if allowed to rest.

3. The marble, if deformed at ordinary temperatures, will be much stronger if the deformation be carried on slowly than if the deformation be rapid. There is every reason to believe that with the extreme slowness of deformation to which the rock is subjected in nature, and the long rest which it subsequently undergoes, the change in shape would be accomplished without any loss of strength.

4. If the deformation be carried on at a higher temperature, the calcite develops freer movement on its gliding planes, and the deformed rock will be relatively stronger than if deformed at the ordinary temperature.

5. Under the conditions to which the rock is subjected in these experiments,—although not under all conditions,—the presence of water has no recognizable influence on the character of the deformation.

6. The specific gravity of the rock is not increased by the pressure to which it is subjected during deformation.

McGill University, Montreal, Canada.

EXPLANATION OF PLATES.

PLATE II.

a. Wrought iron tube enclosing marble column after compression.

b. Column of marble, before and after compression, under a load of 296,725 pounds per square inch (20,875 kilos. per square centimeter). The finer lines of the scale are 1 millimeter apart.

PLATE III.

a. Carrara marble, original. × 60.

b. Carrara marble, caused to flow under pressure of 296,725 pounds per square inch. × 40.

PLATE IV.

Tube with its enclosed column of Carrara marble, cut open after deformation. The finer lines of the scale are 1 millimeter apart.

Art. XLIII.—*The Heat of Formation of the Oxides of Molybdenum, Selenium and Tellurium ; and fifth paper on the Heat of Combination of Acidic Oxides with Sodium Oxide;* by W. G. Mixter.

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

Molybdenum.

Thermal chemistry of molydenum is lacking, owing, perhaps, to the difficulty of burning the metal completely in oxygen. It is remarkable, however, that neither Thomsen nor Berthelot recorded any experiments with it. The writer tried burning molybdenum mixed with carbon for ignition and to supply heat to volatilize the trioxide formed, and the result was imperfect oxidation of the metal. Hence the indirect method with peroxide was used.

Metallic molybdenum for the work was prepared as follows : Compact pellets of pure trioxide were heated in an electric furnace in a porcelain tube through which pure dry hydrogen was passed. The metal obtained was in the form of a gray coherent mass and portions adhering to the tube were rejected.* It was rubbed up in a mortar and passed through a fine sieve. The purity of the metal was determined as follows : It was oxidized by nitric acid, the acid removed by evaporation and the residue cautiously heated until it ceased to lose weight. The following are the analytical data :

	I	II
Metal taken	1·0505	1·1771
Molybdenum trioxide obtained	1·5750	1·7653
Oxygen taken up	0·5245	0·5882
Molybdenum equivalent to oxygen taken up	1·049	1·1764
Per cent of molybdenum as metal	99·86	99·84

While the results indicate that the reduction by hydrogen was not quite complete, very likely there was some loss in oxidizing the metal or in heating the trioxide. Hence the metal was considered pure and no correction was made for 0·15 per cent of oxygen which the above results indicate. The trioxide obtained dissolved completely in ammonia, showing the absence of silica and alumina.

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* Debray (C. R. lxvi, 732) found that molybdenum trioxide affects porcelain at high temperatures. To avoid this the reduction was first tried in a thin platinum tube contained in a porcelain tube. The platinum was made quite brittle and the molybdenum obtained was very slowly acted on by nitric acid. The reason of the action on the platinum was not investigated. In the reduction, where pellets of the trioxide were in contact with the porcelain tube, the porcelain was slightly attacked and the molybdenum adhering to it was found to have taken up a little iron.

The results of burning the metal with sodium peroxide are as follows :

	1	2
Molybdenum	7·000 grams	7·000 grams
Sodium peroxide	25· "	25· "
Water equivalent of system	3,960· "	4,047· "
Temperature interval	3·803°	3·720°
Heat effect	15,060^c	15,055^c
" of oxidation of iron	—48^c	—48^c
" " oxygen absorbed	—31^c	—52^c
	14,981^c	14,955^c
For 1 gram of molybdenum	2,140^c	2,136^c

The mean is 2,138 and for 96 grams of molybdenum it is 205,248^c.

From this result and the heat of union of sodium oxide with molybdenum trioxide found in experiments 3, 4, and 5, the heat of oxidation of molybdenum to the trioxide is derived as follows :

$$3Na_2O_2 + Mo = Na_2MoO_4 + 2Na_2O + \text{............} \quad 205·2^c$$
$$3Na_2O + 3O = 3Na_2O_2 + \text{.....................} \quad 58·2^c$$

$$Na_2O + Mo + 3O = Na_2MoO_4 + \text{................} \quad 263·4^c$$
$$Na_2O + MoO_3 = Na_2MoO_4 + \text{....................} \quad 81·9^c$$

$$Mo + 3O = MoO_3 + \text{..............................} \quad 181·5^c$$
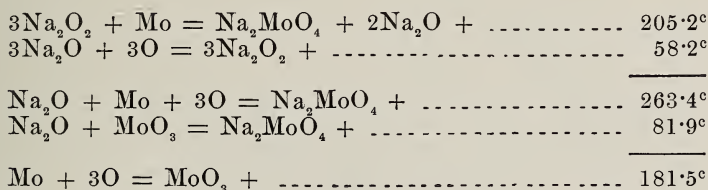
Molybdenum trioxide used in the following experiments was heated in a porcelain crucible to expel moisture, allowed to cool in a desiccator and weighed. Sulphur or acetylene carbon was added to the mixture of the trioxide and sodium dioxide to reduce the latter to oxide and also to furnish heat necessary for fusion. It will be observed that where carbon was used the amount of oxygen evolved was large although sodium oxide was formed in excess of the amount equivalent to the molybdenum trioxide. The following are the experimental results :

	3	4	5
Molybdenum trioxide	7·501 gr.	5·115 gr.	8·140 gr.
Carbon	0·618 "	0·546 "	
Sulphur	----	----	2·000 "
Sodium peroxide	17· "	12· "	21· "
Water equivalent of system	4,164· "	4,018· "	4,196· "
Temperature interval	2·515°	2·145°	3·616°

Heat effect _____	$10,472^c$	$8,619^c$	$15,173^c$
" of oxygen set free___ _____	$+796^c$	$+362^c$	$+39^c$
" " oxidation of carbon__	$-6,876^c$	$-6,075^c$	
" " " " sulphur _	____	____	$-10,542^c$
" " " " iron ____	-48^c	-48^c	-48^c
	$4,344^c$	$2,858^c$	$4,622^c$
For 1 gram of MoO_3_____ ____	579^c	559^c	568^c

The mean is 569^c and for 144 grams it is $81,936^c$.

It was shown[*] that the heat effect of $3Na_2O,R_2O_5$, in which R is phosphorus, arsenic or antimony, is closely related to the

FIG. 1.
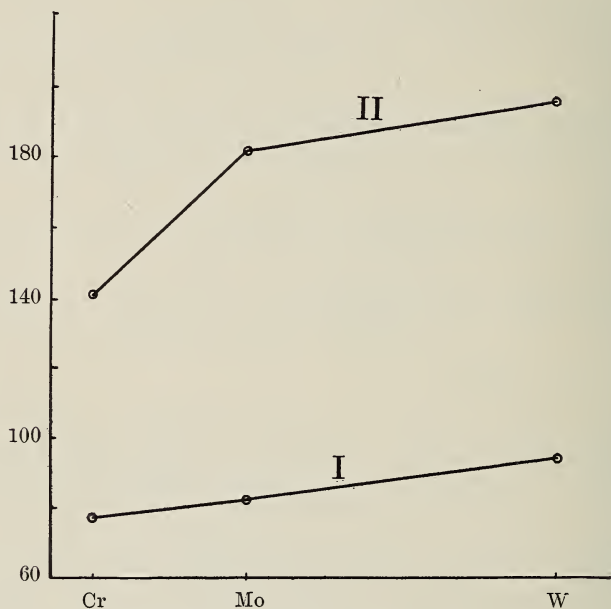
atomic weights of these elements. The same relation appears in the sub-group of chromium, molybdenum, and tungsten. In the figure the atomic weights are plotted as abscissas and the heats of combination as ordinates. The line I indicates the heat of the reaction Na_2O,RO_3, and II of R,O_3.

Molybdenum Dioxide.

Molybdenum dioxide was made by reducing the trioxide as follows: a 100^{cc} pipette was weighed, filled with molybdenum

[*] This Journal, vol. xxviii, 103, 1909.

trioxide, heated in an electric furnace to expel moisture, then the tube was closed with stoppers, allowed to cool and weighed. The reduction was made with pure dry hydrogen at temperatures between 410° and 440° approximately. It required 76 hours and in the last four hours the loss was 20 milligrams. The original weight of the trioxide was 49·795 grams and the total loss in weight 6·175 grams. The composition calculated from these data is MoO_2 99·11 per cent and MoO_3 0·89 per cent. It was not deemed best to try to complete the reduction at a higher temperature than used on account of danger of reducing some of the substance to the metallic state. The following are the experimental data :

	6	7	8
Molybdenum dioxide	10·123 gr.	12·028 gr.	12·000 gr.
Sodium peroxide	13· "	15· "	16· "
Water equivalent of system	3,918· "	3,989· "	4,037· "
Temperature interval	1·802°	2·085°	2·08°
Heat effect	7,060ᶜ	8,317ᶜ	8,397ᶜ
" of oxygen set free	+1,136ᶜ	+1,117ᶜ	+1,128ᶜ
" " oxidation of iron	−48ᶜ	−48ᶜ	−48ᶜ
	8,148ᶜ	9,386ᶜ	9,477ᶜ
For 1 gram of MoO_2	805ᶜ	780ᶜ	789ᶜ

The fusions were good and dissolved in water with evolution of oxygen and no black residue remained. The oxygen set free in the bomb was collected in a flask over water and the volume of it found by weighing the flask containing it, then filling with water and weighing again. The number of cubic centimeters of oxygen at 0° and 760ᵐᵐ multiplied by 1·73 gave the number of calories lost by the change of sodium peroxide to oxide. If the experimental data above are reduced, allowing for the presence of 0·9 of 1 per cent of trioxide in the dioxide used, the result is not essentially different from that given. The mean for 1 gram of molybdenum dioxide is 791ᶜ and for 128 grams it is 101,200ᶜ.

The following are the results of the experiments with molybdenum :

$$Na_2O + MoO_2 = Na_2MoO_4 + \text{................} \quad 101,200ᶜ$$
$$Na_2O + O = Na_2O_2 + \text{.....................} \quad 19,400ᶜ$$

$$Na_2O + MoO_2 + O = Na_2MoO_4 + \text{...........} \quad 120,600ᶜ$$
$$Na_2O + MoO_3 = Na_2MoO_4 + \text{................} \quad 81,900ᶜ$$

$$MoO_2 + O = MoO_3 + \text{.......................} \quad 38,700ᶜ$$
$$Mo + 3O = MoO_3 + \text{........................} \quad 181,500ᶜ$$
$$Mo + 2O = \text{.............................} \quad 142,800ᶜ$$

Selenium.

Determinations were made of the heat effect when gray metallic selenium is burned with sodium peroxide, using 5 to 10 grams of the former for a test. The mixture fused imperfectly. The water solution of the fusions after acidifying with hydrochloric acid gave no precipitate of selenium when sulphurous acid was added, showing that only selenic acid was present. This was confirmed by the fact that a nitric acid solution of the fusions did not decolorize permanganate. The results for 1 gram of selenium were 1216^c, 1208^c, and 1208^c; average 1211^c. For 79.2 grams it is $95,900^c$.

Two combustions were made of a mixture of crystalline selenium dioxide, sodium peroxide, and sulphur. 13.940 and 7.652 grams of selenium dioxide were taken respectively. The results for 1 gram of SeO_2 were 644^c and 588^c. Two other determinations were made, taking 6.118 and 7.109 grams of selenium dioxide and an excess of sodium peroxide. These two fusions were good and oxygen was not liberated, proving conclusively that all of the SeO_2 was oxidized to SeO_3, and that the reaction was $Na_2O_2 + SeO_2 = Na_2SeO_4$ and not $Na_2SeO_3 + O$. The heat effect for 1 gram of SeO_2 was 617^c and 637^c. The fusion giving 588^c contained some sodium selenite and the result should be discarded. The average of the remaining three is 632^c and of the two highest results it is 640^c. This last number multiplied by 111.2 gives 71.200^c for the heat effect of Na_2O_2, SeO_2.

The results of the combustions of sodium peroxide are as follows:

$$3Na_2O_2 + Se = Na_2SeO_4 + 2Na_2O + \text{-----------} \quad 95.9^c$$
$$3Na_2O + 3O = 3Na_2O_2 + \text{-------------------} \quad 58.2^c$$

$$Na_2O + Se + 3O = Na_2SeO_4 + \text{----------------} \quad 154.1^c$$

$$Na_2O_2 + SeO_2 = Na_2SeO_4 + \text{------------------} \quad 71.2^c$$
$$Na_2O + O = Na_2O_2 + \text{------------------------} \quad 19.4^c$$

$$90.6^c$$

The heat of formation of crystalline selenium dioxide derived from these results is $154.1 - 90.6 = 63.5^c$. Thomsen's figures are 57.1^c derived from the heat effect when the dioxide is reduced in hydrochloric acid solution by sodium hydrosulphide and also from the heat of formation of $SeCl_4$ and its hydrolysis. His results by the two methods are practically identical. Thomsen used amorphous selenium and the writer the grey metallic modification, and as the change of the amorphous form into the crystalline evolves heat the writer's results would have been a little higher had he used amorphous selenium. The reason

for the difference of 6.4^c between Thomsen's result and the writer's is not apparent. He stated that the hydrolysis of $SeCl_4$ is complete and is probably right in this view since selenium dioxide dissolves in dilute hydrochloric acid without appreciable heat effect.

R. Metzner[*] found the heat of H_2SeO_4,Aq to be the same as that H_2SO_4,Aq. On the assumption that the heat effect of SeO_3,H_2O is the same as SO_3,H_2O, he calculated that $Se + 3O = 42.1^c$, using $Se,3O,Aq = 76.660^c$ (T). That is, $SeO_2 + O = -14.4^c$. This explains, according to Metzner, why SeO_3 can not be isolated. The view that $SeO_2 + O$ is an endothermic reaction accords with the results of the experiments with sodium peroxide. The observed heat effect of Na_2O_2,SeO_2 is 90.6^c; adding 14.7^c, the heat absorbed by the oxidation of SeO_2 gives 105.3^c for the heat effect of $Na_2O,-SeO_3$. If we consider $Se,2O = 63.5$ and subtract 14.7^c we have for $Se,3O = 48.8^c$ and

$$Na_2O + Se + 3O = \text{\dotfill} 154.1^c$$
$$Se + 3O = \text{\dotfill} 48.8^c$$
$$Na_2O + SeO_3 = \text{\dotfill} 105.3^c$$

This result is identical with that found from the reaction between Na_2O_2 and SeO_2, but substituting another number for 14.7 in the calculation will give equal numbers. The heat of formation of Na_2SeO_4 in solution calculated from Thomsen's data is 262.3^c; subtracting 99.8 for the heat effect of $2Na,O$ gives 162.5^c for $Na_2O,Se,3O$. The heat of solution of Na_2SeO_4 has not been determined but it is negligible, as a rough test with 15 grams of Na_2SeO_4 in 200^{cc} of water gave a rise of approximately 0.1^c. The writer is unable to explain why 154.1^c obtained by burning selenium with sodium peroxide is so much lower than the number derived from Thomsen's experiments.

It should be stated that attempts were made to determine the heat of formation of selenium dioxide by burning in a bomb a mixture of selenium and charcoal. In one instance the bomb was filled with a crystalline mass of selenium dioxide, but the combustion was incomplete. In other experiments the mixture burned only on the surface.

Tellurium.

The tellurium used in the work was purified by dissolving the crude metal in acid and making a fractional precipitation with sulphur dioxide or by recrystallizing the nitrate. The precipitated tellurium was fused in hydrogen. Tellurium and

[*] Ann. Ch. Phys. (7), xv, 225.

its dioxide do not burn well with sodium peroxide and sulphur was added to supply the heat requisite for combustion. Tellurium dioxide was obtained by heating the nitrate and fusing the residue. Telluric acid was prepared by Staudemaier's[*] method by oxidizing the dioxide with chromium trioxide. The telluric acid was slowly heated in an electric furnace to 375–400° and until a sample did not yield water on melting. The per cent of trioxide was calculated from the loss of oxygen on heating a weighed portion until the weight was constant. It was considered better to correct for tellurium dioxide present than to attempt to remove it by hydrochloric acid. Two different preparations of tellurium trioxide were used. That for Experiment 5 contained 80·8 per cent of trioxide, and for 6, 91·3 per cent. The following are the experiments:

	1	2
Tellurium	5·000 grams	6·000 grams
Sulphur	1·000 "	1·000 "
Sodium peroxide	20· "	30· "
Water equivalent of system	3,866· "	4,032· "
Temperature interval	2·883°	3·096°
Heat effect	11,146^c	12,483^c
" " of sulphur	−5,271^c	−5,271^c
" " " iron	−48^c	−48^c
" " " oxygen absorbed	−34^c	−34^c
	5,793^c	7,130^c
For 1 gram of tellurium	1,159^c	1,188^c

The result for 127·5 grams of tellurium is 149,700.

	3	4
Tellurium dioxide	10·000 grams	10·000 grams
Sulphur	1·000 "	1·000 "
Sodium peroxide	21· "	21· "
Water equivalent of system	3·906· "	3·896 "
Temperature interval	2·968°	2·978°
Heat effect	11,593^c	11,602^c
" " of oxygen evolved	+51^c	+110^c
" " " sulphur	−5,271^c	−5,271^c
" " " iron	−48^c	−48^c
	6,325^c	6,393^c
For 1 gram of tellurium dioxide	633^c	639^c

[*] Zeitschr. anorgan. Chem., x, 189.

The result for a gram molecule of tellurium dioxide is
$159.5 \times 636 = 101.400^c$.

Substance taken	5		6	
Substance taken	10·060 grams		6·000 grams	
Composition of { TeO$_3$	8·209	"	5·478	"
substance { TeO$_2$	1·951	"	0·522	"
Sulphur	1·000	"	0·800	"
Sodium peroxide	16·	"	14·	"
Water equivalent of system	3,963·	"	3,152·	"
Temperature interval	2·802°		2·537°	
Heat effect	11,104^c		7,996^c	
" " of oxygen evolved	+1,072^c		+636^c	
" " " TeO$_2$	−1,241^c		−332^c	
" " " iron for ignition	−48^c		−48^c	
" " " sulphur	−5,271^c		−4,216^c	
" " " TeO$_3$	5,616^c		4,036^c	
For 1 gram of TeO$_3$	684^c		737^c	

The mean of the results is 708, which gives for the reaction
$Na_2O + TeO_3 = Na_2TeO_4 + 175.5 \times 708 = 124,300^c$.

Summary of results.

$3Na_2O_2 + Te = Na_2TeO_4 + 2Na_2O + \ldots \ldots 149.7^c$
$3Na_2O + 3O = 3Na_2O_2 + \ldots \ldots 58.2^c$

$Na_2O + Te + 3O = Na_2TeO_4 + \ldots \ldots 207.9^c$
$Na_2O + TeO_3 = Na_2TeO_4 + \ldots \ldots 124.3^c$

$Te + 3O = TeO_3 + \ldots \ldots 83.6^c$

$Na_2O_2 + TeO_2 = Na_2TeO_4 + \ldots \ldots 101.4^c$
$Na_2O + O = Na_2O_2 + \ldots \ldots 19.4^c$

$Na_2O + TeO_2 + O = Na_2TeO_4 + \ldots \ldots 120.8^c$

The heat of formation of crystalline tellurium dioxide is
$207.9 - 120.8 = 87.1$. Thomsen's result of 77.2^c for TeO$_2$Aq is
too low since TeCl$_4$ does not hydrolyze completely. The
result of experiments 5 and 6 giving 124.3^c for the heat of
combination of Na$_2$O and TeO$_3$ is to be considered as approxi-
mate only on account of the large correction for oxygen set
free, and hence the heat of formation of TeO$_3$ derived is to be
regarded as an approximation. Since the trioxide and dioxide
of tellurium give nearly the same heat when fused with
sodium peroxide, it is evident that the oxidation of crystalline

TeO_2 is accompanied by little or no heat effect. The results indicate that the reaction is slightly endothermic.

The heat effect of Na_2O,SO_3 derived from Thomsen's data is $125 \cdot 6^c$ and from the writer's[*] $123 \cdot 7^c$. That of Na_2O,TeO_3 is $124 \cdot 3$ approximately. If we take $162 \cdot 5^c$ based on Thomsen's results and subtract $Se,3O = 42 \cdot 4^c$, we have $120 \cdot 1^c$ for $Na_2O,-SeO_3$. The heat of the reaction Na_2O,RO_3 where R is sulphur, selenium or tellurium, is probably nearly the same in all cases. This much is however, evident, that it does not increase or diminish notably with increasing atomic weights as it does in the reaction Na_2O,R_2O_5 where R is phosphorus, arsenic, antimony, and bismuth,[†] or in Na_2O,RO_3, where R is chromium, molybdenum and tungsten. Moreover the heat effect of Na_2O-RO_3 is in all cases higher where R is sulphur, selenium or tellurium, than where R is chromium, molybdenum or tungsten.

[*] This Journal, vol. xxvi, 125.   [†] Loc. cit.

Art. XLIV.—*Contributions to the Geology of the Grand Canyon, Arizona.—The Geology of the Shinumo Area* (continued); by L. F. Noble. (With Plate V.)

Part II.

Algonkian.

Grand Canyon Series.

Name.—The unaltered pre-Cambrian sedimentary rocks of the Grand Canyon region were first studied by Walcott (Walcott, *b*) at the eastern end of the Kaibab division of the Canyon. They are described as a series of sedimentary rocks, 12,000 feet in thickness; comprising limestones, shales, sandstones, and interbedded flows of lava; separated both from the underlying Vishnu schists and from the overlying Cambrian sediments by profound unconformities; and exposed over a considerable area in the greater depths of the Grand Canyon and in the inter-canyon valleys of the north side. To this series of sedimentary rocks the name " Grand Canyon series" was given by Walcott. A slight unconformity of erosion was found to occur in the middle of the series. The strata lying below this minor unconformity were designated as the "Unkar terrane," while those lying above it were designated as the " Chuar terrane." The Unkar terrane derives its name from Unkar valley, in which these strata are typically exposed. The Chuar terrane is named from its typical exposures in Chuar valley. These two valleys are parallel inter-canyon valleys of the north side of the Colorado river in the area described by Walcott.

Distribution in the Grand Canyon.—There are six localities within the Grand Canyon between the mouth of the Little

Colorado in the eastern end of the Kaibab division and the mouth of Tapeats Creek some 80 miles below in the eastern end of the Kanab division, where the strata of the Grand Canyon Series are exposed between the crystalline schists of the Archean and the basal Tonto sandstone of the Cambrian. The location of these exposures is shown on the map accompanying this article.   Five of the localities are within the Kaibab division; the sixth is within the Kanab.

The first of these localities is the classic area below the mouth of the Little Colorado described by Walcott.   This is the largest areal exposure of these rocks in the Grand Canyon, and includes both the Unkar and Chuar groups.

The second locality lies five miles west of the first at the head of the inner gorge of Clear Creek on the north side of the Colorado river within the depths of the Ottoman Amphitheater.   The exposure is limited to less than a square mile. It comprises a small portion of the basal Unkar and is structurally a unit with the first locality.

The third locality lies along the north side of the Colorado river at the mouth of Bright Angel Creek opposite the railroad terminus and hotels of the Sante Fe Railroad.   About 1000 feet of the basal portion of the Unkar group are there represented and the areal extent of the exposure is about three square miles.   This locality has been briefly described by Ransome (Ransome, *a*).   It lies about 10 miles west of the type locality.

The fourth locality comprises a limited exposure of basal Unkar strata which lies in the depths of the Hindu Amphitheater on the north side of the Colorado river about three miles up Crystal Creek from its mouth.   It is situated some 20 miles west of the type locality.   The areal extent of the exposure is about one square mile.   It is as yet undescribed.

The fifth locality lies about the mouth of Shinumo Creek about 30 miles west of the exposures of the type area.   It comprises about 12 square miles in areal exposure and represents nearly the entire thickness of the Unkar group.   It is hitherto undescribed in geological literature and is the subject of the succeeding pages of this article.

The sixth locality is situated on the Colorado river just above the mouth of Tapeats Creek in the eastern end of the Kanab division of the Canyon, about 12 miles northwest of the mouth of the Shinumo in a direct line and about 25 miles down the river in its actual course.   The length of the exposure is about three miles in the bed of the river and in its narrow gorge beneath the Tonto sandstone.   About 4,000 feet of the basal portion of the Unkar group are exposed, striking N.W.–S.E. and dipping about 15° N.E.   This locality is

structurally a unit with the exposures of the Shinumo area. It is unmentioned in geological literature.

In the western end of the Kanab division in a section across the Grand Canyon at the foot of Toroweap valley, 50 miles west of the Shinumo area, Dutton figures " rocks of Silurian and Archean unconformable" in the bed of the river beneath the basal Tonto sandstone of the Cambrian (Dutton, *a*, p. 88). It is probable that these " Silurian" rocks there represent the Grand Canyon series.

Whether these rocks appear at places in the Shivwits division between the Vishnu schist and the Tonto sandstone is not at present known.

Stratigraphic position, structure, and distribution in the Shinumo Area.—Two unconformities determine the stratigraphic position of the sediments of the Grand Canyon series in the Shinumo Area : they are separated from the underlying Vishnu schists of the Archean by a profound unconformity which represents a base-leveled surface of erosion, and from the overlying Tonto sandstone of the Cambrian by an unconformity which represents a similar base-leveled surface above.

The strata of the Grand Canyon series here constitute a wedge-shaped mass whose apex lies along the south side of the Colorado river parallel to its northward course in this part of the area. The mass as a whole constitutes one great tilted block, which in turn consists of a great number of minor tilted and rotated blocks pitching at successively greater angles northeast away from the apex of the wedge, until at a distance of three miles from the Colorado river the whole mass is dropped by a profound fault which brings up the underlying Vishnu schist from a great depth,—a structure which strikingly resembles that of the area of similarly faulted Triassic blocks of the Connecticut valley. The strike of the strata is N. 40° W. The dips are variable : in general the strata of the fault blocks near the apex of the wedge dip 10°–15° N.E.; near the center of the wedge the dips average 25° N.E.; while in proximity to the line of the great limiting fault on the northeast they are completely reversed by the " drag " along the fault plane. The truncation of this pre-Cambrian structure by the unconformity at the base of the Tonto sandstone is absolute.

The great pre-Cambrian fault that limits the wedge upon the northeast represents the exposure in the basement rocks of the line of displacement of the West Kaibab fault and displays in the most spectacular manner a phenomenon analogous to that described by Walcott upon the line of the East Kaibab monocline (Walcott, *a*). Upon the line of the ancient fault in the Shinumo area two later displacements have taken place after

the deposition of the entire Paleozoic series of the Canyon wall and probably later strata. The first of these is a monoclinal flexure which reverses the throw of the pre-Cambrian fault, while the second is a still more recent fault superimposed upon the line of the monoclinal flexure.

The strata of the Grand Canyon series are exposed beneath the Tonto sandstone in all that part of the inner gorge of the Muav-Flint Creek canyon which is on the south side of the great pre-Cambrian fault,—a distance of about three miles. They are exposed for three miles in the gorge of the Shinumo Canyon; for seven miles along the north side of the Colorado river; and in all the inter-canyon valleys within that distance which are eroded below the base of the Tonto sandstone. The two largest of these inter-canyon valleys are the "East Wash," a mile east of the Shinumo, and the "Asbestos Canyon," three miles to the west.

The gorge of the Colorado river has everywhere been trenched to a depth sufficient to expose the Vishnu schists along the river beneath the overlying strata of the Grand Canyon series. This is due to the fact that the course of the river lies close along the southern apex of the wedge.

The exposures on the south side of the river are more limited, due to the thinning out of the wedge in that direction and the lack of inter-canyon valleys trenched beneath the Tonto sandstone. The strata are exposed for two miles above and one mile below a point opposite the mouth of the Shinumo.

A southwestward bend in the river in the western part of the area carries it beyond the apex of the wedge, below which point the Tonto sandstone caps the Vishnu schists which lie in the river gorge. Southeastward up the river, in the eastern part of the area, a similar relation obtains.

The hard middle members of the Unkar resisted the erosion which preceded the deposition of the Cambrian sandstone and stood as an island in the Tonto sea.

This long monadnock of quartzite runs across the area in a N.W.–S.E. direction parallel to the general strike of the strata of the wedge, and a narrow outcrop of these quartzites is exposed along the Tonto platform on the north side of the river just at the base of the Redwall cliff, running for a distance of about five miles beyond the main areal exposures about the mouth of the Shinumo and uniting with the limestones of the upper Tonto group to form the lower part of the great cliff of Redwall limestone. In the eastern part of this exposure the quartzite monadnock projects 700 feet above the base of the Tonto sandstone. Westward from the exposures about the Shinumo the prolongation of the monadnock along the strike of the quartzites exposes them in a narrow outcrop upon the Tonto platform one mile west of the Shinumo.

The total areal exposure of the Grand Canyon series in the Shinumo area is about 12 square miles.

In following up the Shinumo from its mouth to the point where it leaves the lateral gorge of the Muav-Flint Creek canyon, a traverse is made of the total exposed thickness of the Unkar group from the unconformity at the base to the highest member that is limited by the profound fault on the northeast. There can hardly be a more magnificent illustration of details of geological structure than is here revealed. Along the entire western side of the Shinumo canyon, in cliff faces a thousand feet above the bed of the stream, is displayed every detail of the structure beneath the basal Tonto sandstone. Westward down the Colorado river the intersection of the two great unconformities forming the apex of the wedge is seen in the cliff face above the river bank, below which point the river narrows in its somber gorge in the Vishnu schists. From here northeastward, in the cliff faces along the western wall of the Shinumo canyon, bed after bed of the Unkar strata appears, wedging out southwestward beneath the plane of the unconformity beneath the Tonto sandstone. Every detail of the successive fault blocks of the great wedge is clearly shown,—their increasing tilt northeastward, the dips of the fault planes that bound them, and the occasional down-dropped wedges. Above runs the plane of the pre-Tonto unconformity, revealing in cross section the monadnock in this peneplain which existed as a rocky island during the inroads of the Tonto sea, the debris from its wave-cut cliffs being incorporated and preserved to the minutest detail in the Tonto sandstone. In the background, bed above bed in conformable succession, lies the horizontal Paleozoic section in the wall of the mile-deep Canyon. After traversing a thickness of 5800 feet of Unkar strata in a distance of three miles dipping northeastward into the bed of the stream, the traveler crosses the line of the great pre-Cambrian fault of more than 5800 feet and comes once more into the Vishnu schists on the farther side of the Muav-Flint Creek canyon.

Here again is an instance of the simplicity with which the geological structure is revealed in this wonderful country. Along the whole northern wall of the lateral gorge lie the Vishnu schists below the Tonto sandstone cliff. On the southern side, at the same level, lie the upper sandstones of the Unkar, their beds dragged up sharply against the fault line, which lies in the bed of the stream. The whole Paleozoic system on the northern side of the gorge has been dropped 500 feet by the torn monocline of the West-Kaibab fault, reversing the throw of the pre-Cambrian fault on the same line in the basement rocks. Looking westward up the Muav Canyon, the beds of the Paleozoic are seen bending down

against the fault line in a graceful arc. Far up the canyon at its head under the Muav Saddle, the more recent fault has reversed its throw and restored the throw of the monoclinal flexure. There is not a detail of this structure that may not be seen at a glance.

Sediments of the Unkar Group.—Lithology.

Preliminary Outline.—The pre-Cambrian sedimentary rocks of the Shinumo area represent the greater part of the Unkar group of the Grand Canyon series of Algonkian age. The upper, or Chuar, group is not represented in the area. Although these sediments present no more evidence of alteration or metamorphism, aside from local igneous contact phenomena, than the overlying beds of the Paleozoic, they are destitute of fossils or decisive evidence of life. In the absence of fossils the natural basis for dividing the group into component members is the lithology. On this basis the Unkar group in the Shinumo area is divisible into five members, succeeding each other in conformable stratigraphic succession. It is not intended that the importance of this division should be greatly emphasized. Its chief value lies in the fact that it furnishes a basis for comparing the lithological succession of the Unkar group in this area with that in the type locality described by Walcott 30 miles to the east, as well as a basis for distinguishing in a broad way the main changes in the physical conditions under which these sediments were laid down.

At the base, resting upon the profoundly eroded and baseleveled surface of the metamorphic rocks of the Vishnu series,

Synopsis.

Tonto Group
Unconformity.

Unkar Group.

5. Micaceous shaly sandstone (exclusive of 36 feet of intrusive rock) _____ 2297

4. Sandstone and quartzite _____ 1564

3. Argillaceous and arenaceous shale (exclusive of 950 feet of intrusive rock) _____ 580

2. Calcareous shale and limestone_____ 335

1. Basal conglomerate_____ 6

Total _____ 4782 ft.

Unconformity
Vishnu series.

is a thin conglomerate. This constitutes the basal member of the Unkar. Overlying the conglomerate is a series of limestones and calcareous shales. These grade upward into argillaceous and arenaceous shales which are intruded by a thick sill of diabase, and are succeeded in turn by great thicknesses of sandstone and quartzite. The uppermost exposed member of the group in the area is a thick series of micaceous shaly sandstones.

It has been shown that these strata lie in a wedge-shaped mass inset in the Vishnu schists, and that this wedge is composed of a great number of smaller titled fault blocks. It is apparent from this relation that nowhere in the Shinumo area can the thickness be measured in one unbroken section. Since, however, the lithological characters of the strata are constant and easily recognized, and since the throw of the faults that bound the titled blocks seldom exceeds 100 feet, the restoration of a section showing the unbroken sequence is not a matter of great difficulty.

Detailed sections were made upward from the base of the Unkar through each fault block until its limiting fault was reached. The highest bed measured was then located in the next block to the northeast, and the measurement resumed at that point. Except in the fifth, or highest member of the group, all sections were measured with a tape along the nearly vertical wall faces of the box canyons of the Shinumo and other washes that cut across the strike of the strata. In the fifth, or highest member of the group, the strong drag of the great fault on the northeast has flexed and contorted these shaly sandstones in such a manner that accurate measurement with the tape alone was impossible. Their thickness was computed by the aid of trigonometric formulæ, using the combined data afforded by the use of the tape, the topographic map, and observations of the varying strike and dip.

The section incorporated in this article was made in two places. The greater part of the total thickness was measured in a traverse up the Shinumo. This section includes all the strata above the diabase sill which is intruded midway in the "arenaceous and argillaceous shales" which comprise the third member of the Unkar. It would have been perfectly possible to make a complete section of the group in a traverse of the entire course of the Shinumo from the basal unconformity at the mouth of the creek to the great fault three miles above, although four faults cross the creek between its mouth and the place where the diabase sill dips beneath the bed of the stream. But a place was found in the canyon of the East Wash where all the strata between the basal unconformity and the diabase sill lie in a continuous unfaulted section, in a fault block that

is tilted about 10° N.E. The section of the basal members of the group was measured in this locality, where the sequence is unbroken by faulting.

Detailed Section.

First Member.—Basal Conglomerate. The surface represented by the upper unconformity that separates the Unkar group from the basal Cambrian is a striking enough example of a base-leveled surface, although monadnocks rise in places to a height of 700 feet above the base of the Tonto sandstone. But the surface represented by the lower unconformity that separates the Unkar group from the Vishnu is an almost perfect plane : nowhere in the seven linear miles exposed in the Shinumo area can a difference in relief be observed that exceeds 20 feet. The depth of weathering below this surface appears to be slight, in spite of the enormous amount of rock that has been removed, and the weathering appears to be the result of physical disintegration rather than of chemical decomposition.

The basal conglomerate is an arkose conglomerate varying in thickness from 1 to 6 feet in the Shinumo area. It is composed of angular or subangular fragments of the rocks of the underlying Vishnu series, cemented by a matrix of red arkose mud which usually contains small fragments of pink feldspar. Occasionally the matrix contains small rounded grains of quartz.

The degree of induration of this conglomerate presents all variations from a hard, dense, siliceous rock, which fractures across matrix and enclosed rock fragments alike, to an easily disintegrated rock in which the matrix crumbles away from the enclosed fragments. This phenomenon, however, does not depend upon original cementation, but upon metamorphic effects produced by the diabase sill that is intruded in the overlying rocks, the degree of induration depending upon how far the conglomerate lies below the contact of the sill.

The matrix is usually of the same composition everywhere in the area. The character of the enclosed fragments, however, is sharply localized by the character of the underlying rock. The rock which underlies the conglomerate in the East Wash is the quartz-diorite of the batholith previously described. For three feet below the conglomerate the diorite is weathered along the joints into roughly angular blocks. These joints are filled with the red arkose material of the matrix. Above follows a layer of the conglomerate one foot in thickness, composed of weathered fragments of the diorite cemented with the red arkose material. Then follows a layer six inches thick composed of small rounded quartz pebbles and

fragments of chert of the same character as that contained in the overlying limestones. The whole is cemented with the red mud. The conglomerate is very little indurated in this locality. Although the contact of the diorite with the mica-schists in the underlying Vishnu is not two hundred yards distant, there is not a fragment of the mica-schist to be observed in the conglomerate.

In the Asbestos Canyon, four miles to the west of the East Wash, the underlying rocks are mica schists and veins of quartz and pegmatite. Here the Vishnu schist is scarcely weathered at all below the unconformity. The overlying conglomerate is 6 feet thick and consists of angular fragments of the underlying mica-schists, fragments of pegmatitic feldspar and vein quartz, and the arkose cement described above. The degree of induration is here very great, and the rock fractures across the grains like a hard, dense quartzite. This is due to the fact that the lower contact of the diabase sill lies only 150 feet above this basal conglomerate in the Asbestos Canyon, while in the locality in the East Wash it lies 550 feet above.

Two important features characterize the basal conglomerate of the Unkar in the Shinumo area; the arkose nature, and the lack of sorting and transportation of the component fragments.

Second Member.—Calcareous Shales and Limestone. The section was measured on the west side of the canyon of the East Wash. This and all the following sections read from the base upward, *a.* 1 being the bottom bed, overlain by *a.* 2, etc.

CHARACTER	THICKNESS
a. Basal white limestone.	
1. White, nodular, cherty limestone. The chert occurs in nodules with a roughly concentric structure somewhat suggestive of the structure of Cryptozoön_____	1′ 6″
2. White, cherty limestone carrying the chert in thin parallel bands which are etched out by the weather on the cross sections. The surface of each chert layer shows polygonal cracks suggestive of sun-cracks in shale. This structure belongs to each separate chert layer and is not a columnar structure. The weathered surfaces of these chert layers are dotted with small cubic depressions which were apparently formed by the leaching out of some mineral of a cubic habit_____	4′ 6″
Total_____	6′

CHARACTER   THICKNESS

b. *Argillaceous and calcareous red shale and limestone.*

1. Soft, purple shale		6″
2. Purple, cherty limestone	1′	
3. Purple shale with occasional bands of purple calcite	4′	
4. Purple, crystalline limestone	1′	
5. Alternating layers of buff and chocolate-red shale with a splintery habit of weathering and a roughly concretionary structure. Like all the succeeding shales and sandstones of the Unkar they are mottled with light-colored spots which are usually circular or elliptical in form and of all sizes	5′	6″
6. Blue limestone, white for 1″ at the base and showing dendritic markings		5″
7. Red shale	1′	5″
8. Blue limestone		4″
9. Red shale	3′	10″
10. Purple limestone		6″
11. Calcareous, red shale with three thin bands of purple limestone	9′	10″
12. Red, crystalline limestone	1′	
13. Red shale	1′	
14. Red, crystalline limestone	1′	
15. Red shale	11′	
16. Blue limestone		3″
17. Red shale	1′	
18. Blue limestone		2″
19. Pink limestone	1′	
20. Red shale	4′	4″
21. Cherty, white limestone		4″
22. Compact, red shale forming a cliff	8′	
23. Alternating layers of buff and red shale	13′	6″
24. Dense, purple, calcareous shale carrying bands of pink calcite and forming a cliff. Contains occasional thin bands of chert	9′	6″
25. Blue, calcareous shale with an onion-like concretionary structure on a large scale	5′	
Total	85′	5″

c. *White limestone.*

1. Thin-bedded, white, cherty limestone carrying the chert in parallel bands, and containing three paper-thin layers of purple shale. Weathers to a white powder. Dendritic markings are present   2′

2. Nodular, white, cherty limestone. The chert is present in irregular nodules of no definite shape.

Character	Thickness
The upper part of the stratum has a paper-thin bedding giving it the aspect of a calcareous shale. The limestone weathers to a white powder. Dendritic markings are present _____	2′
3. Dense, homogeneous, white, crystalline limestone, forming a cliff. The upper part is thin-bedded _____	3′ 8″
4. Homogeneous, thin-bedded, white, crystalline limestone containing occasional thin bands of chert and nodules whose character suggest the structure of Cryptozoön _____	8′ 6″
5. White limestone carrying a large amount of chert in undulatory and gnarled bands _____	2′ 4″
6. Lumpy and gnarly, white limestone carrying chert in large irregular nodules. Crumbles to a white powder _____	2′ 6″
7. Purple shale _____	
8. Layers of undulatory-banded, bluish chert_____	1′ 10″
9. Soft, purple shale _____	5″
10. Layer of gnarled and twisted chert nodules in a matrix of white talc. The surface of the talc is covered with dendritic markings _____	2′
11. Thin-bedded, white limestone crumbling to white powder or weathering into thin plates like a shale _____	2′
12. Soft, purple shale _____	1′
13. Thin-bedded, crystalline, white limestone _____	3′ 10″
14. Soft, purple shale _____	1′ 10″
15. Dense, blue, crystalline limestone forming a small cliff_____	3′
16. Homogeneous, thin-bedded, white limestone, crumbling to a white powder and weathering into plates like a shale_____	15′
17. Dense, crystalline, blue limestone _____	4″
18. Purple shale_____	3′ 3″
19. Layers of undulatory-banded, nodular chert in a matrix of earthy white limestone _____	3′ 10″
20. Thick-bedded layers of pure, homogeneous, white marble, forming the strongest cliff in the second member of the Unkar_____	6′ 8″
21. Same in thinner beds _____	6′ 6″
22. Undulatory-banded, cherty limestone becoming crystalline above _____	10′
23. Red shale below and purple shale above, separated by a thin layer of chert _____	5′
24. Thick-bedded, crystalline, white limestone of the same character as 20, forming a strong cliff _____	3′ 6″

CHARACTER	THICKNESS
25. Thin-bedded, crystalline, white limestone _____	5′ 6″
26. Gnarled and nodular, white, cherty limestone__	7′
27. Very hard, dense layer of flint forming small cliff _____	5″
Total_____	105′ 2″

d. Blue slate and white limestone.

1. Soft, purple shale _____	3′ 6″
2. Hard, blue slate forming small cliff_____	1′
3. Fissile, blue slates with fine partings _____	7′
4. Thin-bedded, purple, crystalline limestone ____	1′ 2″
5. Dense, purple, crystalline limestone forming a small cliff_____	7″
6. Same as 4 _____	2′ 2″
7. Same as 5, forming small cliff _____	8″
8. Thin-lamellar, spotted, blue slate_____	6′ 6″
9. Gnarly layers of fine-lamellar, blue calcareous slate with a very coarse concretionary structure. Irregular nodules of chert occur in the middle portion _____	33′
10. Dense, blue, crystalline limestone forming small cliff _____	2′ 3″
11. Thin-bedded, platy, white limestone_____	2′ 6″
12. Very thin-lamellar, fissile, blue slate_____	3′
13. Calcareous, blue slate forming a cliff _____	3′
14. Thin-bedded, platy white limestone_____	4′ 6″
15. Fissile, blue slate_____	7′
16. Dense, lumpy, white crystalline limestone ____	2′
17. Pinkish-green, fissile, siliceous slate of a jaspery appearance forming a cliff _____	5′
18. Layers of dense, white, crystalline limestone separated by thin bands of pale-green, talcose material _____	10′
19. Dense, red and black-banded jasper, weathering green between the layers and forming a cliff. The layers contain shrinkage cracks and ripple marks _____	11′ 4″
20. Layers of dense, white, crystalline limestone separated by bands of pale green, talcose material _____	2′
Total _____	108′ 2″

Synopsis of second member of the Unkar.

a. Basal white limestone _____	6′
b. Argillaceous and calcareous red shale and limestone	85′ 5″
c. White limestone _____	105′ 2″
d. Blue slate and white limestone_____	108′ 2″
Total thickness_____	304′ 9″

When the specimens of these rocks were examined in the laboratory it was found that all the limestones were more or less dolomitic. The limestones of division "*c*" were found to be entirely dolomites.

Thin sections were cut from specimens from twenty separate beds in the second member. Eighteen of these slides were cut from the limestone strata and two from the red shales. The sections of the limestones were cut both from the chert bands and the nodules and from the limestone itself, for the purpose of ascertaining the exact mineralogical character of these rocks, and in the forlorn hope that they might reveal traces of a structure that could be referred to something organic. No minerals other than calcite and quartz were revealed by the microscope in any of the slides. The silica of the chert bands and nodules was found to exist in the form of interlocking grains of quartz. None of the grains were rounded and there was no suggestion that the quartz grains of the chert bands represented an inwashed sand. Nor was there any trace of an organic structure revealed, either in the chert or in the limestone. The purer limestones were found to consist of calcite (or dolomite) alone, the crystalline forms having the typical structure of marble. The impure varieties were found to consist of mixtures of quartz and calcite in all proportions. The greater part of the limestone was of this impure character. The shales were found to consist of a fine impalpable ferruginous or calcareous mud, containing occasionally a minute grain of quartz.

Several features of interest are shown in the lithologic section of the second member of the Unkar as a whole.

Ripple marks and sun cracks appear for the first time in the shales in stratum No. 18 of division "*d*," just below the highest limestone stratum at the summit of the member.

The increasing intensity of metamorphic phenomena in the section from the base upward may also be noted. This is due to the approaching proximity to the lower contact of the diabase sill which is intruded in the member above. The metamorphic action is manifested in the shales by their change upward both in color and in degree of induration: the shales of division "*b*" are almost entirely red; from the summit of this division upward the color changes to purple and blue. Below division "*d*" the shales are soft and crumbly; within this division, however, they become dark blue slates, while in the upper part they become extremely hard, siliceous jaspers.

The vertical succession of the strata is seen to be broadly characterized by continual and rapid alterations of limestone and shale. According to the dominance of either type of rock the four divisions *a*, *b*, *c*, and *d* are separated: division "*a*" is

entirely limestone, "*b*" is alternating limestone, and "*d*" predominantly shale. Thus there are four major cycles of oscillation upon which the minor cycles are superimposed.

A comparison of the above section in the East Wash with a section measured in the Asbestos Canyon, four miles to the west, is of interest. In the Asbestos Canyon the "basal white limestone" (*a*) has a thickness of 30 feet contrasted with a thickness of 6 feet in the East Wash. The lower stratum of "nodular, cherty limestone" is there 7' 9", contrasted with 1' 6" in the East Wash. The upper stratum of "parallel-banded, cherty limestone" is 22' 3" in the Asbestos Canyon, containing in the middle an intercalated layer of purple shale, and near the top a thin layer of rather fine arkose conglomerate. The " argillaceous and calcareous red shales and limestones " of division "*b*" have a thickness of 88 feet in the Asbestos Canyon contrasted with 85' 5" in the East Wash. They do not have the red color that characterizes them in the East Wash, but are purple and blue, and much indurated. This change of color and difference in degree of induration is due to their closer proximity to the diabase sill in the Asbestos Canyon.

The correspondence in lithographical character and vertical succession of these two sections four miles apart is so close that the individual strata of the sections can be matched bed for bed. The only marked contrast in thickness occurs in the basal white limestone (*a*).

Third Member.—Argillaceous and Arenaceous Shale.

Section measured at East Wash in continuation of the preceding section.

a. Cliff-forming jasper.

1. Dense, hard layer of blue-black jasper mottled with red spots and showing no banding in the mass, forming with the three following layers a strong perpendicular cliff. This is the most resistant rock in the Unkar. Where the under surface shows beneath the overhang of the cliff it is sun-cracked on a large scale and in several generations.------------------------------   28'
2. Same general character as 1, but showing a banded structure. The lower 2 ft. are slaty and weather out, giving the cliff an overhang.------   19'
3. Same as 2 with a soft slaty layer at the base.--   14'
4. Same as 2 and 3 with a soft layer at the base.   12'
   ———
   Total   73'

b. Calcareous blue slate.

1. Slaty, black jasper, sun-cracked throughout... 12'
2. Pink, crystalline limestone.................... 1' 6"
3. Slaty, blue jasper with small red spots....... 4' 6"

Total 18'

c. Cliff-forming jasper.

1. Dense, hard layer of blue-black jasper mottled with red spots, forming with the following layer a strong cliff............................ 14'
2. Same as 1 with a soft slaty layer at the base which weathers out, giving the cliff an overhang. 3' 6"

Total 17' 6"

d. Sandy quartzitic jasper.

1. Slaty, blue, spotted jasper.................... 4'
2. Fine-grained, pink quartzite, ripple-marked ... 5'
3. Slaty, blue, spotted jasper.................... 12'
4. Fine-grained, pink quartzite................... 4'
5. Slaty, blue, spotted jasper with sun-cracks..... 6'
6. Fine-grained, pink quartzite, ripple-marked... 1'
7. Pink, quartzitic jasper....................... 5'
8. Fine-grained, pink quartzite.................. 4'
9. Fine-grained, pink, sandy jasper, sun-cracked.. 11'

Total 52'

e. Red and blue jasper.

1. Banded, blue jasper with curious spots. Sun-cracked throughout .... 22'
2. Red and black banded jasper .... 9'

Total 31'

f. At this horizon is intruded a sill of diabase, whose thickness varies from 650 feet on the Shinumo to 950 feet or more in the Asbestos Canyon.

The remainder of the section was measured in a traverse up the Shinumo, starting with the upper contact of the diabase sill.

g. Blue slate and quartzite forming a cliff............... 20'
h. Blue slate forming a slope....................... 100'
i. Red, argillaceous shale — sun-cracked throughout. The rock is very soft and forms a slope together with the underlying blue slate..................... 91'
j. Alternating, vermilion, argillaceous shale and sandstone.

The alternations in this series occur with remarkable regularity. The sandstone is white in color and is compact and

fine-grained. It is cross-bedded and ripple-marked throu;
out. The shales of the alternating beds are very soft ε
weather out, leaving etched-out bands between the sandsto:
which are very conspicuous in the cliff-faces. On the unc
surface of each sandstone layer are beautifully preserved s
cracks. The shales are fine-grained, fissile, and argillaceous
The succession in this alternating series is as follows :

No.	Bed	Thickness	S. S.—Sh. cycle
1.	Sandstone	4′ 2″	
2.	Shale	3′10″	8′
3.	S. S.	2′	
4.	Sh.	3′	5′
5.	S. S.	1′	
6.	Sh.	2′	3′
7.	S. S.	7′	
8.	Sh.	10′ 6″	17′ 6″
9.	S. S.	5′	
10.	Sh.	3′	8′
11.	S. S.	6′	
12.	Sh.	2′ 6″	8′ 6″
13.	S. S.	6′	
14.	Sh.	3′ 6″	9′ 6″
15.	S. S.	6′	
16.	Sh.	3′ 6″	9′ 6″
17.	S. S.	7′ 6″	
18.	Sh.	4′	11′ 6″
19.	S. S.	3′ 6″	
20.	Sh.	6″	4′
21.	S. S.	2′	
22.	Sh.	1′	3′
23.	S. S.	3′10″	
24.	Sh.	2′ 6″	6′ 4″
25.	S. S.	2′	
26.	Sh.	6′ 6″	8′ 6″
27.	S. S.	3′	
28.	Sh.	4′	7′

Total,   109′ 4″   Ave.,   7′10″

k. Alternating, vermilion, arenaceous shale and sandstone.

The sandstone is white, compact, and fine-grained. It ;
cross-bedded and ripple-marked throughout. The undε
surface of each sandstone layer is sun-cracked where it re
upon the arenaceous shale. The shale is vermilion in co or,
soft, and very sandy. Sun-cracks occur throughout.
The succession is as follows :

1. Sandstone . . . . 9′ 4
2. Arenaceous shale . . . . 21′ 1″
3. Sandstone . . . . 9′
4. Arenaceous shale . . . . 11′ 8″
5. Sandstone . . . . 2′
6. Arenaceous shale . . . . 24′
7. Sandstone . . . . 1′

<div align="right">Total   78′ 1″</div>

Synopsis of third member of the Unkar.

a. Cliff-forming jasper . . . . 73′
b. Blue slate with calcareous band . . . . . 18′
c. Cliff-forming jasper . . . . 17′ 6″
d. Sandy quartzitic jasper . . . . 52′
e. Red and blue jasper . . . . 31′
f. (Intrusive diabase)
g. Blue slate and quartzite . . . . 20′
h. Blue slate . . . . 100′
i. Red argillaceous shale . . . . 81′
j. Alternating vermilion argillaceous
    shale and S. S. . . . . 109′ 4″
k. Alternating vermilion arenaceous
    shale and S. S. . . . . 78′ 1″

<div align="center">Total thickness   579′11″</div>

Thin sections were cut from several specimens of the jaspers. The slides were unsatisfactory, however, because of the exceedingly fine grain of the rock. The highest power of the microscope revealed nothing more than an impalpable silicified mud. A slide of the "quartzitic jasper" showed it to have been a somewhat arkose sandstone indurated to a siliceous quartzite. It was seen to be composed chiefly of small rounded quartz grains about which secondary silica had been deposited, lying in a fine arkose matrix made up of small fragments of pink feldspar. A thin section was also made from a specimen of one of the sandstone layers in the "alternating argillaceous shale and sandstone" of division "*j*." The rock proved to consist of small, well-rounded grains of quartz, cemented by silica in the form of secondary quartz. It is a pure, fine-grained sandstone.

The metamorphic effects produced by the diabase sill intruded at the horizon "*f*" are seen in the lithologic section of the third member given above. This metamorphic action is manifested in three ways:

    1. Induration by silicification,—jaspers.
    2. Induration by baking,—slates.
    3. Decoloration,—red to blue and black.

It was noted in the summary of the features of the second member that the shales became successively slates and jaspers above, while their color changed from red to blue. In the third member the shales are represented entirely by jaspers and quartzites. Just below the contact the induration is very great, and the jaspers are tough and vitreous; the prevailing color is blue or black. Above the contact the overlying rocks are hard blue slates for 20 feet, succeeded by 100 feet of less indurated slate, grading upward into the original red shale.

The metamorphic effects above and below the contact differ in degree of intensity as well as in kind: above the contact the induration and decoloration characterize only about 100 feet of strata; below the contact this action extends through 300 feet. Above the contact the strata are characterized by baking and decoloration only, changing the red shale into a blue slate; below the contact there has been a considerable addition of silica, transforming the red shales into blue and black jaspers; added to this are the effects of baking and decoloration.

It may be said in summary that the third member is characterized by argillaceous shales in the lower portion, which grade upward into arenaceous shales and sandstones through the interesting series of alternations described in division "*j*." There is hardly a stratum in the entire member that does not bear marks of shallow water origin, manifested by either suncracks, ripple-marks, or cross-bedding.

Fourth Member.—Sandstone and Quartzite.
Section on the Shinumo.

a. Purple-brown sandstone of fine grain containing locally an occasional lense of fine conglomerate and sometimes a thin local bed of red or purple shale. The sandstone is cross-bedded throughout ----------------- 406′

b. Compact, white quartzite of fine and uniform grain, displaying a faint cross-bedded structure. This quartzite is the most resistant rock in the fourth member. It is exposed everywhere in one massive perpendicular cliff face, which does not display the slightest break except where it is cut by faults. Wherever its base rests upon a shaly lense the under surface displays well preserved mud-cracks. The face of the cliff is stained magenta by the ferruginous cement of the shale lenses in the overlying sandstones, which washes down from above ------------------------------- 119′

c. Purple-brown sandstone of the same character as *a* ---- 353′

d. Banded, white quartzite, stained magenta on the exposures, and forming a cliff ------------------------- 120′

e. Fine-grained, purple sandstone with a white band in the middle. The white band is constant and presents a conspicuous feature by which this purple sandstone can be distinguished at a distance of several miles. The rock is cross-bedded and sometimes displays a "twisted and gnarled" structure .... 150′

f. Compact, cliff-forming, white quartzite of the same character as b, though not so massive in structure ... 250′

g. Banded white quartzite .... 20′

h. Irregularly bedded sandstone ....

    1. "Curiously twisted and gnarled layers," of fine-grained white sandstone containing large red spots of a circular and elliptical form. The upper part of the bed is more massive. The twisted and gnarled structure seems to have been a phenomenon of the original deposition. It gives the rock an appearance which suggests that the original sand was moist and plastic and once flowed by rolling over and over in the form of a quicksand.   105′

    (It may be noted that a bed of this character is described by Walcott in his section in Unkar Valley. (Walcott b, page 511.) It occurs at the same horizon as the bed described above, and contains the same red spots.)

  2. Banded, purple sandstones .... 20′

  3. Green, cross-bedded sandstone .... 21′

                                          146′

The total thickness of the fourth member of the Unkar is 1564 feet.

Slides were cut from several specimens of the sandstones and quartzites. All were found to consist of small rounded quartz grains, the size of which seldom exceeds 0.7^{mm}. This extreme fineness and roundness of the grains, as well as the cleanness of the sorting, is remarkable. The cement is usually siliceous, sometimes slightly ferruginous. A slide was made from a specimen taken from one of the small conglomerate lenses in division a. The conglomerate was found to consist of small rounded quartz pebbles, lying in a fine arkose matrix. Occasional large angular fragments of orthoclase and microcline were revealed.

In summary it may be said that the fourth member is characterized by great thicknesses of pure, fine-grained sandstone of a uniform character. All divisions of the member are resistant to the weather and form cliffs. Ripple marks and cross-bedding occur throughout.

Fifth Member.—Micaceous Shaly Sandstone.

Section measured in Fault Wash, west side of Shinumo Canyon.

a. Gray-green, pinkish-green, and brown micaceous shaly
    sandstones, cross-bedded and ripple-marked, varying
    in character only through gradations in color. Fre-
    quent arenaceous and argillaceous shaly partings occur,
    causing the rock to weather like a soft sandy shale.
    The shale partings are usually green. Some of the
    sandy layers near the base show the "gnarled and
    twisted structure." _____ 1100'
b. The green, gray, and brown beds of *a* pass upward
    through change of color into red and vermilion beds
    of the same general character. These are likewise
    micaceous shaly sandstones, cross-bedded and ripple-
    marked, with arenaceous and argillaceous shaly part-
    ings, which display well preserved mud-cracks. The
    shaly partings are either green or red _____ 1197'

            Total _____ 2297'

    The summit of the Unkar section is obliterated in the beds
of division *b* by the plane of the pre-Tonto unconformity.
The highest beds of this division lie at the upper end of the
Fault Wash, dragged against the Vishnu schist on the north
by the great pre-Cambrian fault previously described, and the
whole overlain by the Tonto sandstone.

    In the uppermost part of division *b* are four thin sills of
rotten basaltic rock, weathering green and crumbling to small
fragments. They occur between the beds of vermilion sand-
stone and shale. Their intrusive character is shown by the
fact that they have baked and decolorized the vermilion
beds for a few inches both above and below the contacts,
changing the color to purple. The rock is too badly weathered
to allow a petrographic determination in thin section.

    In summary the fifth member of the Unkar may be charac-
terized as a series of micaceous shaly sandstones of uniform
character, varying only in color, and bearing marks of shallow
water origin throughout.

    Comparison with the type section in Unkar Valley.—
A comparison of the above section of the Unkar group with
that described by Walcott (*d*) in the type locality 30 miles to
the east reveals the fact that the correspondence between the
two sections is very close, both in thickness and in lithological
succession; only in the lower portions do they differ materi-
ally. The type section in Unkar valley is characterized by a
greater thickness of the basal conglomerate, and by only a third
as much limestone in the members which correspond to the sec-
ond member on the Shinumo; the deficiency in limestone is made
up by greater thickness of arenaceous and argillaceous shale.
Proceeding upward in the section there is a somewhat greater

proportion of sand in that division of Walcott's section which corresponds to the third member on the Shinumo. The succeeding members correspond closely in character and thickness even to the minor divisions ; an example of this is the "gnarled and twisted layers" previously cited.

The writer had the privilege of examining Mr. Walcott's field specimens in the National Museum in Washington and was particularly impressed by their absolute lithological identity with the series collected by himself from corresponding horizons on the Shinumo. The two series of specimens, with the exception of those rocks altered by local metamorphic phenomena, might have come from the same locality.

DIABASE INTRUSIVE IN THE UNKAR.

Occurrence.—The diabase occurs in the form of an intrusive sheet or sill which occupies three separate stratigraphic horizons in the Unkar sediments in different parts of the Shinumo area. On the west side of the Asbestos Canyon three miles west of the Shinumo it is intrusive in the limestones of division *c* of the second member of the Unkar at a horizon 15 feet above their base. On the east side of the Asbestos Canyon it ascends out of this horizon and breaks across the overlying limestones and shales in an eruptive contact. Most of the lower, and part of the upper, sections of the eruptive contact are beautifully displayed in the walls of this canyon, but the complete exposure is obliterated above by the truncating unconformity at the base of the Tonto sandstone. Between the exposures in the Asbestos Canyon and the main areal exposures about the mouth of the Shinumo, the pre-Cambrian structure is hidden beneath the sandstone of the Tonto platform. Where the diabase reappears in the exposures about the Shinumo it is found to lie intruded midway within the shales of the third member of the Unkar at a horizon 400 feet above that which it occupies in the Asbestos Canyon. This is the stratigraphic position which it holds in all the exposures of the central part of the Shinumo area. Eastward up the river from the East Wash the diabase again disappears beneath the pre-Tonto unconformity. But directly under Havasupai Point, about three miles farther east, limited outcrops of the basal portion are exposed in small inter-canyon valleys on both sides of the river. Here the lower contact of the diabase lies just at the top of the "white limestones" of division *c* of the second member of the Unkar.

The thickness of the sill is approximately 650 feet on the Shinumo and 950 feet on the west side of the Asbestos Canyon. Eastward from the Shinumo the outcrop is considerably

thinned by a strike fault, precluding the possibility of measuring the thickness in that direction.

PETROGRAPHY.

Megascopic.—The fresh specimens characteristic of the greater part of the mass show it to be a tough, heavy, holocrystalline rock of medium to coarse grain and of a grey color. The minerals visible to the unaided eye are plagioclase, olivine, augite, and an occasional grain of magnetite. Although the olivine exceeds the augite in amount, it is less conspicuous to the eye. Aside from a somewhat waxy luster of the feldspars, the rock is remarkably fresh. The weathered surface has a characteristic warty appearance, imparted by the presence of lumps or balls which are of a coarser grain and different texture than that of the mass of the rock and are more resistant to the processes of disintegration. These lumps and balls can be seen to consist of coarse ophitic intergrowths of augite and plagioclase. The diabase weathers by mechanical disintegration to a greenish-olive sand in which are innumerable lumpy kernels of all sizes derived from the ophitic masses described above. The rock has no typical columnar structure, but usually displays a rough vertical jointing such as is characteristic of granite.

Microscopic.—The slides examined show the typical rock to consist primarily of plagioclase feldspar (near labradorite) and olivine in about equal amounts, with a subordinate quantity of augite and brown biotite. A very little magnetite is present. The feldspar is somewhat altered, but all the other minerals are fresh. The olivine occurs characteristically in rather large, rounded crystals of automorphic habit. The augite is chiefly confined to the globular masses which weather out as lumps and kernels and does not characterize the rock as a whole. Slides cut from these kernels show them to be composed entirely of augite and feldspar. The augite is enclosed within the feldspar, displaying beautiful examples of ophitic texture. Several of the magnetite crystals were observed to have rims of brown biotite. The small amount of magnetite is rather remarkable, and it seems likely on this account that the olivine is rich in magnesia. Because of the predominance of olivine and plagioclase in the greater part of the rock, the diabase is classified as an olivine-diabase with a troctolitic aspect.

Variations in character.—All parts of the mass are subject to variations in texture and composition toward a coarser grain. These are of two kinds. The first type occurs in the ophitic intergrowths of augite and plagioclase in the lumps and balls described above, and is a segregation phenomenon character-

izing the mass as a whole; sometimes this texture becomes very coarse, the separate crystals of augite or plagioclase attaining an inch in length. The second type occurs in typical pegmatite dikes cutting the diabase in many places and varying in width from a few inches to several feet. The minerals are plagioclase and augite and the texture is usually ophitic, although not always so. In some of these dikes crystals of plagioclase exceeding three inches in length were observed.

The contact facies of the diabase are frequently fine-grained or glassy, but never for more than a few inches from the contact. The slides typical of this zone reveal a hyalopilitic arrangement of glass with skeleton crystals of magnetite between badly altered crystals of feldspar.

For about a half-mile east and west of the Shinumo there occurs in the upper part of the diabase sill along the upper contact a pink holocrystalline rock of medium grain. The contact of this rock with the overlying blue slates is sharp and well-defined. Downward it appears to grade into the normal diabase, and no definite line of contact can anywhere be observed. Unfortunately the writer did not collect transition specimens, but took only one specimen from the middle of the pink mass. The slide from this specimen when examined under the microscope showed it to be a granular rock of medium texture, consisting of rather fresh crystals of orthoclase, with subordinate quartz and a somewhat altered ferromagnesian mineral which was made out to have been originally a hornblende. Some of the quartz displayed a micrographic arrangement within the feldspar. The rock is a typical hornblende-syenite, and is apparently an interesting example of differentiation in place within the diabase sill. But a more complete set of specimens across the apparent transition zone must be collected before such a conclusion can definitely be established.

In the Asbestos Canyon both the lower and upper eruptive contacts of the diabase are ragged and considerably injected. Many small dikes penetrate the country rock from the main mass. They are glassy in texture and badly altered.

Ransome, in his report upon the "Geology of the Globe Copper District, Arizona" (Ransome *b*, p. 80 ff.) describes a diabase of post-Carboniferous age occurring in thick sills in the pre-Carboniferous sedimentary rocks of that region. This diabase closely resembles the Algonkian diabase described above, both in mineralogical character and in the presence of the ophitic balls of plagioclase and augite. The analogy is made the more striking by the fact that several small masses of pink hornblende-syenite are described occurring within the diabase sills of the Globe district as a possible segregation phenomenon within the diabasic magma.

Contact metamorphism.—Since the diabase sill occupies relatively different horizons in the Unkar strata upon the Shinumo and in the Asbestos Canyon, and since in the former locality the strata between which the sill is intruded lie in undisturbed sedimentary contact in the latter locality, and vice versa, the study of the respective contact effects upon the invaded strata could be made with great facility.

The contact effect upon the shales which lie above and below the diabase along the Shinumo has already been described in the detailed section of the Unkar: there the shales were shown to be altered to jaspers by baking and silicification. It was shown that the intensity of metamorphic action was much greater below the sill than above, extending through 300 feet of strata below the lower contact and through only 100 feet above the upper contact. In the Asbestos Canyon these rocks lie in undisturbed sedimentary contact and are there unaltered red shales.

The contact effect upon the limestones can be studied in the Asbestos Canyon, where the diabase sill lies intruded within them. Immediately below the lower contact of the diabase, which is sharp and well defined, is a thin layer of green serpentine. Below lie layers of pure crystalline limestone (dolomite) alternating with layers of the same character containing bands and nodules of serpentine. Within one of the layers containing the bands and nodules of serpentine are cross-fiber veins of golden-yellow chrysotile asbestos which are parallel in general trend to the bedding of the limestone. These limestones are the layers at the base of division *c* of the second member of the Unkar. They overlie the red shales of division *b*, which are here baked to blue slates.

Section below diabase contact (reading upward from the base)

Dense, purple, calcareous slate (*b*, 24 of second member
    of Unkar) _____ 9 $'$
Soft, blue slate (*b*, 25) _____ 3 $'$
Nodular, cherty limestone (*c*, 1, 2) _____ 4 $'$
Banded, crystalline limestone with bands and nodules of
    serpentine (*c*, 3, 4,) _____ 10 $'$
Serpentinous, nodular and banded layer carrying veins
    of asbestos _____ 1 $'$
White, crystalline limestone with bands and nodules of
    serpentine _____ 2 $'$
Pure, white, crystalline limestone _____ 1 $'$ 6 $''$
Layer of green serpentine _____ 2 $'$
Diabase.

Above the upper contact of the diabase the limestones contain several alternating layers of green serpentine and narrow

veins of asbestos occur at several horizons in proximity to the contact.

The geological occurrence of the asbestos is fully described by Diller in " Mineral Resources of the U. S. for 1907 " (Diller, *a*), and again by the same writer in " Mineral Resources for 1908 " (Diller, *b*). The contribution of the writer of the present article consists of the further data afforded by a microscopic study of the rocks associated with the asbestos in this locality. A microscopic study was made of 25 thin sections cut from the limestones, the bands and nodules of serpentine, and across the veins of asbestos. Aside from the serpentine and asbestos no other minerals were revealed in the limestones beyond the dolomitic calcite and interlocking grains of quartz already described in the slides cut from the limestones of the same horizon in the section on the East Wash, where the same strata lie in undisturbed sedimentary contact. The texture of the limestones is entirely that of marble. The serpentine of the bands and nodules shows no trace of an alteration structure which might indicate a derivation from pyroxene, hornblende, or olivine. The slides cut across the veins of asbestos showed them to be later than the serpentine in which they are usually enclosed. A great number of veins of asbestos of microscopic size was revealed in some of the slides where their presence was unsuspected. Some of these veins were observed cutting across both the serpentine and the limestone in the same slide.

The asbestos which occurs in the larger veins is commercially of high grade and the fiber is of great tensile strength. It is pronounced by Diller to be the best in quality yet found anywhere in the United States. (Diller, *b*, p. 11.) Locally the crossfiber is 4 inches in length. The horizon of the larger veins is confined, so far as is known, to the limestones which lie beneath the lower contact of the diabase sill. The veins above the contact, although more widely distributed through the limestones, are usually of smaller size. The horizon below the contact is not absolutely constant in stratigraphic position and may lie anywhere from 3 to 15 feet below the contact. The width of the veins within this horizon varies greatly from place to place, so that a vein of three inches in width in one locality may be represented by a zone of innumerable small veins in another, but the actual continuity of the zone that carries the asbestos is rarely broken.

Conclusions.—The serpentine and asbestos occur in the limestones only where these strata are invaded by the diabase sill; where the diabase lies between shales there is no development of these minerals within the invaded strata. In no place in the area are they developed within the diabase itself. It is therefore clear that they are a contact metamorphic

phenomenon conditioned by the invasion of the limestones by the diabase. It seems probable, as suggested by Diller (*a*, p. 72), that the serpentine which encloses the veins of asbestos is derived from some mineral in the limestones and not from the diabase. The limestones themselves are magnesian, and locally siliceous in the form of chert bands and nodules. In another part of the area the conversion of the shales to jaspers where they are in contact with the diabase is evidence that the fumarolic action accompanying the injection of diabasic magma was manifested by aqueous and probably siliceous emanations and was fairly intense. It seems possible that the operation of the fumarolic action upon the elements already present in the magnesian limestones might have been sufficient to convert the more siliceous portions into serpentine. The occurrence of the asbestos in veins that cut both the nodules of serpentine and the limestones is evidence that the formation of the cross-fiber asbestos was itself a somewhat later phenomenon.

Age and Correlation.

The Grand Canyon series is referred to the Algonkian in the usage of the United States Geological Survey and is tentatively correlated with the Keweenawan series of the Lake Superior region and with the Llano series of Texas, following the conclusions established by Walcott (*b*, p. 518). In the Shinumo area the profound nature of the unconformity which separates these strata from the basal Tonto sandstone is even more striking than in the area described by Walcott, while the certainty of their stratigraphic position is in its clearness and spectacular character probably unparalleled in the world.

Geologic History.

Outline.

The following sequence of events may be distinguished:

1. Deposition of the Vishnu sediments, source unknown.
2. Regional metamorphism.
   a. Subsidence and profound burial.
   b. Orographic movement of folding and compression resulting in recrystallization and schistosity, accompanied or preceded by injections of pegmatite.
   c. Elevation, accompanying or succeeding the orographic movement.
3. Batholithic invasion of quartz diorite.
4. Later pegmatitic injections.
5. Long cycle of erosion carried through to a featureless peneplain of no relief, which truncates the very roots of the Vishnu structure.

6. Sudden incoming of the shallow Unkar sea.
7. Deposition of the Unkar sediments and succeeding strata of the Grand Canyon series in shallow water (or upon land ?)
8. Intrusion of diabase sills.
9. Orographic movement of block faulting and tilting accompanied or succeeded by elevation.
10. Long cycle of erosion carried through to a peneplained surface of small relief.
11. Incoming of the Tonto sea, succeeded by the deposition of the Paleozoic strata of the wall of the Grand Canyon.

The earliest event which is decipherable in the geologic history of the Shinumo area is found in the blurred and mangled record of the Vishnu schists. Far back in the dark ages of geologic time a thick series of more or less arkose sands and muds was accumulating upon a subsiding floor. So much may be reasonably inferred from the mineralogical character of the quartz schists of the mica and hornblende type. So dim and vague is the record that the base of this series, the floor upon which it was laid down, the thickness, and the location of the land mass from which it was derived must, perhaps, remain forever unknown. Following the long accumulation and burial of these sediments came an orographic movement which wrote across the older manuscript in a newer and bolder hand, blurring the ancient writing with the stamp of deep-seated regional metamorphism, and imparting to the manuscript the aspect of a palimpsest. The regional metamorphism is conceived to have been brought about by deep burial of the sediments, followed by folding and compression, which engraved upon them the characters of recrystallization and schistosity in slow process of time, and accompanied by their elevation into lofty mountains. Somewhat later the cores of these mountains were intruded by great masses of igneous rock, here in the form of quartz diorite, followed by pegmatitic injections. Perhaps while this orographic movement was still in progress the forces of erosion were already at work. Then followed a tremendous cycle of erosion carried through to the very end, planing away the ancient mountains to the basal roots, and reducing hard and soft rocks alike to an utterly flat and monotonous level. Such was the completion of the cycle of this vast unknown and unnamed æon of time.

The next event is the beginning of another great cycle of sedimentation resulting in the deposition of the Grand Canyon series of Unkar and Chuar strata, ushered in by the sudden invasion of a shallow sea which swept over the featureless desert surface of the Vishnu plain, depositing the basal conglomerate of the Unkar. The clue to the inferences as to the character of this incoming sea, of the rock mantle which it

found covering the plain, and of the climate of the time is preserved for us in the basal conglomerate described in a previous part of this article. It was there noted that the weathering below the surface of the peneplain was slight, and the product of physical disintegration rather than of chemical weathering; that the matrix of the conglomerate is red in color and arkose in nature; that the pebbles are angular and show no evidence of transportation and sorting. We may therefore conclude that the conglomerate represents the soil in place which covered the Vishnu plain. All the evidence points to an arid climate,—the lack of chemical weathering, the freshness of the arkose feldspar, and the red color of the matrix, all indicating a lack of vegetation and abundant moisture which could decompose the soil and reduce the iron which imparts the red color. It is therefore not unlikely that the Vishnu plain was a vast desert at the incoming of the sea. The absolute lack of transportation, sorting, and rounding of pebbles indicates that the incoming sea had little chance to rework the soil mantle by its waves. It seems impossible to account for this phenomenon except by a sudden invasion of the sea across the Vishnu desert. If we interpret the past in the light of the present our only guide is to seek to picture some present condition on the earth which parallels that preserved in the geological record. A possible clue may lie in the conditions about the Caspian Sea to-day. There is in that region a desert about the shores of the Caspian which lies below the present level of the Black Sea; a sudden rise in the level of the ocean might cause the latter to overflow the low barrier which separates it from the Caspian, and in this way a sudden inundation of the desert would be accomplished. It is now thought that wind erosion may carry the surface of an old desert to a level below that of the sea if the cycle is continued to extreme maturity. Such forces might have been active in the last stages of the Vishnu peneplain.

The deposition of the alternating limestones and shales of the second member of the Unkar seems to have taken place in a permanent water body into which mud was frequently washed. It may be noticed from the section of this member that the alternations are almost innumerable. The exact cause of this is speculative. Possibly the alternations are due to climatic oscillation: a movement from an arid to a semi-arid climate would load the rivers with sediment, while arid intervals would retard their flow, if not dry them up entirely, resulting in a temporary clarifying of the sea and a deposition of limestone. Whether the limestones are the result of organic agencies or of purely chemical precipitation is also a matter of speculation, since in regard to decisive evidences of life the

geological record is silent. It is believed that the water body was for the most part shallow, since sun-cracks appear in the shales in the upper part of the member below the highest limestone strata. What the polygonal cracks and the small cubic depressions in the banded cherty layers of the basal limestones mean the writer does not know. The cracks are suggestive of sun-cracks and the depressions strongly resemble salt hoppers.

The most striking feature of the third member is the great abundance of sun-cracks throughout the shaly strata and of ripple-marks and of cross-bedding in the sandstones. The researches of Professor Barrell have made it clear that extensive sun-cracking is a feature which has a maximum chance of preserval on broad flood plains or deltas in an arid climate. (Barrell, *a*, pp. 524–568.) In the opinion of the writer of the present paper, the extreme abundance of these cracks in this member of the Unkar is hard to account for except by postulating wide delta flats or flood plains. Furthermore, the bright red color of the shaly strata in connection with the mud cracks seems to bespeak an arid climate with little or no vegetation to reduce the iron. It is at least certain that all this part of the Unkar was deposited in very shallow water which often evaporated entirely, leaving broad mud flats exposed to a hot sun. In the upper part of the member is the series of alternating shales and sandstones already described in detail: as may be seen from the sections, the alternations are frequently as regular as clockwork. The sandstone layers are composed of fine, cleanly sorted and rounded quartz grains, ripple-marked and cross-bedded, while the shales are a fine red mud. It is thought that the clean character of the sandstone layers of this alternating series is a mark of climatic oscillation: a climatic movement towards a wetter climate, if increasing the ratio of run-off to erosion, causes the rivers to flow on a lower grade and sweep seaward the piedmont deposits of sand and gravel; as the clay was largely sorted from those deposits when they were first laid down, their redistribution accompanied by a secondary sorting on a delta surface or sea-bottom would be marked by extreme cleanness.

Great thickness, clear sorting, and extreme fineness and roundness of grain are the characters which distinguish the fourth member, which is composed entirely of sandstones and quartzites. All strata are characterized by cross-bedding and ripple-marks, bespeaking shallow water. The origin of these great thicknesses of sandstone is a puzzle. The clean sorting seems to indicate long transportation: it is not impossible that the rivers carrying this material might have flowed through a great desert of dune sands, picking up and carrying material

such as is deposited in the Indus delta to-day from a similar source. Occasional lenses of fine conglomerate within some of the strata suggest scoured and filled stream channels.

The upper member of the Unkar again bears all the marks of shallow water origin : mud-cracks, ripple-marks, and cross-bedding characterize the entire thickness. The addition of micaceous material and of some feldspar gives a slightly arkose character to the rock; possibly a crustal movement rejuvenating the land mass supplying the sediments was responsible for the change in character. Here again are marks of aridity, seen in the vermilion color and the vast development of mud-cracks.

All subsequent Unkar and Chuar deposits have been removed by the truncation of the pre-Cambrian structure by the plane of the base-leveled surface of erosion beneath the Tonto Sandstone.

In summary it may be said that the evidence obtainable from the lithologic record of the Unkar sediments in the Shinumo Area points probably to an arid climate, and almost surely to deposition in shallow waters ; first in a permanent body of water and later in deltas or on flood plains. Which of the latter conditions prevailed the writer is not competent to say.

The predominance of clastic sediments instead of limestones in the basal portion of Walcott's section, 30 miles east, suggests that that area was nearer to the shore line of the early shallow sea. The close correspondence of the stratigraphic succession and lithology in all higher members in the two areas suggests uniform conditions over at least that distance.

The next event which can be read from the geologic record is the invasion of the Unkar strata by a thick sill of diabase in the lower members, and by four thin sills of basaltic rock in the upper part of the section.

Following this came an orographic movement of block faulting and tilting, accompanied or succeeded by elevation, breaking the strata of the Grand Canyon series into great crustal blocks, and throwing them into high ranges of mountains which in character and aspect were probably not unlike the faulted ranges of the Great Basin or the desert ranges of Arizona.

Then began a second vast interval of erosion, gnawing slowly but surely into these faulted mountains, reducing them in slow process of time through stages of youth, maturity, and old age, and finally planing away all except the very hardest strata of their cores to form the broad monotonous expanse of a base-leveled surface. The monotony of this surface was broken only by an occasional monadnock of hard Unkar quartz-

ite, resisting the forces of erosion in that ancient plain by virtue of the terrific hardness which causes the same strata to-day to wall in the deep box-canyon of the Shinumo. These monadnocks of the Cambrian plain may be compared with the Baraboo ridges of Huronian quartzite which by virtue of their homogeneity and hardness still stand as prominences which have weathered repeated cycles of erosion. It is probable that this cycle of erosion was not finally completed until well along in lower Cambrian time.

The next event is the incoming of the Tonto sea. Although this chapter belongs to the Paleozoic history recorded in the horizontal strata of the walls of the Grand Canyon, that part which is involved with the distribution of the Unkar strata upon the pre-Tonto surface may properly be anticipated here.

It is not unlikely that this invading sea transgressed a surface which strongly resembled the present surface of the great Laurentian peneplain of Canada with its broad areas of crystalline rocks in which are inset occasional blocks of Paleozoic strata, and above which stand occasional monadnocks of quartzite. The story of the invading sea is written in the Tonto Sandstone, locked up in which is a record of marine transgression which on account of the vertical sections and absence of soil is clear beyond belief. When the Tonto sea came in over the surface of the ancient peneplain the monadnocks stood out as islands which were gradually overwhelmed and buried in the sands of the deepening sea. The long ridge of the quartzites of the middle Unkar in the Shinumo area has already been described. It stood out as a long narrow rocky island whose longer axis extended for an unknown distance northwestward along the strike of the strata. The long southwest face of this island was undercut by the marine planation to form a steep cliff. Every detail of the face of this old sea cliff is preserved in the Tonto sandstone in the cross-sections cut by the present canyons across its face: at its base, huge angular blocks of Unkar quartzite as large as houses are preserved in the Tonto sandstone in the exact position where they fell and lodged; farther out from the base are masses of large bowlders, worn and rounded by the pounding of the waves; these become smaller and smaller and finally run out into lenses of fine pebbly conglomerate, representing the shingle of the ancient beach, dragged out by the undertow. No more striking example of a fossil sea cliff can be imagined.

By far the most impressive feature of this wonderful country is to traveller and geologist alike the mile-deep pathway of the Colorado River of the West across the great plateaus. The stupendous and glaring record of erosion revealed to us

in the cutting of this mighty gorge has almost blinded us to the realization of the immensity of the vastly greater record revealed in its walls. But the story told by the two intersecting unconformities in the bottom of the gorge,—two ancient cycles of sedimentation, uplift, and erosion carried to a finish, separated by hopelessly lost intervals of time, resulting twice in the planing down of lofty mountain ranges to the very core, written vaguely at first on a blurred and time-worn record, and later in an increasingly clearer and bolder hand,—the slow accumulation of the strata of the Canyon wall on the floor of the Paleozoic sea, the subsequently erased record of the accumulation of vast thicknesses of Mesozoic and Eocene strata, separated in turn by great intervals of erosion, and even the " great denudation " which has stripped these later strata back fifty miles to the terraces of Utah—represents a lapse of time compared with which the cutting of the Grand Canyon is but the passing of an afternoon ; for in the light of present knowledge it is safe to say that the Grand Canyon was entirely cut since the time when, according to the fossil record, the remains of man first appear on earth.

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Auburn, N. Y., January, 1910.

gr
ar

36° 30'

36° 15'

36°

112° 30'   112° 15'   112°   111° 45'
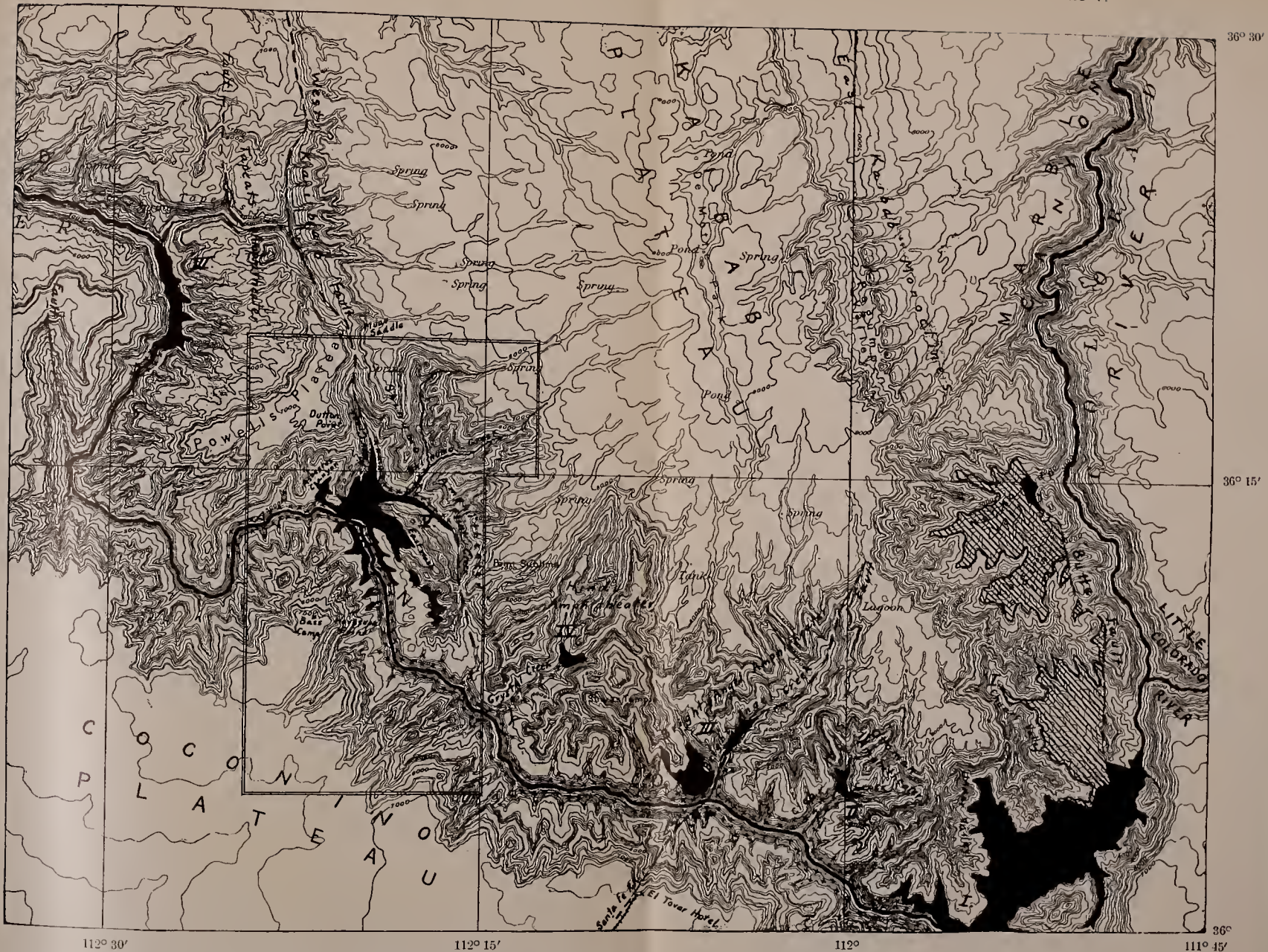
Map showing the Shinumo area (within double ruled lines) and distribution of Grand Canyon and Vishnu Series. From the Kaibab and Echo Cliffs topographic sheets, U. S. G. S. Contour interval, 250 ft. Scale about 5½ miles per inch.

Faults, — — — —. GRAND CANYON SERIES: *Chuar Group*, cross hatched. *Unkar Group*, solid black; I, Type area described by Walcott; II, Ottoman area; III, Bright Angel area; IV, Hindu area; V, Shinumo area; VI, Tapeats area. VISHNU SERIES, x x x x.

Art. XLV.—*On the Effects of Certain Magnetic and Gravitational Forces on the Motion of the Moon;* by Ernest W. Brown.

1. There exists a difference between the observed and computed places of the moon which has hitherto defied explanation. Its magnitude is so great in comparison with the accuracy obtainable both in theory and observation that it seems highly improbable that it should be due to error of any kind. From the observational side it has been known for over thirty years and during that time many efforts have been made, without success, to find its cause in the ordinary gravitational theory. It therefore seems pertinent to inquire whether some force or forces whose existence is only suspected may not be the cause of the discrepancy.

In setting forth the hypotheses mentioned below, my object is not at the outset to present a solution of the difficulty, and indeed no solution which can be accepted at the present time is offered. The reasons for the publication of the results of the investigation are of a different nature. The first is the consideration of certain forces whose constants are unknown but whose magnitudes can certainly be limited. It becomes possible in this way to exclude hypotheses which before actual computation do not appear to be highly improbable. The second object is to point out forces which are able to produce the inequality but which require to be confirmed by observations of a kind different from those obtained by the old methods of positional astronomy. And a third is for the purpose of indicating certain directions in which observations may be useful for the purpose of testing these hypotheses.

A possible magnetic attraction between the earth and the moon has occasionally been suggested, though its detailed consequences do not appear to have been worked out. The results below show that, although the magnitude of this attraction need not be very great, if it be a constant force its direction is unusual; or, if the magnitude of the force itself varies, the difficulty is only removed a step further back in that we know of no cause for such variation. The result arising from the figure of the sun demands conditions which may possibly be fulfilled but for which we must await further evidence. The supposed long-period term in the libration of the moon may in time be tested. For this purpose a long series of accurate observations would be necessary. In any case, such a series is needed in order to furnish more exact information than we at present possess of the motion of the moon about its center of mass, and this quite independently of any theory, gravitational or otherwise.

The mathematical developments by which the statements made below have been obtained are somewhat long and tedious. Since the results are either of a negative character or are obtained from hypotheses for which there is little or no collateral evidence, it seems unnecessary to develop at length the methods employed. When a disturbing function has once been obtained, it has now become a simple matter to compute rapidly the effect on the motion of the moon with the formulæ employed for the planetary terms, so that the details can be given at any time when the need for them may arise.

2. *The outstanding inequalities in the moon's motion.*—On several occasions during the past thirty years, Newcomb has examined the observations of the moon to try and find out what outstanding secular or long-period inequalities there may be in its motion which have not been explained by theory. Of these, the best known is the slow decrease in its period which increases its apparent longitude by $2''$ multiplied by the square of the number of centuries from the epoch of reckoning. This is generally ascribed with good reason to tidal friction and it is not necessary to consider other causes of change except for the purpose of finding the amount of the frictional effect.

But Newcomb has also discovered a large change which appears to be periodic and which he deduced from observations of occultations of stars by the moon. His last paper[*] includes observations of this kind from the beginning of the seventeenth century, a range of nearly 300 years. The change appears to be periodic, with a coefficient of about $12''$, a period of about 270 years and a phase which puts its maximum effect near the year 1795. Mr. P. H. Cowell makes the period about 350 years and the coefficient $18''$ on the assumption that there is no secular change to be ascribed to tidal friction.[†] It is this long-period term for which no cause has as yet been assigned. There are also indications of a term with a period of about 60 years and a coefficient between $2''$ and $3''$; also a term with a period of some 20 years and a coefficient rather less than $1''$. The last may possibly disappear when a comparison with the new tables of the moon's motion has been made and the arbitrary constants properly adjusted.

3. *Errors due to observation or theory.*—It is quite a simple matter to show that the peculiarities of observations on the moon cannot produce such a term. The majority of them are made at night and not very near new moon, and the moon itself has librations which alter its apparent diameter, but none of these can give rise to so large a term. There is the possibility of errors in Hansen's tables; but with the correc-

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[*] Monthly Notices R. A. S., vol. lxix, p. 164.
[†] Monthly Notices R. A. S., vol. lxv, p. 84.

tions now applied, it is extremely unlikely that further errors showing a periodicity of this kind are present.

The ordinary gravitational theory must at the outset be excluded. It has been so thoroughly investigated that there seems to be no likelihood of a term with so large a coefficient as 12″ having escaped detection. The term has frequently been ascribed to planetary action, but this action has now been treated in detail by several writers, and, in my own work on the subject, several thousands of terms were examined. Not the slightest possibility of the existence of a coefficient of anywhere near this magnitude has arisen. It may be noted that we are searching for a term nearly as great as the largest known term produced by planetary action, and further, that the next largest term has a coefficient only one-tenth of the required size. To ascribe the term to this cause would mean a defect in the theory so great that a total reconstruction would probably be necessary if an omission had been made.

4. *Method of investigation.*—The chief point is the period of the term, which is known from observation to be about 270 years. Now from the lunar theory we know that this period can be produced in three ways. It may be the effect of a nearly constant force on a term having this period, already present in the expressions for the moon's longitude. If the force be periodic, the period of the force must be either the period of the effect, or else the combination of the period of the force with one of the known periods in the moon's motion must produce the period of the effect. Now the period of the effect being 270 years, we must either look for a force having a period of 270 years, or else we must look for a force whose period differs from one of the lunar periods by a small quantity which runs through its changes in 270 years. The hypothesis of a nearly constant force is extremely improbable.

There is another point in the investigation that makes it easy to reject some of the hypotheses which may be brought forward. The mean annual motion of the perigee, as derived from theory and observation, shows no outstanding difference greater than 3/10 of a second ; and a similar statement may be made with respect to the node. If, therefore, we assume the existence of some force which gives a motion to the perigee, or to the node, much greater than this amount, the hypothesis must be rejected.

5. In the examination of long-period terms in the moon's motion there is one point of great importance in the consideration of the magnitude of the disturbing force. If the force has a period near that of the month, this period not depending on the mean motion of the moon, the factor which is chiefly responsible for the large coefficient depends on the *square* of

the number of months contained in the period; but if the force has the same period as the effect, then the factor is only the first power of this number. With a period of 270 years, the factor is 3600, so it makes an essential difference whether the force is of long period or approximates to a month. If it approximates to the period of the perigee, or to that of the node, we still get the square of the factor, but there are small factors which enter and which may diminish the square of the large factor to some number between 10^5 and 10^6.

6. Certain forces may be rejected with but little calculation. Those which arise from a supposed resisting medium will give secular and periodic changes, the latter with periods the same as those of known terms in the moon's motion. Again, Jupiter has an ellipticity of about 1/17, and therefore might affect the motion of the moon. I have examined this and find that its effect on the moon is at most about 1/1300 of the principal effect produced by the planet. A small factor in the disturbing function reduces this very considerably. It is certain that t heeffect of Jupiter's ellipticity must be insensible. Further, there is a group of small planets lying between Jupiter and Mars which will undoubtedly have some influence on the moon's motion; but this influence, when calculated, is seen to affect chiefly the motions of the perigee and node. The resulting addition to these motions cannot be more than a few hundredths of a second per annum; otherwise the group would more seriously alter the motions of the inner planets than is possible, owing to the close agreement between theory and observation.

It may therefore be assumed that no gravitational action of the sun, earth, and planets, considered as particles, has been left out of account. Further, the figures of the earth and Jupiter, considered as spheroids, have been treated; the other planets are too small or too far away for their figures to have sensible influence. A possible non-spherical form of the sun will be treated in § 7. The constant term due to the figure of the moon has been taken into account, but an effect which would be caused by a certain kind of minute libration of the moon, if it existed, will be considered in § 9. Light pressure is also ineffective in producing a long-period term, and, indeed, any effect from it is too small to be detected within historic times.

7. *Hypothesis of an equatorial ellipticity of the sun's figure.* —Owing to its rotation, the figure of the sun is not a perfect sphere. There will be a slight difference between the equatorial and polar axes. This difference cannot, however, do more than alter the mean motions of the perigee and node by a minute amount.

The hypothesis under examination demands that the sun be not symmetrical with respect to every plane which passes through its axis of rotation, and further, that the period of rotation approximates closely to one of the lunar months. To justify the former we must suppose that the nucleus of the sun's mass is a solid body or behaves like one; otherwise it is improbable that an equatorial ellipticity could permanently subsist. A coincidence of the period of rotation with one of the lunar months is less difficult. Although the photosphere shows periods of rotation differing with different latitudes, it is probable that the nucleus of the sun's mass has a period of rotation like that of a solid body, and that the period is somewhere between the greatest and the least of those observed by watching the motions of sun-spots. Now this period, between 25 and 30 days, may possibly coincide very nearly with one of the lunar months. If it does so with a difference which is small enough, the effect on the moon's motion will be an inequality of very long period, provided the sun has some equatorial ellipticity of figure. We have, therefore, to make two assumptions; one, that the period of rotation of the sun very nearly coincides with one of the lunar months, and second, that its moments of inertia about two axes lying in the equatorial plane of the sun are not equal. The computation of such an effect is somewhat troublesome, but it gives a perfectly definite result. If the period of the sun's rotation with respect to a line joining the earth and sun differs from the period of the synodic month by a small quantity, so that the two phases only coincide once in 270 years, it is only necessary to assume that the effective ellipticity* of the sun in its equatorial plane is about 1/46,000. If we assume that the near coincidence is with an anomalistic month, then the ellipticity must be about 1,220 to produce the required term. If the near coincidence is with a nodal month an ellipticity of 1/2200 is sufficient.

These minute values are mainly due to the presence of the factor 3600^2, explained in §5. The introduction of two new hypotheses in order to explain a single phenomenon is objectionable and therefore requires some examination into their probability. Although observation has not yet reached the degree of accuracy required to compare the periods, it will be advisable to examine the material in order to see how closely we can compare them.

The periods of the three months relative to a line joining the mean positions of the earth and sun are :

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* The effective ellipticity is here defined to be the ratio of the difference of the moments of inertia to the product of the mass of the sun and the square of the radius of its visible surface.

Synodic   month, $27^{d}\cdot3317$,
Anomalistic month, $25^{d}\cdot6217$,
Nodal   month, $25^{d}\cdot3254$,

and one of these is to differ from the sidereal period of rotation of the sun by about $0^{d}\cdot0038$, since the angles present in the disturbing function are double the differences, and the period of the empirical term is about 3600 months.

The nodal month is nearest to the values found for the mean solar rotation period by Carrington ($25^{d}\cdot38$) and Spoerer ($25^{d}\cdot23$) from observations of the motion of sun-spots. W. S. Adams,[*] observing the displacements of certain lines of the spectrum, obtains periods ranging from $24^{d}\cdot57$ at the equator to $35^{d}\cdot26$ in latitude 79°. He inclines to the view that the equatorial velocities give a period approximating more closely to the actual period than those of higher latitudes. The evidence so far obtained indicates a possibility that the true rotation period may be close to that of the nodal month relative to the earth's mean radius vector.

A coincidence with the nodal month involves an effective ellipticity of about 1/2200. This might be detected over a long series of observations if the visible surface of the sun were solid. It is extremely unlikely that such an ellipticity would persist as far as the photosphere, which ought on the average to be a level surface. An indirect method may, however, furnish evidence one way or the other. If the ellipticity exists, it is probable that the solar activity would be more marked in two sectors on opposite sides of the solar axis than in the other two sectors. The average period derived from observations of sun-spots or other evidence of abnormal activity would therefore furnish the material to be examined. It is significant that the nodal period lies between the results for the solar period obtained by Carrington and Spoerer. The hypothesis opens up a wide field of speculation and investigation as to its physical consequences, especially on the motion of the outer liquid or gaseous layers of the sun's mass. The belief that the eleven-year period is due to forces within the sun is perhaps less difficult with the hypothesis of such an inequality in the distribution of the mass of the nucleus.

8. *Hypothesis of a magnetic attraction between the earth and the moon.*—For the purposes of this section it will be sufficient to consider the magnetic fields of the earth and moon as equivalent to fields produced by straight solenoids symmetrical with respect to their respective centers of figure. The directions of these solenoids will, in the first instance, be taken arbitrarily, but the main results of the discussion depend on the directions which may be assigned to them.

[*] Astrophysical Journal, March, 1909.

The chief reason that the effect of magnetic attraction may be capable of observation arises from the fact that the resultant force varies as the inverse fourth power of the distance, while gravitation varies as the inverse square. It is in this respect similar to the attraction produced by the ellipticity of the earth's figure, that is, by the difference between the moments of inertia about the polar and equatorial diameters of the earth. For this reason it will be useful to compare the magnitudes of the forces which must be invoked with that produced by the earth's figure. It is, however, to be remembered that the resolved part of the magnetic attraction in any direction differs from that of the earth's figure, mainly because the earth's magnetic axis is not the axis of figure.

The potential of the magnetic attraction may with sufficient approximation be expressed in the form $(u_0 + u_1)/r^3$ where u_0 is a constant and u_1 consists of terms whose mean value for all time is zero, and r is the distance between the moon and earth. It is a simple matter to prove that a force due to a potential u_0/r^3 must have an accelerative effect on the moon less than $5 \cdot 10^{-9}$ of that produced by the earth's attraction on the whole mass of the moon. This fact is deduced from the well-known result that the motion of the perigee, as determined by observation and theory, is not in error by so much as one part in $5 \cdot 10^5$. Now the principal effect of the earth's ellipticity is 10^{-7} of that produced by the main attraction of the earth. Hence the effect of a term u_0/r^3, here supposed to be due to magnetic attraction, must be less than $1/20$ of that of the earth's ellipticity. Further, if the inequality which we seek to explain is produced by a force of the same period as that of the inequality, this force, contained in u_1/r^3, will not be greater than $1/120$ of that of the earth's ellipticity.

These facts give the first negative result, namely, that *the inequality we seek to explain cannot be produced solely by the secular motion of the magnetic axis of the earth.* This secular motion is known with an accuracy for the last 300 years which is sufficient to prove that if it produced the inequality, it would cause an addition to the mean motion of the lunar perigee much greater than the agreement between gravitational theory and observation permits. Such a hypothesis appeared not unreasonable at one time, since there was some reason to think that the period of the secular variation was about 600 years and this would produce an inequality in the motion of the moon of half the period of the change. The period of the secular change, if a real period exists, is now thought to be considerably longer than 600 years.

Next, suppose that the inequality is produced by a variation in position only of an assumed magnetic axis in the moon.

In an exactly similar manner, it is proved that *this axis cannot oscillate about a mean position coinciding with or near the moon's axis of rotation.* The only way in which the variation of *position* is effective is an oscillation about a mean position in the lunar equator. Further, if the oscillations are perpendicular to the equator they must be large (of the order of 20°). If the oscillations are within the equator, the product of the magnetic moment and the amplitude of the oscillation becomes a factor which can be determined from the observed coefficient of the inequality, but there is no information at hand to separate the two terms of the product, since a motion of the perigee is not produced to this order of magnitude.

Let us next suppose that the directions of the magnetic axes are fixed with respect to the axes of figure of the two bodies, and that the inequality is produced by a variation of the product of the magnetic moments. Then, owing to the facts previously mentioned concerning the possible magnitudes of the additional motion of the perigee and the variable force, the extreme range of values of the magnetic moment is never nearer to unity than is the ratio 5/7. That is, the maximum variation from the mean is at least 15 per cent, and its period must be in the neighborhood of 270 years.

A magnetic attraction between the earth and moon has, however, a relatively greater effect on the precession and nutation of the earth than on the motion of the center of the moon, since the principal part is a couple, and the force we have been considering is small compared with this couple. An idea of the maximum magnitude of the assumed forces can be thus obtained. The ellipticity of the earth's surface, as measured by Clarke, is 1/293. The formulæ of precession and nutation, combined with an assumed equipotential surface for the earth, give an ellipticity to the latter of 1/297. The observed coefficient of the nodal term in the motion of the moon gives an ellipticity of a similar order of magnitude. The difference between the two values quoted amounts to about 1/70 of the whole. This limits the resolved part of the magnetic moment along the lunar axis of rotation to 1/70 of the earth's ellipticity. Hence u_0/r^3 must be less than one-half of u_1/r^3.

The formulæ of precession compared with observation do not exclude such a variable part. The amount of the precession in 70 years is 3600″, and the maximum change in this time due to a variable force of the magnitude considered is about 2″. The degree of accuracy attained by observation does not exclude such a coefficient. It might even be possible to detect it, but the investigation would have to extend over the whole range of known observations, and a very large number would be required.

The effect on the constant of nutation is relatively larger,—about $0''·1$ to $0''·2$ in a constant of $9''·2$. This, again, is not excluded by the observations. To detect it with any certainty we should need from five to ten periods of 18 years each.

We must conclude, then, that a variable force with a period of 270 years and a maximum value about $1/120$ of that produced by the earth's ellipticity is not excluded by the observations. If such a force exists with a potential $(u_0 + u_1)/r^3$, so that it may be treated as an addition to the earth's ellipticity, we must conclude that the constant part of the addition is less than $1/70$ and the variable part less than $1/120$ of that caused by the earth's ellipticity.

Either of the two forms of the hypothesis which are admissible, an oscillation of a lunar magnetic axis about a mean position in the lunar equator, or a variable moment with an axis near the lunar axis of rotation, are difficult. There is, however, still another effect not yet considered, and one which, though secondary, is somewhat remarkable. It will be seen in the next section that a minute libration of the moon can, under certain circumstances, have a large effect on its motion. Now any supposed magnetic attraction between the earth and the moon will have its greatest effect in altering the direction of the axes of figure of the moon. The force is the same as that which would affect the precession and nutation of the earth, but its effect is 80 times as great, in general, owing to the earth's mass being 80 times that of the moon. The possibilities in this direction will be considered in § 10.

9. *The effect of the physical libration of the moon's axes.*—It can be shown that if we adopt the ellipticities of the moon's figure as being of the order of magnitude determined by observation, an oscillation within the plane of the lunar equator of the axes lying in that plane with a period of 270 years and a coefficient of $50''$ will produce the observed inequality in the moon's motion.

The physical librations of the moon are of two kinds, free and forced. The forced librations, produced by the motion of the moon round the earth, are for that reason powerless to cause any sensible effect on its motion round the earth,—a result which can be deduced from the equations of motion. There are theoretically three principal free librations each with its own period, dependent on the three ellipticities of the principal sections of the moon's surface. The amplitudes of these librations have not yet been observed and it is generally assumed that they are zero or at least beyond detection by the observations hitherto made. The ellipticities, nevertheless, can be obtained from the forced librations and thence the periods of the free librations.

The libration along the lunar equator of that principal axis of the moon which is directed towards the earth would have, according to theory, a period of between two and three years: the value is doubtful. The period of the second libration is very nearly equal to a month. On examination it is seen that neither of these can cause any sensible effect unless it had an amplitude which would have been detected by observation.

The third libration has a period of between 200 and 300 years. The time is suggestive but its direction of motion is perpendicular to the moon's equator. In order to affect the motion of the moon's center sufficiently it would have to give rise to a libration within the moon's equator. The theory of the motion of the moon about its center of mass must be worked out to a higher degree of accuracy than yet obtained in order to find out whether there may be a long-period term of the kind and size required. On the observational side sufficient material has not yet been accumulated to test the existence of terms of very long period.

An angular change of $100''$ in the position of any axis of the moon is the smallest amount which can be detected by a single observation, with the methods hitherto used. The recent work of Mr. F. T. M. Stratton[*] shows clearly how doubtful the constants of the moon's physical constitution are. This is to be expected, since the librational coefficients from which these constants are determined are of the order of $100''$. Hence a long-period vibration of $50''$ is not at present excluded either by theory or observation.

10. A well known difficulty in the theory of the rotation of the moon is the fact that the ellipticities, as determined from observation, are some sixteen times as great as the ellipticities obtained on the assumption that the outer form of the moon is a level surface. It has already been mentioned that a magnetic attraction between the earth and the moon would produce the largest relative effect on the rotation of the moon. It may be suggested that the forced vibrations which are observed have their origin mainly in a magnetic attraction rather than in the gravitational attraction hitherto considered. The general effect is quite similar.

Nevertheless the free librations in any case depend on the ellipticities alone. If we calculate the free libration in the equatorial plane with the theoretical ellipticities first mentioned, the period, instead of two or three years, becomes 14 years, and this may be still further increased by non-rigidity.

A free period of 17 to 20 years is effective in producing inequalities with long periods and large coefficients in the

[*] Memoirs Roy. Astron. Soc., vol. lix, pt. iv.

motion of the moon's center of mass.   This is due to the near coincidence with the period of revolution of the moon's node. But since the amplitude of the inequality in the moon's motion is directly proportional to the ellipticity, the amplitude of the free libration must be proportionally increased so that it would have to be of the order of 800″.   It seems doubtful that such a large term should have escaped detection.

The results of these various computations are therefore not, on the whole, favorable to the hypothesis that a librational term causes the long-period inequality in the moon's motion. But the magnitudes of the forces which have been considered are so small that a more careful examination into the question of the whole effect of a magnetic attraction on the motion of the moon about its center of mass seems to be a desideratum, in view of the discordance between the theoretical and the observed ellipticities.   This is not the object in view here, but the effects are not confined to any one class of observations and it may be possible to obtain evidence from various sources by which the question can be settled.

Yale University, April 7, 1910.

ART. XLVI.—*The Use of Silver in the Determination of Molybdenum, Vanadium, Selenium and Tellurium;* by CLAUDE C. PERKINS.

[Contributions from the Kent Chemical Laboratory of Yale Univ.—ccxi.]

IN former papers from this laboratory a process for the gravimetric determination of free iodine by means of specially prepared electrolytic silver* and the application of the same process to the determination of combined iodine and other halogens and the estimation of those oxidizers† whose reaction with potassium iodide is definitely known to set free iodine quantitatively have been described. The object of the work described in the present paper was the application of the same process to the determination of some of the rarer elements and the study of the reaction of their oxides upon hydriodic acid in the presence of silver.

To test the reaction of a soluble molybdate upon combined iodine in the presence of silver, a standard solution was made from a weighed amount of ammonium molybdate in which the percentage of molybdenum trioxide had been determined by fusing with a weighed amount of sodium tungstate which contained just enough tungstic acid to insure the absence of carbon dioxide. The ammonia was thus driven off and the amount of molybdenum trioxide was found from the increase in weight of the sodium tungstate.‡ Definite amounts of this solution were added to an excess of potassium iodide, made acid with hydrochloric acid and shaken with the electrolytically prepared silver under an atmosphere of hydrogen. From the increase in weight of the silver the amount of molybdenum trioxide was calculated on the assumption that one molecule of molybdenum trioxide liberates one atom of iodine with the results shown in Table I. These results would tend to show that the reaction takes place according to the following equation :

$$2MoO_3 + 4KI + 4HCl = 2MoO_2I + 4KCl + 2H_2O + I_2.$$
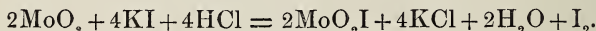
TABLE I.

Ag taken grm.	MoO₃ taken grm.	I₂ found grm.	Calculated MoO₃ grm.	Error grm.
2·0002	0·2127	0·1869	0·2120	−0·0007
2·0006	0·2127	0·1874	0·2126	−0·0001
2·0012	0·2127	0·1870	0·2121	−0·0006
2·0048	0·2127	0·1876	0·2128	+0·0001
2·0000	0·2540	0·2242	0·2543	+0·0003
2·0004	0·2909	0·2571	0·2916	+0·0007

* This Journal, vol. xxviii, 33, 1909.   † This Journal, vol. xxix, 338, 1910.
‡ Gooch and Norton, this Journal, vol. vi, 168, 1896.

In testing the reaction of a soluble vanadate with potassium iodide an exactly analogous process to that used in the case of molybdenum was carried out. The ammonium vanadate was fused with sodium tungstate to determine the amount of vanadium pentoxide contained in it. A known amount of the vanadate was shaken with potassium iodide, hydrochloric acid, and the silver, and the results calculated on the assumption that one molecule of vanadium pentoxide liberates two atoms of iodine. The results shown in Table II would indicate that the reaction takes place according to the equation:

$$V_2O_5 + 2HCl + 2KI = V_2O_4 + H_2O + 2KCl + I_2.$$
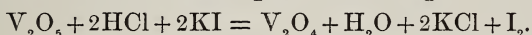
TABLE II.

Ag taken grm.	V_2O_5 taken grm.	I found grm.	Calculated V_2O_5 grm.	Error grm.
2·0012	0·1946	0·2699	0·1939	— 0·0007
2·0012	0·2051	0·2856	0·2051	± 0·0000
2·0024	0·1964	0·2746	0·1972	+ 0·0008
2·0024	0·2362	0·3295	0·2367	+ 0·0005
2·0062	0·2953	0·4106	0·2949	— 0·0004
2·0062	0·2681	0·3729	0·2679	— 0·0002
2·0527	0·5770	0·8038	0·5774	+ 0·0004
2·0006	0·2035	0·2829	0·2032	— 0·0003

With selenium and tellurium it was found that the reduction proceeded to the end, giving the free elements, so that in weighing the residue of silver and silver iodide the amount of selenium or tellurium taken was included. The results obtained indicate that the reactions between selenium dioxide and potassium iodide and between tellurium dioxide and potassium iodide proceed according to the following equations:

$$SeO_2 + 4KI + 4HCl = 4KCl + 2H_2O + Se + 2I_2.$$
$$TeO_2 + 4KI + 4HCl = 4KCl + 2H_2O + Te + 2I_2.$$
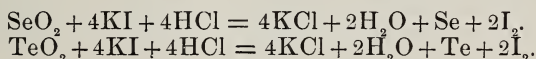
The selenium used was carefully purified by twice crystalizing from nitric acid solution as selenium dioxide and resubliming in the presence of manganese dioxide. Definite amounts of a standard solution of selenium dioxide were added to an excess of potassium iodide in acid solution, and shaken with a weighed amount of the silver under the atmosphere of hydrogen. The increase in weight should represent the iodine liberated plus the selenium taken. The results in Table III were calculated upon the assumption that one molecule of selenium dioxide liberates four atoms of iodine, which gives 13·49 per cent of the increase in weight as the amount of selenium taken.

<div style="text-align:center">T<small>ABLE</small> III.</div>

Ag taken grm.	Se taken grm.	Increase grm.	Calculated Se grm.	Error grm.
2·0133	0·0050	0·0365	0·0049	—0·0001
2·0133	0·0075	0·0529	0·0071	—0·0004
2·5639	0·0126	0·0894	0·0121	—0·0005
2·5639	0·0428	0·3178	0·0429	+0·0001
3·0018	0·0504	0·3799	0·0501	—0·0003

In determining tellurium the dioxide was prepared from the basic nitrate by heating to drive off the nitric acid and the residual tellurium dioxide was heated to constant weight. Definite amounts of a standard solution, made from this product of tellurium dioxide, were added to an excess of a solution of potassium iodide, made acid with hydrochloric acid, and the whole shaken with a weighed amount of the silver under an atmosphere of hydrogen. The increase in weight represents the iodine set free plus the amount of tellurium taken. The results in Table IV were calculated upon the assumption that one molecule of tellurium dioxide liberates four atoms of iodide which gives 20·07 per cent of the increase as tellurium.

<div style="text-align:center">T<small>ABLE</small> IV.</div>

<div style="text-align:center">Te = 127·5</div>

Ag taken grm.	Te taken grm.	Increase grm.	Calculated Te grm.	Error grm.
2·0152	0·0330	0·1654	0·0332	+0·0002
2·0152	0·0990	0·4931	0·0989	—0·0001
2·0815	0·0528	0·2635	0·0529	+0·0001
2·0815	0·0660	0·3294	0·0661	+0·0001
2·0815	0·0990	0·4948	0·0993	+0·0003
2·1693	0·1650	0·8240	0·1654	+0·0004
3·0126	0·1650	0·8258	0·1657	+0·0007
3·0126	0·0660	0·3302	0·0663	+0·0003

The results show that molybdenum, vanadium, selenium, and tellurium, may be determined gravimetrically by making use of the reaction of their oxides in liberating iodine from potassium iodide in an acid solution and combining the free iodine with the specially prepared silver.

Art. XLVII.—*Chemical Composition of Hulsite and Paigeite;** by Waldemar T. Schaller.

Introduction.

In the April number of this Journal for 1908† in conjunction with Mr. Adolph Knopf, who discovered these minerals in Alaska, I published a description of two new borates, hulsite and paigeite. These borates contained both ferrous and ferric iron, magnesia, and a small amount of water. The boric acid was determined by distillation with methyl alcohol and subsequent weighing as lime borate. Only a single determination of the B_2O_3 was given for each mineral. As, however, both analyses footed up well and the ratios, moreover, were fairly close to simple numbers, no doubt was entertained as to the correctness of the results given.

Shortly after, Prof. Clarke informed us that the method of determining boric acid in minerals was being investigated by two students of Prof. Edgar F. Smith, of the University of Pennsylvania. On entering into communication with Prof. Smith, we were enabled to have the boric acid content of both new minerals redetermined by methods devised by E. T. Wherry and W. H. Chapin.‡ It was found that the values first obtained were erroneous, being much too high.§ On again examining the minerals, therefore, to account for the deficiency, tin was found to be present in appreciable quantity in both minerals. It therefore became necessary to revise and extend the original analyses in order to definitely fix the composition of these minerals.

Notes on Chemical Examination.—These borates, having very similar composition, contain ferrous and ferric iron, magnesia, tin, water, boric acid, and there are in addition present in the HCl solution of the sample, silica, alumina and lime, derived from the gangue.

After considerable work performed on these two minerals, the results herein presented were obtained, but the unsatisfactory character of the determinations is fully recognized. A complete revision of all the chemical data is highly desirable, but for this pure material, free from any interfering gangue, is

* A brief abstract of a much fuller paper which is to appear in a forthcoming Bulletin of the U. S. Geological Survey.

† Knopf, A. and Schaller, W. T., Two New Boron Minerals of Contact Metamorphic Origin, this Journal (4), vol. xxv, p. 323, 1908.

‡ Determination of Boric Acid in Insoluble Silicates, Jour. American Chem. Soc., vol. xxx, p. 1687, 1908.

§ This Journal (4), vol. xxv, p. 323, 1908.

necessary, and for the complete elucidation of the problem considerable material must be available.

The present investigation was carried out under two great disadvantages, namely, (1) paucity of material, and (2) the unavoidable presence of considerable gangue in the samples. For the hulsite samples, free from magnetite, less than a gram was available, while several grams of paigeite, as pure as possible, had to suffice. Various questions developed only after some of the analyses had been completed, so that additional material was often needed but could not be had. It was found, too, that the different samples of each mineral varied somewhat in composition due to the different quality and quantity of the gangue and also to isomorphous replacements in the minerals themselves. All these points, developed as the analyses progressed, served to render the results obtained unsatisfactory to the analyst.

Analyses of hulsite.

Three different samples of hulsite were obtained and analyzed, the first two being the ones given in the original paper. Sample No. 1 consisted of about half a gram of magnetite-free hulsite, which was partially analyzed, only ferrous and ferric iron, magnesia, and the insoluble matter being determined. Sample No. 2 was about a gram of material, consisting of a mixture of hulsite and magnetite with but a few per cent of insoluble gangue. Tin was not determined in either of these samples and the value for boric acid given below for sample No. 2 was furnished by Wherry and Chapin.* Sample No. 3 was obtained by reëxamining all the available material and picking out a small amount of non-magnetic hulsite mixed with considerable gangue. The relatively large amount of the gangue that was soluble in acid complicated the discussion of the results.

Only the average of the analyses of samples Nos. 1 and 2 are repeated below, the fuller data being given in the original paper.

Average analyses of samples Nos. 1 and 2, hulsite.

	No. 1.	No. 2.
FeO	33·27	34·44
MgO	10·17	8·48
Fe_2O_3	17·83	27·64
B_2O_3	----	10·44
H_2O	----	1·66
Insol.	10·00	2·24
SnO_2	not det.	not det.

From the analysis of sample No. 3, the ratio of B_2O_3 to Fe_2O_3 is found to be 3 : 2. From this ratio the amount of magnetite

* Loc. cit.

present in the above sample No. 2 can be calculated. The amount of ferric iron belonging to the borate being thus determined, the amount belonging to the magnetite is found, and deducting the proper amount of FeO to form FeO.Fe$_2$O$_3$, the ratios reduce to the figures given beyond, which represent the composition of the magnetite-free hulsite.

The results obtained for the analyses of sample No. 3 are given below. Though considerable insoluble gangue was present, magnetite was entirely absent. The results shown under 1a were made on a small sample of still impurer material and is chiefly of value for the determination of the tin, as the value confirms the other figures given for tin. The ammonia precipitate for sample 1a was not determined, as it was used for various qualitative tests and the calcium precipitate was accidentally lost. The figures given under 1a are not taken into the average. The higher value for the boric acid under columns 1 and 2 is taken in the average instead of the mean of the two values, as the second determination given is believed to be low.

Analyses of sample No. 3, hulsite.

	1a	1	2	3	Average
FeO	-- -	----	----	27·71	27·71
MgO	3·62	----	4·13	4·45	4·29
CaO	----	7·98	9·82	9·54	9·11
Fe$_2$O$_3$	----	----	----	----	15·21
Total iron as Fe$_2$O$_3$	----	----	46·30	45·67	----
SnO$_2$	6·13	6·85	7·15	7·20	7·07
B$_2$O$_3$	----	9·20	8·27	----	9·20
Insoluble	27·42	19·92	17·52	18·44	18·63
H$_2$O, CO$_2$, SiO$_2$, Al$_2$O$_3$	----	----	diff.	----	8·78
					100·00

From the figures given above for the average analysis the ratios were calculated with the following values:

Ratios of analysis of sample No. 3, hulsite.

FeO	·385 ⎫	10·47
MgO	·107 ⎭	
Fe$_2$O$_3$	·095	2·02
SnO$_2$	·047	1·00
B$_2$O$_3$	·131	2·79

The analyses of samples No. 2 of paigeite, as given beyond, give an indication of the amount of calcium oxide which may be derived from the gangue. For 15 per cent insoluble matter the calcium oxide content is about 4 per cent. If this ratio remains fairly constant, there should be, in the above analysis of hulsite sample No. 3, about 5 per cent of lime obtained from the gangue. This would leave approximately somewhat

less than 4 per cent CaO which may belong to the borate mineral.   Assuming this to be so, the ratio of (FeO, MgO, CaO) to Fe_2O_3 would become 11·9 : 1 or nearly 12 : 1.   From the analysis of sample No. 3, given above, we obtain for the formula of hulsite, then, either $10\frac{1}{2}RO.2Fe_2O_3.SnO_2.3B_2O_3 + ?H_2O$, or regarding the 4 per cent of CaO as belonging to the mineral, the formula $12RO.2Fe_2O_3.SnO_2.3B_2O_3 + ?H_2O$.

Discussion of Formulæ of Hulsite.

From the results of the analyses of the three samples of hulsite, as just given, there are derived the following partial formulæ for the mineral.

Partial Formulæ for Hulsite.

	RO	Fe_2O_3	SnO_2	B_2O_3	H_2O
From Sample No. 1 _ _ _ _ _	13·2	2·0	_ _	_ _	_ _
" 2 _ _ _ _ _	12·4	2·0	_ _	3·0	1·9
" 3 } _ _ _	10·5	2·0	1·0	2·8	_ _ or
" 3 } _ _ _	12·0	2·0	1·0	2·8	_ _

From this compilation, incomplete as it is, the most probable formula derivable from the results obtained is $12RO.2Fe_2O_3.$ $1SnO_2.3B_2O_3.2H_2O$ or $(Fe,Mg)_{12}Fe_4SnB_6H_4O_{31}$.   In considering the relations of the various elements, it becomes almost impossible to consider hulsite as a borate of iron (ferrous and ferric), tin and magnesia, as the bases are present in overwhelming amount.   Therefore, the ferric iron may be considered as present as an acid, playing the same rôle as the borates.   On this assumption the above formula may be written : $R''_9(BO_3)_6.[R''_3[Sn(OH)]''' H_3(FeO_3)_4]$.   The tin in hulsite is in a condition which is so easily soluble in dilute acid that it seems more probable to regard it as present as some form of stannic acid.   The presence, however, of stannic acid, in combination with boric and possibly some iron acid, leads to a complicated subject on which it is best to, at present, pass by.

Analyses of Paigeite.

For paigeite, three different samples were prepared and analyzed.   The amount of gangue varied slightly, but no such large variations in the amount were encountered as with hulsite.   Sample No. 1 was the sample on which the first analyses were made.   Tin was not determined in it, and the value given for B_2O_3 is the one determined by Wherry and Chapin.   The average of the analyses is :

FeO _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ 44·48
MgO _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _   1·44
Fe_2O_3 _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ 16·72
H_2O _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _   2·03
B_2O_3 _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _   9·83
Insol. _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ 15·65

The other two samples were prepared from the specimens at hand, sample No. 2, consisting of finely-ground material, for which reason the value for FeO may be somewhat low. Sample No. 3 consisted of coarser material, otherwise very similar in character to that of No. 2.

Analyses of the second sample yielded the following results :

Analysis of sample No. 2, paigeite.

FeO	40·82	....	....	40·82
MgO	2·02	2·01	2·10	2·04
CaO	4·28	4·31	3·81	4·13
Fe_2O_3	18·19	19·34	18·48	18·67
Total iron as Fe_2O_3	63·54	64·69	63·83	....
SnO_2	3·15	3·14	3·26	3·18
B_2O_3	9·10	....	....	9·10
Insoluble	16·18	15·74	16·38	16·10
SiO_2, Al_2O_3, H_2O	....	by difference		5·96
				100·00

Considering all the lime as resulting from the solution of the gangue, the ratios deduced from the above analyses are :

Ratios of analyses of sample No. 2, paigeite.

FeO	·567 ⎫	
MgO	·051 ⎬	29·4
Fe_2O_3	·117	5·6
SnO_2	·021	1·0
B_2O_3	·130	6·2
H_2O	....	....

From these ratios the formula, incomplete in regard to the water content, is $29\cdot4RO.5\cdot6Fe_2O_3.1SnO_2.6\cdot2.B_2O_3. + ? H_2O$.

Analyses of the third sample yielded the following results. The evidence having indicated that the gangue was considerably dissolved by the HCl, direct determinations of the silica and alumina were made.

Analysis of sample No. 3, paigeite.

	1	2	3	Average
FeO	34·68	34·86	35·52	35·02
MgO	2·25	1·89	2·22	2·12
CaO	8·97	8·56	8·84	8·79
Fe_2O_3	14·69	14·84	15·18	14·90
Total iron as Fe_2O_3	53·22	53·57	54·62	....
SnO_2	2·77	2·86	2·76*	2·80
B_2O_3	....	6·71	7·16	6·94
Insoluble	18·62	18·81	18·29	18·57
SiO_2	3·28	2·78	3·25	3·10
Al_2O_3	2·51	2·41	2·09	2·34
H_2O, etc.		by difference		5·42
				100·00

* A fourth determination of SnO_2 gave 2·97 per cent.

In the ratios of the above analysis, the CaO, SiO_2 and Al_2O_3 are excluded as belonging with the insoluble matter to the gangue. As obtained from the average analysis, they are:—

Ratios of analysis of sample No. 3, paigeite.

FeO	·486 }	28·5
MgO	·056 }	
Fe_2O_3	·093	4·9
SnO_2	·019	1·0
B_2O_3	·099	5·2
H_2O	----	

Like one of the hulsite analyses, the calcium oxide is considerably higher in sample No. 3 than in sample No. 2 and it seems as if some of the lime belonged to the borate. It would need only 1·57 per cent. of CaO to raise the ratio of $(FeO + MgO + CaO)$ to SnO_2 from 28·5 : 1, as given above, to 30 : 1. This small amount of lime may, therefore, be considered as belonging to the borate. The ratios then obtained are 28·5 or 30·0 $RO.4·9Fe_2O_3.1SnO_2.5·2B_2O_3 + ? H_2O$.

Discussion of Formulæ of Paigeite.

From the above three series of analyses, the following are the formulæ deduced for paigeite:

Formulæ for Paigeite.

	RO	Fe_2O_3	SnO_2	B_2O_3	H_2O
From sample No. 1	31·1	5·0	---	6·7	5·4
" 2	29·4	5·6	1·0	6·2	---
" 3 }	28·5	4·9	1·0	5·2	--- or
}	30·0	4·9	1·0	5·2	---

The average of the above shows that the most probable formula for paigeite and the one proposed for the mineral is: $30FeO.5Fe_2O_3.1SnO_2.6B_2O_3.5H_2O$. While the above formula is complex and yields a rather high ratio of FeO to SnO_2, there does not seem to be any other interpretation to the analyses. While not impossible that paigeite is a mixture of two or more closely related minerals, nothing but the unusual composition indicates such a mixture. The constant small percentage of tin oxide shows that the mineral is essentially different in ratios from the corresponding hulsite. The occurrence in wavy lamellar masses of fine radiating fibers, the intense shiny black color, the marked tendency as seen in thin sections for the individual fibers and masses to fray out at the ends into a

bunch of very thin fibers, all differentiate this mineral from hulsite, which never shows any indication of fibrosity.

An alternative interpretation of the composition of paigeite is that it is a mixture of hulsite and a fibrous borate. Subtracting from the formula of paigeite the necessary amounts to include all the tin with the hulsite, the following results are obtained:

$$\text{Paigeite} = 30\ \text{FeO}.5\ \text{Fe}_2\text{O}_3.1\text{SnO}_2.6\text{B}_2\text{O}_3.5\ \text{H}_2\text{O}$$

$$\text{minus hulsite} \quad 12\ \text{``}\quad 2\ \text{``}\quad 1\ \text{``}\quad 3\ \text{``}\quad 2\ \text{``}$$

$$\text{there is left} \quad 18\ \text{``}\quad 3\ \text{``}\ \_\_\ \text{``}\quad 3\ \text{``}\quad 3\ \text{``}\ \text{ or}$$

$$6\text{FeO}.\text{Fe}_2\text{O}_3.\text{B}_2\text{O}_3.\text{H}_2\text{O}.$$

Should future investigation prove this to be the case, then the material now called paigeite would consist of a mixture of 1 part hulsite and 3 parts of the borate $6\text{FeO}.\text{Fe}_2\text{O}_3.\text{B}_2\text{O}_3.\text{H}_2\text{O}$, to which the name of paigeite could then be referred. However, on the evidence at hand, it is most reasonable to regard paigeite as homogeneous and with the composition ascribed to it.

To repeat, the formulæ now proposed are, for hulsite, $12(\text{Fe},\text{Mg})\text{O}.2\text{Fe}_2\text{O}_3.1\text{SnO}_2.3\text{B}_2\text{O}_3.2\text{H}_2\text{O}$, and for paigeite, $30\text{FeO}.5\text{Fe}_2\text{O}_3.1\text{SnO}_2.6\text{B}_2\text{O}_3.5\text{H}_2\text{O}$.

Chemical Laboratory,
    U. S. Geological Survey.

SCIENTIFIC INTELLIGENCE.

I. CHEMISTRY AND PHYSICS.

1. *A Gas containing Helium from the German Potash Deposit.*— ERNST ERDMANN gives an account of an inflammable gas which was set free by a blast in the carnallite deposit of a shaft at a depth of 450 meters below the surface. When first liberated, $4\frac{1}{2}$ years ago, it burned with a flame a yard long, and the pressure has since diminished only very gradually, and many thousands of cubic meters of the gas have escaped and burned. As an average of eight analyses the following results were obtained:

Hydrogen	83·6 per cent by volume.
Methane	4·4 " " "
Residue	12·0 " " "

The methane was found to be free from other hydrocarbons of the series, and the absence of oxygen, carbon dioxide, ethylene, and acetylene was established. The residue was found to contain

a considerable amount of helium and also a little neon. These gases amounted to 0·17 per cent by volume of the original gas, or nearly one per cent of the residue, so that it was estimated that at least 12 cubic meters of helium and neon had escaped from the crack in the carnallite during the $4\frac{1}{2}$ years of the flow of gas. It appears that Strutt had already detected a small quantity of helium in carnallite by dissolving the mineral in water.

In speculating in regard to the origin of the hydrogen the author is inclined to discard an ingenious theory advanced by Precht, that this gas arises from the reaction of ferrous chloride upon the water of crystallization of the mineral with the formation of hematite, a well-known constituent of the deposits. In fact, by heating appropriate mixtures in evacuated sealed tubes at 100–110° C. for 160 hours, no evidence of the formation of hydrogen or ferric oxide could be obtained. This experimental result, and the fact of the presence of helium, have led the author to advance the view that radio-activity has been the cause of the formation of hydrogen as well as of helium. Radio-active substances are supposed to have decomposed water into its elements, then the oxygen has reacted with ferrous chloride to form hematite, leaving the hydrogen. The radio-active bodies are supposed to have disappeared from the deposit, on account of being of shorter duration than uranium, which seems to be absent, and which has so long a life that it could not be expected to disappear in the time that has elapsed since the deposits were formed.

The author doubts that the feeble radio-activity of potassium is the source of the helium, although Strutt is inclined to take this view of the matter, for he argues that the helium is by no means uniformly distributed among the potassium salts, and, besides, there is no ground at present for assuming the production of helium from potassium.—*Berichte*, xliii, 777.　　　　　h. l. w.

2. *Detection of Methyl Alcohol.*—A rapid and accurate method for the detection of this substance, particularly in the presence of ethyl alcohol, has been devised by G. Denigès. It is based upon the conversion of the alcohols into their corresponding aldehydes by the action of potassium permanganate under definite conditions, and the testing for formaldehyde by means of bisulphite-fuchsine under conditions that the author has worked out. He takes 0·1^{cc} of the alcohol to be tested in a test-tube, adds 5^{cc} of 1 per cent $KMnO_4$ solution, then 0·2^{cc} (not more) of pure H_2SO_4, and mixes. After 2 or 3 minutes 1^{cc} of 8 per cent oxalic acid is added, and the mixture is agitated. It rapidly becomes decolorized, and when a yellowish wine color is reached, 1^{cc} of pure H_2SO_4 is added and it is agitated again, when it becomes completely decolorized. Then 5^{cc} of bisulphited fuchsine solution are added, the liquid is mixed and allowed to stand, when a violet color, more or less intense according to the amount of methyl alcohol originally present, appears. The color usually reaches a maximum in about 15 minutes, it is very strong with 1 per cent of methyl alcohol, and is appreciable at a dilution of one-thou-

sandth. The Schiff's reagent may be prepared by adding to 1 liter of $\frac{1}{1000}$ fuchsine solution 20^{cc} of sodium bisulphite of 36–40° Baumé, and after 5 or 10 minutes adding 20^{cc} of hydrochloric acid of 1·18 density. In an hour or two the reagent is sufficiently decolorized for use.— *Comptes Rendus,* cl, 832.   H. L. W.

3. *A Substitute for Platinum Wire for Use in Blowpipe Work.*—O. F. KIRBY takes a few asbestos threads as straight and even as possible, dips them into phosphoric acid diluted with one or two parts of water, and heats them gently in the Bunsen flame until most of the water has been driven off. The threads, which are now attached to each other by the acid, but still flexible, are now carefully rolled between the fingers or on paper until a thin, even filament is produced, 2 or 3^{mm} in cross section. They are again carefully heated for a few minutes and finally finished in the blowpipe flame, when they are converted into a brittle rod or wire somewhat resembling porcelain. These rods give perfectly colorless borax beads which have little tendency to fall from the end. They are practically non-conductors of heat, and give no coloration to the non-luminous flame. They can be moistened with water or dilute acids without losing their rigidity, though when left in contact with these liquids for any length of time they become disintegrated and require re-heating before use. Though very brittle, pieces of about 8^{cm} in length will stand a good deal of usage, and pieces half as long may be used without risk of burning the fingers. They have been found to give excellent results in blowpipe work with large classes of students as a substitute for the more expensive platinum wire.— *Chem. News,* ci, 170.   H. L. W.

4. *The Use of Sodium Hypobromite in the Separation of Certain Metals.*—POZZI-ESCOTT has found sodium hypobromite, in the presence of a large excess of caustic soda, a convenient reagent for separating iron and nickel from chromium, aluminum, and zinc. The operation consists in heating the acid solution to boiling, adding a large excess of the alkaline reagent, filtering upon nitrated cotton, dissolving in hydrochloric acid and repeating the precipitation. He recommends the method also for the determination of chromium, vanadium, and molybdenum in steels as more convenient than the method by use of an oxidizing fusion. These acid-forming elements pass into solution while nickel and manganese remain with the iron.— *Bulletin,* IV, vii, 160.   H. L. W.

5. *The Doppler Effect in Hydrogen.*—B. STRASSER shows that the admixture of other gases with hydrogen influences the relative brightness of the stationary lines and the displaced ones. The purer the hydrogen the less bright is the stationary line— with a very pure gas only the displaced line is visible. Gases with larger atomic weights exercise a greater influence on the comparative intensity of the stationary and displaced lines than gases with lower atomic weights. The cathode dust also influences the relative intensities of these lines. A comparison is also made

between the displaced lines in the region near the cathode and at a distance. The value of $\frac{\varepsilon}{m} = 10^4$ has obtained from the canal rays.—*Ann. der Physik*, No. 5, 1910, pp. 890–918. J. T.

6. *Effect of Dust and Smoke on the Ionization of Air.*—From the investigation of A. S. EVE, of McGill University, it appears that " the presence of dust, smoke, mist or other centres charged or neutral in the air causes a transformation from small to large ions. In this way, the total number of ions present may be increased, while the conductivity is diminished. In any region of air where a charge of one kind is predominant, the effect of the presence of centres, neutral or charged, is to increase and accentuate the excess. This tendency must have an important influence in the variation of the potential gradient and on the production of thunder storms."—*Phil. Mag.*, May, 1910, pp. 657–673. J. T.

7. *Measurements in the Extreme Infra-Red Spectrum.*—H. RUBENS and H. HOLLNAGEL show that the interferometer method is preferable to the diffraction grating method in the study of the infra-red region. They have employed a quartz-plate interferometer with "Reststrahlen" and have determined the wave lengths and energy distributions of the Reststrahlen of rock salt, sylvine, potassium bromide and potassium iodide and have obtained a relation between the molecular weight and the mean wave length. The index of refraction of water for $\lambda = 82\cdot3$ μ is of the same order as in the visible spectrum. By the investigation of Reststrahlen the optical spectrum has been extended 2/3 of an octave. Its complete extent is now 10 octaves—two of which are in the ultra-violet, one in the visible and seven in the ultrared.—*Phil Mag.*, May, 1910, pp. 761–782. J. T.

II. Geology.

1. *Paleogeography of North America ;* by CHARLES SCHUCHERT. " Dedicated to those two great leaders in Geology and Stratigraphy, James Dwight Dana and Eduard Suess." Bull. Geol. Soc. Amer., vol. xx, pp. 427–606, pls. 46–101, 1910. Presented before the Society December 30, 1908.—With due regard for the other important contributions to paleogeography which have appeared during the course of the past generation and especially within the past few years, this may still be held the most important single contribution to the subject which has yet been published. Working for many years in the front rank of invertebrate paleontologists, the author's interests have broadened beyond the organisms to the inferences which their relationships imply as to the extent, connections, and durations of the continental seas. Although the concurrence of conclusions from several branches of geologic knowledge is required to attain reasonably safe

results in interpreting ancient distributions of lands and seas, the most important of these is clearly a masterly knowledge of paleontology. The thirty-eight years spent by the author in studying this subject have therefore formed the necessary personal preparation, while the growth of the several fields of geology through the labors of others has supplied a wealth of literature and made possible results which could not have been achieved in any previous decade.

The first 83 pages of the paper give a history of paleogeography from the first maps of J. D. Dana to the present time, and a statement of its methods. This is followed by a discussion of the influences which enter into the shifting of the strand line. A geologic history of the North American seas is also included. The final 77 pages give a description of the maps which follow and the new classification of geologic time suggested by them.

The first distinctive point to be noted in regard to this work consists in the large number of maps, fifty-seven having been prepared and fifty-three published, each representing a separate time interval, and the whole covering geologic time from the Lower Cambrian to the present. The diagram of fluctuating sea levels (pl. 101) indicates that at least this number of maps was necessary in order to reveal graphically the successive important movements that have occurred. All previous maps are therefore too synthetic in that each covers so long a time interval that significant changes of land and sea are concealed.

The second distinctive feature lies in the importance given to disconformities and the cartographic restriction of the original limits of the seas in the direction of the ancient land masses to a short distance beyond the farthermost determined outcrops of their sediments. As is noted by the author, this method may err on the side of too much restriction of the continental seas (p. 446). Most previous maps, both by representing a longer period of time and freely extending the seas beyond the limits of the sediments, have, on the other hand, tended to make the seas too extensive in time as well as in space. By consistently following his method the author is enabled to construct a diastrophic curve (plate 101) which shows the percentages of the present area of North America and of the United States which were exposed as land at each succeeding stage. This is one of the most important features of the paper. It brings out the diastrophic basis for grouping the geologic periods into eras delimited by revolutions, during which practically the whole continent stood for a longer or shorter time above the sea level. On the major rhythm are superimposed the secondary diastrophic waves, each of which marks a transgression and recession of the sea and comprises a geologic period. Defined on this basis, the Cambrian and Ordovician are broken up into three periods each and the Mississippian into two, called by Schuchert the Mississippic and Tennesseeic. The first of these is not, in North America at least, diastrophically distinct from the Devonic, the change being marked faunally

rather than by shiftings of the seas. The fifty-seven maps were planned to bring out this diastrophic basis for the geologic periods, but beyond these earth movements of the second order, which separate the periods, are progressively smaller ones of the third and higher orders which the maps and the curves constructed from them cannot show. For these the maps are still too synthetic.

A study of the work gives a very different impression as to the character of North American paleogeography from that conveyed by the older maps which figure in many text-books. The latter show North America almost submerged at the beginning of the Paleozoic and gradually emerging during the progress of that long eon. The recent maps of Chamberlin and Salisbury, and also those of Willis and others, show quite a wide departure from this older conception, but Schuchert's bring out one totally different. In the latter the amount of North America covered by sea during eleven transgressions and ten emergences up to the end of the Carboniferous averages 22 per cent, but the transgressions being regarded as the longer phases, their average of 29 per cent represents the more permanent amount of water area. Furthermore the maps do not show a gradual emergence and growth of the continent such as have been formerly postulated, but on the contrary far-reaching oscillations of the sea. This is the dominating fact, but it is still true that after the greatest transgression of the middle Ordovician each later inundation covers somewhat less area. There is thus expressed graphically and powerfully what has in recent years come to be believed by many geologists, that wide oscillations of continental seas, producing alternate intermingling and isolation of their faunas, rather than a gradual retreat of the seas, was the controlling principle of Paleozoic time. The maps in connection with the discussions of the text give also a conception of the topographic relief of the continent during this greater part of the fossil-bearing earth record. The thin and patchy sediments representing many epochs and the wide prevalence of limestone, the numerous disconformities, only recognizable by finding hiatuses in the fossil record, indicate the reign of extremely shallow seas lying on lands which barely rose above their level. Except for the systems of axes on the two sides of the continent which were elevated from time to time and shed great quantities of waste into the neighboring troughs, the continent was awash. Across now one and now another part of this continental interior the ocean rolled on and off in waves whose periods were measured by more than a million of years.

A review of so important a paper as this should not, however, contain a mere summation of contents but also to some extent an examination of the principles upon which it is constructed. Professor Schuchert argues that unlike but synchronous faunas of otherwise similar environment could not in the Paleozoic be explained by differences in temperature of ocean waters or by sea

currents, but the existence of land barriers must be postulated to separate them. Furthermore he holds that wide and shallow seas could not be broadly subject to bottom scour in the way now observed in limited localities, but would record their presence by means of sediments. These two principles as rules of very general though of course not universal or rigid application seem well taken and give definiteness to the problem. In regard, however, to the valuation of the disconformities some departure of view may be held from that which the author entertains. He states :

"Neither can it be admitted that . . . extensive sheets of limestone have suffered erosion. If the latter were true, outliers of these missing horizons would be found, for the land was so low that the wearing away could not have removed them completely over hundreds of miles of extent " (p. 442).

That is, the disconformity is valued as entirely a land interval rather than as partly a sea interval, A, followed by a land interval, B, during which the sediments of time, A, are removed. The reviewer would consider that A instead of being of negligible value may comprise almost any part of the entire value $A + B$ of the disconformity. Blackwelder has well discussed this idea in the "Valuation of Unconformities"[*] and Gilbert has clearly called attention to the fact that we are ignorant of the maximum extent of the great transgressions and still more ignorant of the former maximum areas of lands, since the landward sediments are immediately subjected to erosion upon the least retreat of the sea and continue to be eroded through all later time. The seaward limits of the greater unconformities are, on the other hand, forever concealed.[†] This paper of Gilbert's, so far as the reviewer is aware, is the first in American literature to call in question the general conception prevailing until recent years of the continuous reign of the Paleozoic continental seas. The questions raised by Gilbert are strikingly answered in the affirmative through the investigations of the past decade. The exceptional preservation of outliers of the great transgressions hundreds of miles from the nearest regular outcrops, in some places by downfaulting, in others by fossiliferous fragments having fallen down fissures and so escaping erosion, indicates how accidental is our knowledge of the supposed limits of the great transgressions. Limestones furthermore being subject to attack by solution are the most reducible of formations in a humid climate, as indicated by the broad limestone valleys rapidly developed at baselevel. Consequently under a suitable climate it is to be expected that outlying sheets left above baselevel might be completely dissolved away without leaving a trace of their former existence. The theory of probabilities would indicate that the plane surface of disconformities should more often be due to unlimited though slight emergence of the land with following subaërial planation,

[*] Blackwelder, Jour. Geol., vol. xvii, pp. 289–299, 1909.
[†] Continental Problems, Bull. Geol. Soc. Amer., vol. iv, pp. 178–189, 1892.

aided to some extent by marine planation, rather than that uplift of the land should take place until it was exactly flush with the surface of the sea. Schuchert's diastrophic curves are therefore presumably too limited in width of oscillations and too smooth. The latter point is illustrated by the Pleistocene, which is shown on his curve as a straight line representing gradual emergence of the continent to its present state, whereas it is known from the drowned river valleys that geologically rapid and profound oscillations have occurred and the continent now stands notably lower than in that portion of the Pliocene when the mature valleys now submerged were excavated.

On the other hand, the study of faunas indicates that no great oscillations have been missed and by adopting the most conservative method of mapping Schuchert finds the marked oscillations which give him the basis for the new time scale. The result proves the wisdom of caution in extending the limits of the seas. But while the permanency of these maps and their great value as a basis for future work is fully recognized, extensions of the seas will probably be made in many cases by using symbols such as Chamberlin and Salisbury and Willis have employed to indicate probable but unprovable extensions beyond the limits set by Schuchert.

Passing next to that part of the paper which deals with the causes rather than the results of paleogeographic change, the great debt owing to Suess is made apparent. The chief cause of the world-wide inundations is ascribed to the erosion of the lands and the filling in of the seas, so that an erosion cycle is also an inundation cycle. The emergences are ascribed to crustal movements which increase the relief of the earth, chiefly by increasing the volume of the ocean basins. The broad movements of the strand line are therefore largely due, both negative and positive movements, to changes of sea level, more than to movements of the land, but it is especially in positive movements of the strandline that this is so. The problem, however, is by no means a simple one and the author classifies continental seas according to the dominant feature of their existence. The classification terms are not mutually exclusive, since he regards nearly all as *aggrading seas*. During the period of advance they will be *transgressing seas* and some of them will be *synclinal seas*.

To this valuable part of the paper exception may be taken, however, on two points. First, the author frequently ascribes vertical warps, even in the continental interiors, to "thrusts from the oceans," by which is meant of course "the oceanic crustal segments." But it will be seen that for the collapse of geosynclines situated *within* continental platforms and often far removed from the ocean basins, the *immediate* cause is a thrust between two continental elements while the *ultimate* cause is held to be the contraction of the earth's interior. Furthermore, horizontal thrust in the crust has at most only a remote connection with many vertical movements. "Thrusts from the oceanic segments" is therefore an expression to be cautiously used, but as the

causes of earth movements constitute a subject not immediately connected with paleogeography the doubtful use of this term does not affect the conclusions of the paper.

The other point on which difference of opinion may be held is regarding a looseness in the use of the terms *syncline* and *anticline*, a looseness which may be noted not infrequently in paleontologic literature.

In this paper syncline is used indiscriminately for syncline geosyncline and downwarp, and anticline for the contrary terms. At the present time it is well recognized that synclinal and anticlinal folds are adjustments to horizontal pressure dependent upon stratified structures and die out in the deeper and unstratified crust. Their size is determined by the competency of the stronger beds to resist stress. For those broader axial folds which involve the deeper crust and are generated by isostatic as well as compressive forces, Dana has provided the terms *geosyncline* and *geanticline*. For the combination of smaller folds superimposed on greater, Van Hise has used the terms *synclinorium* and *anticlinorium*, though as Rice has pointed out, his use of the term *synclinorium* is an unjustifiable departure from Dana's original definition.* For broad vertical regional movements not clearly defined but in which horizontal thrust appears to play no direct part, the physiographers have coined the terms downwarp and upwarp, or arch. While the examples grade toward each other, the types are markedly distinct and in paleogeography there would seem to be a gain by their clear recognition. To illustrate the use of these terms in their defined senses it may be said that it is the subsidence of geosynclines and the irregular downwarps of the negative continental elements which have determined the limits of the epi-continental seas. Downwarp may also be a preferable term to *basin* for such gentle depressions without raised rims as constituted the *Indiana* and *Ohio basins* of upper Paleozoic time. Usage, however, sanctions in this connection the word basin, though the same word is employed for intermontane depressions and the oceanic abysses.

<div style="text-align:right">J. B.</div>

2. *Virginia Geological Survey,* THOMAS LEONARD WATSON, Ph.D., Director. Bulletin No. I–A. Annual Report on the Mineral Production of Virginia, 1908; by T. L. WATSON. Pp. 139, 25 figures and map. University of Virginia, Charlottesville, 1909.—The Report on the Mineral Production of Virginia contains not only statistical material well illustrated by maps, but also historical and general geologic information regarding the occurrences of rocks and minerals of value. A further interesting feature is the brief account of the general geology of the state. The mineral products discussed are as follows : Iron ores and pig iron, manganese ores, gold and silver, copper, lead and zinc, coal, coke, clay and clay products, lime and cement, sand

* On the Use of the Words Synclinorium and Anticlinorium, Science, vol. xxiii, 1906, pp. 286, 287.

and gravel, sand-lime brick, stone, abrasive materials, silica, mica, feldspar, asbestos, talc and soapstone, barytes, gypsum, salt, mineral paints, marl, pyrite and pyrrhotite, arsenic, phosphate, graphite, rutile (titanium), monazite, mineral waters, precious stones.   H. E. G.

3. *Geological and Archæological Notes on Orangia ;* by J. P. JOHNSON.   Pp. 102, 45 figures and bibliography.   New York and London (Longmans, Green & Co.).—This volume might be called an expanded notebook on the geography of Orangia (Orange River Colony).   It is the sort of description which is of interest to one who desires a knowledge of the country and its people.   Interesting notes on climate, topography, on the diamond, coal and salt prospects are mingled with data regarding the plant and animal life of the region, population, history of settlement, and present social and industrial conditions.

The horizontally bedded rocks of the Karroo system extend over nearly the entire territory with the exception of rocks of earlier age exposed near Vredefort by planing down of an anticline by marine denudation.   Chapters 3 and 4 are devoted to a discussion of the kimberlite dikes and pipes and the diamond mines.   The superficial deposits give evidence of a change in climate during recent geologic time.   Ancient spring deposits and buried sand dunes are in evidence.   An interesting series of "pans" apparently corresponding to the "buffalo wallows" of North America are found in several localities.   The larger pans are bounded on one side by large dikes which intercept the movement of ground water and determine the location of wells.

The prehistoric inhabitants of this district are discussed in chapters 6 to 8.   Two distinct groups of stone implements, the Acheulic and the Solutric, have been found, the former supposed to be much older than the latter.   The richness of the collections may be indicated by the fact that on one Solutric site there were gathered 1300 flakes and unfinished implements, as well as 700 finished flake tools.   The petroglyphs and rock paintings of animals, men and mythological beings, which are figured in chapter 8, are especially interesting as indicating the stage of development of those prehistoric people.   H. E. G.

4. *Handbuch der Regionalen Geologie ;* herausgegeben von G. STEINMANN und O. WILCKENS.   Heidelberg, 1910 (C. Winter).— The aim of the projectors of this work is expressed in the title. It is to produce a series of volumes which shall give in condensed form, and yet with sufficient detail, an account of the regional geology of the entire world, so far as now known.   It is proposed to carry out the work in 8 volumes of about 600 pages each.   The price per sheet, or signature, to subscribers is to be 50 pfennigs, or about 5 dollars a volume.   In executing the work the authors will have the help of a great number of geologists, all the principal civilized countries being represented.   One thought that the proposal immediately suggests is that the different volumes for practical use will have very different values.

Thus, for example, Germany, Bohemia, Denmark, Netherlands, and Belgium, with an area of say 260,000 square miles, are to be treated in one volume and one is also projected for the two Americas and Antarctica, or say 17,000,000 square miles. It is of course true that the geology of central Europe has been studied in relatively great detail as compared with the larger part of the Americas and that over wide areas the geology of the latter is on a simpler and broader scale, yet to compress only a part of what is known of this vast area into one volume will require so sketchy a treatment that, as a source of information for regional geology, its value can only be small, compared with the first volume mentioned. It is to be hoped that as the work proceeds this part may be enlarged and more contributors added, if it is to have an international scope and use.

The first sample of the work to appear now lies before us. It is vol. I, part 2, and covers Denmark. It is from the pen of Prof. N. V. Ussing of Copenhagen. It is a masterly presentation of the subject and, in the 38 pages allotted, a remarkable amount of detailed information is conveyed, relating to physiography, stratigraphy, fossils, geological history, tectonics, resources of economic value, etc. and a full bibliography. It is an excellent model for the entire work. L. V. P.

III. Miscellaneous Scientific Intelligence.

1. *United States Coast and Geodetic Survey. Report of the Superintendent,* O. H. Tittmann, *showing the Progress of the Work from July 1, 1908, to June 30, 1909.* Pp. 184, with 4 appendices and 10 pocket maps. Washington, 1909.—This report contains the usual statement of the work accomplished by the Survey during the year ending June 30th, 1909. It is accompanied by four Appendixes giving Details of Field and Office Operations (Nos. 1 and 2), also Results of Magnetic Observations for the time named (No. 3), and further (No. 4), the Distribution of Magnetic Declination in Alaska and adjacent regions for 1910. This last Appendix, as also No. 3, is by R. L. Faris and is accompanied by a chart giving the lines of equal magnetic declination and of equal annual change in Alaska for 1910.

The Survey has also issued another volume of the results of the observations at the permanent magnetic observatories ; this is for the observatory at Sitka and covers the years 1905 and 1906. This report has been prepared by Daniel L. Hazard, and is accompanied by thirty-six figures reproducing the magnetograms for the principal magnetic storms.

2. *Connecticut Geological and Natural History Survey. Bulletin No. 14. Catalogue of the Flowering Plants and Ferns of Connecticut ;* by a Committee of the Connecticut Botanical Society, consisting of C. B. Graves, E. H. Eames, C. H. Bissell, L. Andrews, E. B. Harger, and C. A. Weatherby. Pp. 569.

Hartford, 1910.—This important work has been carried through by the above-named committee of the Connecticut Botanical Society without personal compensation, the State contributing $300 for incidental expenses. It gives a complete list, according to present knowledge, of the flowering plants and ferns growing without cultivation within the limits of the state ; the names are, in general, those of the seventh edition of Gray's Manual. This list includes .1948 flowering plants and ferns ; of these 1487 are believed to be native to the state and 461 to have been introduced by man either designedly or by accident. In addition there are numerous forms distinct enough to receive names although not given specific rank, bringing the total number of plants named in the book to 2228. The introduction gives an interesting history of botanical investigation in the state, beginning with that of Dr. Levi Ives (1819), and continued by many active workers ; an appendix includes a statistical summary of the plants of Connecticut. Teachers of botany and all interested in our native plants will welcome this thorough and carefully prepared volume. Copies may be obtained from the State Librarian for seventy-five cents, or gratuitously, where needed by scientific men or teachers for professional use.

3. *Kraft das ist animalische, mechanische, soziale Energien und deren Bedeutung für die Machtenfaltung der Staaten;* von Prof. Dr. E. Reyer. Zweite Auflage. Pp. vii, 471, Leipzig (Wilhelm Engelmann), 1909.

Soziale Mächte als Ergänzung der Arbeit über " Kraft " ; von E. Reyer. Pp. 111, 34 figures.—Readers of the earlier edition (see v. xxvii, 272) of Dr. Reyer's thoughtful discussion of this broad and important subject will be glad of this new edition, which takes into account the many recent factors in modern industrial progress.

4. *Publications of the Alleghany Observatory of the University of Pittsburgh.*—The following memoir of vol. I has recently been distributed.

No. 21. A Comparative Study of Spectroscopic Binaries ; by Frank Schlesinger and Robert H. Baker. Pp. 135–161.

5. *Bulletin of the University of Kansas.*—The following has been recently issued: Engineering Bulletin No. 1 (vol. xi, No. 1), A Ballistic Electro-Dynamometer Method of Measuring Hysteresis Loss in Iron ; by Martin E. Rice and Burton McCollum. Pp. 23, with 5 figs. Lawrence.

The Philosophy of Happiness : A Consideration of Normalism ; by R. Waite Joslyn. Pp. 200. Elgin, Ill. (Normalist Publishing Co.)
La Vita Della Ricchezza ; by Emanuele Sella. Pp. 252. Turin, 1910. (Fratelli Bocca, Editori.)

ALEXANDER AGASSIZ.

THE sudden death of Mr. Agassiz was announced in the last number of this Journal. He was returning on the steamer "Adriatic" from a trip to Egypt and southern Europe, in company with his son Maximilian, and was apparently in about as good health as usual, of late years. He was found dead in his berth, on March 27th.

In his death the world has lost one of its most eminent scientific men, and probably the most liberal patron of natural science that this country has known.

He not only conducted, at great cost, numerous extensive explorations of the deep sea and coral islands and reefs in all the great oceans, but he personally wrote many of the volumes of reports on the results of his expeditions. Moreover, he induced many of his colleagues, both in this country and Europe, to write reports on his various collections, paying personally all the expenses of their publication, including the most liberal illustrations, and provided in his will for their completion, by a bequest of $100,000, besides an equal amount for the general uses of the Museum. His zoological and embryological works, both before and after his deep-sea explorations, were voluminous and of great importance, and his contributions to our knowledge of the physical geography and geology of all the great coral-reef regions are of inestimable value.

But aside from these investigations, the building up of the Museum of Comparative Zoology, from the comparatively small institution, with small funds, as it was left at the death of his father, into a magnificent museum, liberally endowed, and filled with a wonderfully rich collection, has been one of the great achievements of his life. He was not only its curator and director for many years, but also by far the most liberal of its patrons, for his gifts to the Museum amount to upwards of a million dollars.

However, to the world at large he is, no doubt, more widely known as the eminent mining engineer and financier, who developed and managed during many years the great Calumet and Hecla Copper mine, which made him and some of his friends wealthy. It is stated, in the Mining and Scientific Press, and in the Engineering News, that this is the greatest single copper mine in the world, and that it has paid in dividends over $110,000,000. Its wonderful success was due to his skill and energy. When Mr. Agassiz commenced to develop it in 1865–6, it was considered as almost worthless.

He was also interested in various other important lines of business. But his fame, apart from his scientific work, will, in

the long run, depend rather upon the wise uses to which he devoted a considerable part of his fortune, than upon its acquisition.

Mr. Agassiz came to America in 1849, at the age of 14 years. He graduated at Harvard in 1855; in 1857 he took the postgraduate degree of B.S. in Civil Engineering; and in Zoology in 1862; LL.D., 1885. In 1859-60 he was employed in the Coast Survey, on the Pacific Coast, and on the Northwest Boundary Survey. While there he made some collections of the marine fauna for his father, and also sent him some very beautiful drawings of acalephs, actiniæ, etc., which the writer saw at that time, and with which his father, Prof. Louis Agassiz, was very much pleased. He returned to Cambridge, owing to the urgent desire of his father, to continue his zoological studies and especially to assist his father in the installation of the collections in the new Museum building, which had then just been built and was not finished. During the next few years he was an assistant in the Museum, associated with Lyman, Hyatt, Shaler, Putnam, Packard, Scudder, Morse, the writer, and others, many of whom have also passed away.

In 1866-7 he was induced to undertake the development of the Calumet and Hecla mine, on Lake Superior, where he remained as superintendent most of the time till 1869, and with which he was connected as president or director till his death. While there, in the early years, he experienced great hardships and exposure, and contracted an illness from which he never fully recovered.

He was appointed Curator and Director of the Museum, after the death of his father, in 1874 and retained that position till 1898, when he resigned it. He was also fellow of Harvard University, 1878 to 1884, and 1886-1890; overseer 1873-78 and in 1885, and became Director of the University Museum of Harvard in 1902.

He had been a member of the National Academy of Sciences since 1866, and for a number of years was its president. More recently he has been its Foreign Secretary, up to his death.

He was a member of a large number of other scientific societies, both in this country and Europe, and received numerous other honors.

Among his earlier scientific expeditions was one to the Andes and Lake Titicaca, in 1875, where he obtained many archeological and zoological specimens. From 1877 to 1880 he spent most of his winters in deep-sea dredging on the "Blake Expeditions," mostly in the West Indies and Gulf of Mexico. The collections thus obtained were very large and valuable and have given origin to many valuable reports. Mr. Agassiz himself wrote the general account of the work and its results in two volumes, "Three Cruises of the Blake." He also made trips to the West Indies and Bermuda, to study the geology of the coral reefs. He also made an extended exploration of the great Barrier Reef of Australia, in a steamer chartered for the purpose in Australia, in 1896.

About that time the writer remembers a remark that he made, in conversation, to the effect that he proposed to devote the rest of his life to the exploration and study of the coral-reefs and islands of the Pacific and Indian Oceans. In pursuance of this idea he obtained from the U. S. Government the use of the steamer " Albatross," of the U. S. Fish Commission, for several long trips, both for deep-sea dredging and coral-reef work. However, he personally paid the " running expenses," such as for the coal, oil, etc., and his scientific outfit and assistants. He told me personally that these trips and those of the " Blake " were often no pleasure trips for him, for they involved a great amount of hard work and much sea-sickness at times.

In 1891 he made his first cruise in the Albatross for deep-sea explorations of the Pacific Ocean off S. America, Central America, the Galapagos Islands, and Mexico ; in 1897 he explored the coral reefs of the Fiji Islands ; in 1899 and 1900 he made a very extended exploration of the Pacific coral islands, including the Marquesas, Paumotu, Society, Fiji, Ellice, Gilbert, Marshall, Caroline, Ladrone and other groups, and to Japan. In 1904 and 1905 he again explored the ocean depths off the west coasts of North and South America, extending his cruise to Easter Island and the Paumotus.

In December, 1901, and January, 1902, he explored the great Maldive Archipelago of coral islands in the chartered steamer " Amra," steaming 1600 miles among the islands. The fully illustrated report of this expedition by Mr. Agassiz is of great interest and value.

One of the most important results of his explorations of the coral islands was the complete confirmation of the view, already held by many geologists, that most coral reefs and islands, both Atlantic and Pacific, are built upon eroded banks and shoals of ancient rocks, and are not of such great thickness as had been supposed, nor ordinarily due to gradual but extensive sinking of the land, as Darwin and Dana believed.

Mr. Agassiz was less known and appreciated popularly than his illustrious father, but this was due partly to the fact that he wrote few popular works and delivered very few public lectures. Nor did he teach classes in the University. But his scientific publications exceed those of his father.

His specialties in Zoology were Hydrozoa and Echinoderms— especially the Echini, in which he was the leading authority. In Geology the structure and origin of coral islands and reefs were his specialties. Among his earlier papers, however, there is one on the embryology of annelids, one on the young stages of fishes, and another on the larval development of *Balanoglossus.*

The following list, which includes most of his more important publications, is by no means complete, but it will serve to give a good idea of the variety and great extent of his published works. He told the writer, a day or two before he started on his last trip, that he had other reports in preparation, and that he

expected to do some work on them while away. He, also, at that time, authorized him to have 140 quarto plates printed for the report on the Alcyonaria of the Blake Expeditions. Most of his own publications, relating to his various explorations, if in quarto were published in the Memoirs of the Museum of Comparative Zoology, and the octavo ones in the Bulletin of the Museum.

Embryology of the Starfish. 4to, 8 plates. 1864.

North American Acalephæ. 248 pp., 4to, 360 text figures. 1865.

Preliminary Report on the Echini and Starfishes dredged in deep water between Cuba and the Florida Reef by L. F. de Pourtales. 54 pp. 8vo. 1869.

Revision of the Echini, 4to, 774 pp., with Atlas of 94 plates. 1872–1874.

Zoological Results of Hassler Expedition. I, The Echini. 4to, 23 pp., 4 plates. 1874.

Embryology of the Ctenophoræ. 41 pp. 4to, 5 plates. 1874.

North American Starfishes. Part I, Embryology of the Starfish. Part II, On the Solid Parts of Some North American Starfishes. 143 pp. 4to, 20 plates. 1877.

Palæontological and Embryological Development. 1880.

Report on the Echinoidea dredged by the Challenger. 321 pp. 4to, 64 plates. 1881.

Report on the Echini. Results of dredging by the Blake. 94 pp., 32 plates, 4to. 1883.

Three Cruises of the Steamer Blake, in the Gulf of Mexico, in the Caribbean Sea, and along the Atlantic Coast of the United States. 1877 to 1880. Two volumes, 8vo, 545 text cuts and maps. 1888.

Calamocrinus Diomedæ, a new Stalked Crinoid. 95 pp. 4to, 32 plates. 1892.

A Reconnaissance of the Bahamas and of the elevated reefs of Cuba in the steam yacht "Wild Duck," January to April, 1893. 203 pp., 4 plates. 1894.

A Visit to the Bermudas in March, 1894. 72 pp. 8vo, 30 plates and a map. 1895.

Acalephs from the Fiji Islands, 47 pp. 8vo, 17 plates. 1899 (with A. G. Mayer).

Preliminary Report, and List of Stations of the Albatross Expedition of 1899 and 1900, 114 pp. 4to, 21 charts. 1902.

The Coral Reefs of the Tropical Pacific. 443 pp. 4to, 238 plates. 1903.

The Medusæ of the Albatross Expedition of 1899–90. 40 pp. 4to, 14 plates. 1902 (with A. G. Mayer).

The Coral Reefs of the Maldives. 4to, 193 pp. and an atlas of 82 plates, 1903.

The Panamic Deep-Sea Echini, 254 pp. 4to, 112 plates. 1904.

Reports on the Scientific Results of the Expedition to the Eastern Tropical Pacific, by the Albatross, 1904 to 1905. 75 pp. 4to, 96 plates and maps, 1906.

Many of the plates illustrate the huge prehistoric statues on Easter Island and the scenery of the Galapagos.

Hawaiian and other Pacific Echini. The Cidaridæ. 50 pp. 4to, 44 plates. 1907 (with H. L. Clark).

A visit to the Great Barrier·Reef of Australia in the steamer "Croydon," during April and May, 1896. 55 pp., 42 plates, 1898.

The Islands and Coral Reefs of Fiji. 167 pp., 120 plates. 1899.

Hawaiian and Other Pacific Echini. 88 pp. 4to, 17 plates. 1908 (with H. L. Clark).

Echini : The Genus Colobocentrotus. 42 pp. 4to, 49 plates. 1908.

Hawaiian and Other Pacific Echini. The Echinothuridæ. 63 pp. 4to, 30 plates. 1909 (with H. L. Clark).

The Tortugas and Florida Reefs. 27 pp. 4to, 12 plates and maps, 1883.

The Porpitidæ and Velellitæ. 16 pp. 4to, 12 plates. 1883.

<div align="right">A. E. Verrill.</div>

Professor Robert Parr Whitfield was born at Willowvale, Oneida Co., N. Y., on May 27, 1828, and died at Troy, N. Y., on April 6, 1910.

Professor Whitfield's parents were ·English, and when young Whitfield was about seven years of age, in the fall of 1835, the family went to England. From England the Whitfields returned to America in 1841, finally locating at Whitestone, adjoining Utica, N. Y. Here Prof. Whitfield's scientific life began, and for a time, consonant with the promiscuous impulses which first start the naturalist in his course of observation, he turned his attention to many fields of natural history. In his twentieth year Prof. Whitfield married. For nine years he continued his vocation as a maker of philosophical instruments at Utica, but, through his membership in the Utica Society of Naturalists, was constantly associated with students of nature.

During these years he became acquainted with Colonel Jewett, and thus came in contact with a representative collection of fossils and shells, and the beginnings of his interest in paleontology, which finally excluded all other phases of scientific activity, were laid.

Through Colonel Jewett he became employed in the service of the New York State Survey under Prof. James Hall, and in Albany his scientific influences were strengthened, educational facilities increased, and a continuous intercourse with workers and leaders in science began. Meek, Hunt, Logan, Billings, Leslie, Safford, Agassiz, Conrad, Hayden, were a few names among the crowd of visitors to Prof. Hall's home, and in this multitudinous circle Whitfield's acquaintance with men of science was greatly extended.

His work was felt and illustrated in the publications of the Survey. He became lecturer in the chair of Applied Geology, at the Troy Polytechnic Institute, and in March 1876 resigned his position in Albany, and came to the American Museum of Natural History, where he installed the great Hall Collection of Fossils.

Besides his work on the New York Survey, Prof. Whitfield was engaged in work for the Ohio, Wisconsin, New Jersey and Black Hill Surveys, while papers furnished to journals of science, and the series of special studies published in the Bulletin of the American Museum of Natural History, complete his life of scientific activity.

Among contributions to science which merit the distinction of being classed as discoveries were his detection of the muscular impressions in "true Lingula" in the Trenton limestone, his observations on the internal appendages of Atrypa, his reference of the fossil forms *Dictyophyton* and *Uphantænia* to sponges, his description of a fossil scorpion from the Silurian rocks of America, his notice of new forms of marine Algæ in the Trenton limestone, the demonstration of *Balanus* in the Marcellus Shale, his papers on fossil teredo-like forms (*Xylophomya*), and the proof of three genera in a single individual of *Heteroceras*. The long series of papers on systematic paleontology, in which many new genera and species occur, with numerous observations in morphology and correlation, identify his name with American Paleontology.   L. P. G.

Sir William Huggins, the veteran English astronomer, died in London on May 12, at the age of eighty-six years. He was one of the first to use the spectroscope in the study of the heavenly bodies, and the importance of his researches into the constitution of the comets, the stars and nebulæ can hardly be overestimated.

Professor Knut Johan Ångström, the eminent Swedish physicist, died on March 4, in the fifty-fourth year of his age. He was the son of Anders Johan Ångström, the pioneer worker in exact quantitative work on the solar spectrum, and his labors were devoted to the same field of solar physics ; his most important investigations had to do with absorption phenomena, particularly in the infra-red, and with the measurement of solar radiation.

Professor Julien Fraipont of the University of Liège, Belgium, died March 22, 1910, at the age of 53 years. At the time of his decease he was rector of the University and professor af animal geography and paleontology. Author of many papers on zoölogy, paleontology and anthropology and a member of many learned societies, including the Royal Academy of Belgium, Dr. Fraipont was perhaps best known for his work (issued in 1887 jointly with Professor Max Lohest) on the fossil race of Spy, entitled : La race humaine de Néanderthal ou de Canstadt en Belgique. Recherches ethnographiques sur des ossements humains découverts dans des dépôts quaternaires d'une grotte à Spy et détermination de leur âge géologique.

Dr. H. Landolt, Professor of Chemistry at the University of Berlin, died on March 14, at the age of seventy-eight years.

Dr. E. Philippi, Professor of Geology at Jena, and geologist to the German Antarctic Expedition of 1901–03, died in March.

Dr. Richard Abegg, Professor of Chemistry at Breslau, died on April 3, in his forty-second year.

INDEX TO VOLUME XXIX.*

A

Absorption and phosphorescence, Brüninghaus, 189.

Academy, National, meeting at Washington, 463.

Adams, F. D., flow of marble, 465.

Africa, Blood-sucking flies, Austin, 92.

Agassiz, A., obituary notice, Verrill, 561.

Alabama, Pleistocene flora, Berry, 387.

Allegheny Observatory, see **Observatory.**

Allen, E. T., analysis of metals used in thermometry, 151.

Allen's Commercial Organic Analyses, Leffmann and Davis, 263.

Antarctic Expedition, National, 198.

Antlitz der Erde, Suess, 269.

Arizona, Grand Canyon geology. Noble, 369, 497.

B

Bacteriology, Dairy, Russell and Hastings, 200.

Bedell, F., Direct and Alternating Current Testing, 83.

Berry, E. W., Cretaceous Bauhinia from Alabama, 256; Pleistocene flora of Alabama, 387.

Bigelow, F. H., general circulation of the earth's atmosphere, 277.

Binn, La Vallée de, Desbuissons, 195.

Birkeland, K., Norwegian Aurora Polaris Expedition, 272.

Bitumens, solid, Peckham, 459.

Black Hills, Dakota, etc., geology and water resources, Darton, 267.

Bosworth, R. S., crystals of silver sulphate and dichromate, 293.

Botany, Clute, 272.

Brigham, W. T., Hawaiian Volcanoes, 363.

British Museum catalogue, Bryozoa, 195.

Brown, E. W., effect of magnetic and other forces on the motion of the moon, 529.

Browning, P. E., separation of cerium, 45.

C

Cambridge Natural History, Harmer and Shipley, 92.

Camel, fossil, Nebraska, Loomis, 297.

Canada balsam, refractive index, Schaller, 324.

— geol. reports, 365.

Cape of Good Hope geol. survey, 194.

Carnegie Foundation, 4th Annual Report, 274.

— Institution, at Washington, 8th Year Book, 274; publications, 368.

Chemical analysis, Quantitative, Clowes and Coleman, 80.

CHEMISTRY.

Analyse Volumétrique, Duparc and Basadonna, 458.

Arsenic, etc., estimation of, Palmer, 399.

Bromides of barium and radium, relative volatility, Stock and Heynemann, 79.

Bromine, free, determination, Perkins, 338.

Cadmium amalgams, Smith, 264.

Cerium, separation, Browning and Roberts, 45.

Colloidal solutions, formation from metals, Svedberg, 187.

Dye, purple, of the ancients, Friedländer, 262.

Helium, gas containing, Erdmann, 549.

Hydrogen, determination of, Paal and Hartmann, 458.

— chloride, action of light upon, Coehn and Wassiljewa, 79.

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*This Index contains the general heads, BOTANY. CHEMISTRY (incl. chem. physics), GEOLOGY, MINERALS, OBITUARY. ROCKS, ZOÖLOGY, and under each the titles of Articles referring thereto are mentioned.

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CONTENTS.

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