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AMERICAN AMPHICŒLIAN CROCODILES

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As long ago as 1849, Sir Richard Owen described[1] a genus (*Hyposaurus*) of amphicœlian crocodiles from the Cretaceous of New Jersey, based upon imperfect anterior dorsal vertebræ, whose chief characteristic was the unusual development of the hypapophyses. But little has been added to our positive knowledge of the genus since its original description, though the remains of such animals are said to be common in the New Jersey deposits. Leidy, in 1865, described and figured[2] other vertebræ, and also assigned to the same genus certain fragments of hollow propodial bones. Cope, in 1869, also described[3] additional vertebræ and limb bones, with illustrations, but I think there is much uncertainty as to the correlation of these limb bones with the vertebræ. He also mentioned certain parts of the skull, from which it would appear that Owen was correct in locating his genus among the longirostres. However, Cope at the same time referred portions of the rostrum of one specimen from the same horizon and same locality as those of the specimens which he referred to *Hyposaurus rogersi* Owen, to a distinct species, under the name *Hyposaurus fraterculus*, but which he afterward removed[4] to the genus

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[1] Owen, *Quarterly Journal of the Geological Society*, Vol. V (1849), p. 383.

[2] Leidy, *Cretaceous Reptiles*, p. 18, Plate III, Figs. 4, 16–21; Plate IV, Figs. 1–12.

[3] Cope, *Extinct Batrachia*, etc. (1869), p. 80, Plate IV, Figs. 10, 11.

[4] Cope, *Cretaceous Vertebrata* (1875), p. 254; *Proceedings of the Academy of Natural Sciences*, Philadelphia, 1875, p. 19.

Gavialis, where it remains to the present time, though doubtless belonging in one or another of the tomistomid genera which have been described from the New Jersey deposits, if not really a *Hyposaurus*, as Cope first believed.

Leidy founded the genus and species *Thoracosaurus grandis* upon dermal plates from the same horizon.[1] He later assigned to the same species,[2] under the name *Thoracosaurus neocesariensis* De Kay,[3] an excellent skull, unassociated with other bones. I have read attentively Leidy's descriptions and remarks, as also those of Cope, concerning this and other specimens referable to this species, and nowhere do I find a positive collocation of the type with procœlous vertebræ, though Leidy assigned to the species the procœlous vertebræ previously described by Owen as *Crocodilus basifissus*.[4] It is probable, however, that *Thoracosaurus* is really a procœlian crocodile, since *Holops* Cope, a nearly allied, if not identical, genus, has been definitely associated with procœlous vertebræ.[5] Furthermore, Koken referred to the same genus,[6] though with some hesitancy, a skull from the Maastrichtian of northern Germany, which he identified specifically with *Thoracosaurus macrorhynchus* (Blaineville) Leidy,[7] originally described from the Lower Eocene of Germany. This geographical distribution is not at all remarkable, since we know that the genus *Mosasaurus* has a like distribution in the Maastrichtian of Belgium and the Cretaceous of New Jersey, as also the Pierre of the interior. We may, therefore, accept both *Thoracosaurus* and *Holops* as procœlian crocodiles, though further information as to the skeletal structure of each is highly desirable.

As to the third genus of crocodiles reputed to be procœlian from the Cretaceous of New Jersey, *Bottosaurus* Agassiz,[8] I do not think

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[1] Leidy, *Proceedings of the Academy of Natural Sciences*, Philadelphia, Vol. VI (1852), p. 35.

[2] Leidy, *Cretaceous Reptiles* (1865), p. 5, Plates I–III.

[3] DeKay, *Zoology of New York*, Part III, p. 28, Plate XXII, Fig. 9 (*Gavialis*).

[4] Owen, *Quarterly Journal of the Geological Society*, Vol. V (1849), p. 381, Plate X, Figs. 1, 2.

[5] Cope, *Extinct Batrachia*, etc. (1865), p. 69, Plate I, Fig. 13.

[6] Koken, *Zeitschrift der Deutschen geologischen Gesellschaft*, 1888, p. 754.

[7] Leidy, *Cretaceous Reptiles* (1865), p. 8.

[8] Agassiz, *Proceedings of the Academy of Natural Sciences*, Philadelphia, Vol. IV (1849), p. 169.

matters are as satisfactory. It is evident that the type species of the genus, *B. harlani* Meyer, is a broad-faced or brevirostrate form, but I do not feel so sure that it has procœlous vertebræ. Harlan based his species *Crocodilus macrorhynchus* Harlan (non-Blaineville) upon the larger part of the right mandible, which has been figured and more fully described by Leidy.[1] This mandible is very peculiar in lacking, apparently, the large foramen, so characteristic of all procœlian crocodiles, ancient and modern, and of the known amphicœlian forms, save certain species of *Goniopholis*[2] and other Goniopholididæ, such as *Pterosuchus*.[3] Indeed, the Parasuchia or Phytosauria, which I would exclude from the Crocodilia in the widest sense, have such a foramen. Cope later added another species, *B. tuberculatus*,[4] to the genus, but I fail to find any positive evidence of congenerousness with the type species, nor am I assured that the form is brachystomous even. *B. perrugosus* Cope, which may be the same as *Crocodilus humilis* Leidy, from the Laramie Cretaceous of eastern Colorado, was only provisionally referred to the genus.[5] A gigantic procœlian crocodile is not at all uncommon in the uppermost Cretaceous of the West, as mentioned by Hatcher and as I have seen from western Texas. No other evidence is forthcoming that *Bottosaurus* has procœlous vertebræ. If it really has, then an important fact has been for the most part overlooked hitherto, the presence of broad-faced crocodiles, with a short mandibular symphysis, from so low an horizon, forms which might stand in more immediate ancestral relationship with the modern Crocodilidæ than do any of the known Tomistomidæ (Rhynchosuchidæ) of the Cretaceous. I cannot resist the suspicion that *Bottosaurus* will eventually be found to be an amphicœlian form. It is a remarkable fact, as Koken has shown,[6] that the early longirostrate procœlian crocodiles are scarcely distinguishable generically, save in their vertebræ, from their contemporary longirostrate amphicœlian forms, and it is

[1] Leidy, *Cretaceous Reptiles* (1865), p. 2, Plate IV, Figs. 19–23.

[2] Owen, *British Fossil Reptiles*, Vol. I, p. 642, Plate XLII, Fig. 2.

[3] Owen, *Fossil Reptiles of the Wealden Formation* (1878), Supplement VIII, p. 10.

[4] Cope, *Extinct Batrachia*, etc. (1865), p. 230.

[5] Cope, *Cretaceous Vertebrata* (1875), p. 68, Plate VI, Figs. 5–8.

[6] Koken, *Paleontologische Abhandlungen* (1887), Vol. III, p. 93.

altogether likely that a similar likeness existed in those early crocodilian times between the amphicœlian Bernissartidæ and such forms as *Bottosaurus* must have been if really procœlian. Marsh has stated, however, that there are several forms of amphicœlian crocodiles in the New Jersey deposits,[1] and has, indeed, named one of them *Hyposaurus ferox*.[2]

Whatever may be the real truth in the case, that the upper New Jersey Cretaceous rocks have yielded the remains of longirostrate amphicœlian crocodiles seems definitely determined from certain remarks made long ago by Professor Cope incidentally in his description of *Hyposaurus derbianus* from Brazil.[3] These remarks have been so completely overlooked by all other writers upon fossil crocodiles, whether in textbooks or in technical papers, that I venture to quote them in entirety. Even Hay omitted reference to the paper in his remarkably complete catalogue of North American fossil vertebrates.

> The genus *Hyposaurus* has been hitherto represented by but one well-known species, the *H. rodgersi* Owen, of the Greensand of the Cretaceous No. 5[4] of New Jersey. Specimens in my possession demonstrate that the genus *Hyposaurus* belongs to the Teleosauridæ of St. Hilaire. It differs from *Metriorhynchus* Meyer in the presence of distinct lachrymal bones, and in the relatively small size of the prefrontals. From *Teleosaurus* proper it differs in the robust size and vertical direction of the teeth. The orbits are vertical and the sagittal region is a keel. In the *H. rodgersi* the frontal bone is narrower than in any of the species figured or described by Deslongchamps. The palatal foramina extend forward to the line of the posterior maxillary teeth, and the anterior border is rounded, not acute as in most species of the family. The specimens are not sufficiently complete to enable me to state positively the generic distinction from *Steneosaurus*. In *Teleosaurus* the vertebral hypapophyses only appear on the first and second dorsal vertebræ, while, as Owen observes, they are present on many of the dorsals in *Hyposaurus*. This peculiarity, and the great contraction of the frontal bone, render it very probable that the genus is distinct from *Steneosaurus*, but the diagnostic character yet remains to be discovered.

If the genus is closely allied to the true species of *Steneosaurus*, then it is quite certain that *Hyposaurus* is a member of the Teleo-

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[1] Marsh, *American Journal of Science*, Vol. XIV (1877), Sep. p. 14.

[2] Marsh, *Proceedings of the Academy of Natural Sciences*, Philadelphia, 1871. p. 104.

[3] Cope, *Proceedings of the Academy of Natural Sciences*, Philadelphia, Vol. XXIII; *Paleontological Bulletin*, No. 40 (1885).

[4] Doubtless the Manasquan Marls.

sauridæ in the narrow acceptation. But Cope mentions no species, and it is now known that certain species referred to *Steneosaurus*, especially *S. geoffroyi* Owen,[1] do not belong in this genus,[2] or family even, but rather with the Pholidosauridæ, possibly *Pholidosaurus*. The lateral orbits which Cope gives for *Hyposaurus* is not a teleosaurid character. *S. geoffroyi* has elongated nasals, quite different from those of *Teleosaurus* proper, and it is probable that *Hyposaurus* will be found to possess them also, as in *Teleorhinus* Osborn. It is interesting to observe, however, that *Hyposaurus derbianus* "sends upward [from the jugals] a postorbital branch, which is external as in other Teleosauridæ, and not internal as in the Crocodilidæ"—a strong teleosaurid character that would remove the species from the Pholidosauridæ.

The horizon of *H. derbianus* is given by Cope as the equivalent of the "Fox Hills," that is of the Fort Pierre,[3] and perhaps equivalent to the New Jersey deposits. The specimen was from the province of Pernambuco.

A second genus of longirostrate amphicœlian crocodiles, from an earlier horizon, has been recently described by Osborn[4] from the Benton Cretaceous of Montana. Osborn separates the genus from *Hyposaurus* by the lesser curvature of the propodial bones, but, as I have stated, it is somewhat doubtful whether we actually know the propodials of *Hyposaurus* sufficiently well to afford this information, if at all; and the author seemed unaware that the longirostrate, if not teleosaurid, character of *Hyposaurus* is established. (The bones figured by Leidy do not show the curvature.) He compares the genus with *Teleosaurus*, to which there seems to be little real relationship, but does not compare it with such forms as "*Steneosaurus*" *geoffroyi*, which has elongated nasals, or with *Pholidosaurus* (*Macrorhynchus*), to which it does appear to be allied. *Teleosaurus* has short nasals and upwardly directed orbits, bordered posteriorly by a rather stout, external rim of bone; *Pholidosaurus* has lateral orbits, as described by Cope for *Hyposaurus* and Osborn for *Teleorhinus*, and nasals

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[1] Owen, *British Fossil Reptiles*, Vol. III, p. 144, Plate XVIII.

[2] Koken, *Paleontologische Abhandlungen* (1887), Vol. III, p. 91.

[3] Stanton and Hatcher, *Bulletin 257* (1905), United States Geological Survey, p. 66.

[4] Osborn, *Bulletin of the American Museum of Natural History*, Vol. XX (1904), p. 239.

extending to the premaxillaries or anterior nares as in *Teleorhinus*. The elongation of the nasals occurs also in other longirostres, like *Teleidosaurus*, etc., as well as in most of the brevirostrate amphicœlian forms, such as *Goniopholis*, *Nanosuchus*, *Notosuchus*, and *Petrosuchus*. In all, or nearly all, reptiles having a greatly elongated mandibular symphysis, the splenial takes part in the union, as in *Teleidosaurus*, *Hyposaurus*, and other longirostrate amphicœlians, the gavials, plesiosaurs, *Champsosaurus*, etc. Most of the other characters given by Osborn for *Teleorhinus* are of wider than generic application, save the antero-posterior compression of the teeth, which also occurs in other of the long-snouted amphicœlian forms. It is therefore difficult to interpret the affinities of his genus prior to a more complete description of the excellent material upon which it was based. I have scarcely a doubt, however, that it belongs with the Pholidosauridæ rather than the Teleosauridæ.

During the past season several specimens, more or less fragmentary, of longirostrate crocodiles, including the posterior part of two skulls, quite different from each other, and cervical vertebræ were obtained from the Hailey shales of western Wyoming, by the University of Chicago party. I was first inclined to locate their horizon in the Niobrara, because of the presence of a distinctly Niobraran genus of plesiosaurs, but a more careful study of the stratigraphy of the Benton convinces me that it belongs somewhere in the Carlyle formation. The skulls both agree in having very narrow parietals, very large supratemporal fenestræ, small laterotemporal vacuities, and large orbits. The upward process from the jugal seems, in one of the specimens at least, to be internal, as in the Pholidosauridæ. I cannot distinguish either of the species at present from *Hyposaurus*, though it is not impossible that one or the other may be *Teleorhinus browni* Osborn. From the lowermost part of the Benton, just above the Dakota, Mr. William Reed some years ago collected a longirostrate skull in Wyoming. It would seem, hence, that crocodile remains are widely distributed throughout the Benton of the Rocky Mountain region.

In 1872 Cope named,[1] and in a later work figured,[2] a single

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[1] Cope, *Proceedings of the American Philosophical Society*, Vol. XII, p. 310.

[2] Cope, *Cretaceous Vertebrata* (1875), p. 52, Plate IX, Figs. 8, 8*d*.

vertebra from the supposed Benton Cretaceous of Kansas, which he referred to *Hyposaurus* under the specific name *H. vebbii* or *H. vebbianus*. The locality whence his type was obtained is such that its horizon can only be the upper part of the Lower Cretaceous. Cope believed at first that the form was longirostrate, and so indeed it may yet prove to be. Within recent years I have recognized various fragments of the skull and vertebræ of what are evidently brevirostrate crocodiles from what probably is the same horizon as that of the type of *H. vebbii*, in southern Kansas. Whether or not the form or forms which they represent are conspecific with *H. vebbii* remains to be proven, but there is no doubt of the occurrence of a brachystomous crocodile in the Comanche of Kansas.[1]

In 1878 Professor Cope described[2] from the Morrison beds of southern Colorado the vertebræ of a small amphicœlian crocodile under the name *Amphicotylus lucasii*. In 1888[3] he collocated with these vertebræ a skull and various other bones, from the examination of which he reached the conclusion that the genus is identical with *Goniopholis* Owen, confined, so far as known otherwise, to the Purbeck and Wealden of England, Belgium, and northern Germany. In September of 1877, a few months prior to the appearance of Cope's description of *A. lucasii*, Professor Marsh briefly described[4] a genus and species of brachystomous amphicœlian crocodiles from the Morrison beds of Morrison, Colo., under the name *Diplosaurus felix*. I doubt not that the genus is identical with *Amphicotylus*, and, in much probability, the species is also identical with that of Cope. Marsh, however, refused to accept the synonymy of *Goniopholis*, figuring his species, without comment, in 1896[5] under its original name *Diplosaurus felix*. He, however, never gave any characters to distinguish his genus, and his figure shows, it is seen, a marked resemblance to those of various species previously assigned to *Goniopholis*, and especially *G. simus* Owen.[6] I have very recently

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[1] Williston, *University of Kansas Geological Survey*, Vol. IV (1898), p. 78; Vol. II (1878), p. 391.

[2] Cope, *Bulletin of the United States Geological Survey of the Territories*, Hayden.

[3] Cope, *American Naturalist*, Vol. XXII (1888), p. 1106.

[4] Marsh, *American Journal of Science*, Vol. XIV (1877), p. 254.

[5] Marsh, *ibid.*, Vol. II (1896), p. 61.

[6] Owen, *Fossil Reptiles of the Wealden and Purbeck Formations* (1878), Supplement VIII, Plate V.

examined the type specimen, and am more firmly convinced of its congenerousness with *Goniopholis*. We may, therefore, assume that both *Amphicotylus* and *Diplosaurus* are synonyms of *Goniopholis*, as did Zittel.[1]

Marsh has also referred to the genus *Diplosaurus* a fragment of a propodial bone discovered by him in 1868 in the Baptanodon beds of the Uinta Mountains.[2] Inasmuch as it must be almost, if not quite, impossible to determine with any degree of assurance the generic affinities of his species from such very incomplete material as he possessed, and as his specimen has never been described or figured in the slightest, the name *D. nanus* Marsh must be considered as purely *nomen nudum*. The specimen may be of a brevirostrate crocodile, but, considering the beds in which it was found, it is far more probable that it really belongs with a dolichostomous form.

Very recently Dr. W. J. Holland has described and figured[3] an excellent skull from the upper Morrison beds of Freeze Out Mountains, Wyoming, as *Goniopholis? gilmorei*. While the author was justified in assigning a new specific name to his specimen, he has given us no distinctive characters, nor was it possible for him to do so. The pitting of the superior surface of the skull is quite unknown in either *G. lucasi* or *G. felix*. The former species was, as we have seen, based exclusively upon vertebræ, and no description or figure has ever been given of any part of a skull presumably or definitely conspecific with the type. The type specimen of *G. felix* does not exhibit the superficial markings, though doubtless it will when fully extricated from its matrix, to which is yet adherent the thin exterior portion from which the major part of the skull has been removed.

Such pitting of the superior surface of the skull is quite characteristic of the genus *Goniopholis* and allied forms, and while it is possible that a close comparison of uninjured specimens might reveal specific characters, such is doubtful. The low parapet of bone bordering the posterior inner margin of the superior temporal

[1] Zittel, *Handbuch der Paleontologie* (1890), Vol. III, p. 676.

[2] Marsh, *American Journal of Science*, Vol. XIV (1877), p. 346.

[3] Holland, *Annals of the Carnegie Museum*, Vol. III (1905), p. 431.

vacuity on the parietal and "mastoid" bones is of doubtful specific value, as one, I think, will be assured from the comparison of different skulls of modern crocodiles.

The teeth, as figured by Dr. Holland, are not unlike those of *Goniopholis tenuidens* Owen.[1] That the specimen belongs in the genus *Goniopholis* I have little or no doubt—at least there appears to be less difference between our species and certain European ones, than between the known European species. No procœlous vertebræ have ever been found in the Morrison beds, nor indeed any from below the Upper Cretaceous in any part of the world, unless the vertebræ figured some years ago by Seeley from the English Wealden are truly crocodilian in nature.[2] I cannot agree with Dr. Holland in the belief that the arrangement of the bones on the under side of the cranium of his specimen is like that of the modern crocodiles. The under part is somewhat injured posteriorly, as stated by Dr. Holland, and as I can corroborate from an examination of this specimen, the whole of the false palate back of the maxillæ wanting. We have no reason to assume, however, that the structure here differs materially from that of the Goniopholididæ in the boundaries of the posterior nareal openings; if it does agree with the modern crocodiles in this respect, it would of course remove the form from the Goniopholididæ and substantiate another generic appellation.

Of the four specific names that have heretofore been given to the goniopholidids from America, the three based upon specimens from the Morrison beds may all be valid, and it is not at all improbable that they represent more than one species; but, so far, we have no conclusive evidence that such is the case.

I may add that crocodilian teeth are widely distributed in the upper Morrison horizons, as also in the Comanche deposits of western Kansas.

Coelosuchus reedii, genus and species new.

Recently I have received for examination, from the University of Wyoming, through its curator of paleontology, Mr. William Reed, the remains of a large amphicœlian crocodile, evidently of a brachy-

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[1] Owen, *British Fossil Reptiles*, Vol. I, p. 642.

[2] Seeley, *Quarterly Journal of the Geological Society*, 1887, p. 212.

stomous form. They were collected during the past season by Mr. Reed in the vicinity of Wilcox, Wyo., in a dark shale of the Graneros division of the Benton, and below the heavily laminated shales which must be ascribed to the Mowrie beds of Darton. I have recognized what I believe to be the same horizon, also fossiliferous, two hundred miles or more to the northwest in Wyoming, lying below the laminated shales yielding numerous fish scales and fish bones. The Hailey shales lie some four hundred feet higher than this horizon, above the Mowrie shales, and above thin layers of limestone which may represent the Greenhorn limestones of Darton. Mr. Reed has traced the Wilcox fossiliferous horizon for about thirty miles into Carbon County on Troublesome Creek, where it also yields vertebrate fossils.

The fossils sent me are for the most part more or less fragmentary and water-worn. They include two or three species of plesiosaurs, one of which seems closely allied to *Trinacromerum anonymum* Williston, from the Benton of Kansas; various fragments of the carapace and plastron of a large, thick-shelled turtle; the spine of a shark, not unlike those of *Corax* from the Cretaceous of Kansas; small shark teeth; and a large premaxillary bone with a single long tooth, whose systematic position I have not yet determined.

I can distinguish but a single species, among the crocodilian remains preserved, though they differ greatly in size and may in reality be of different forms. Of course, none of the bones can be associated together as of one individual.

The ilium (Fig. 1) differs from that of a modern crocodile in the greater elongation of the posterior process, and in the relatively less width of the bone. An ischium (Fig. 5) of a smaller individual differs in the less expansion of the distal end, its more rounded posterior angle, and the greater obliquity of the shaft of the bone. The pubes of several individuals are represented by more or less fragmentary parts, all of about one size. One nearly complete specimen is shown in Fig. 2. It is also noticeable for the slenderness of the shaft, and the moderate dilatation of the distal extremity, differing markedly in this respect from the known forms of *Gòniopholis* and *Bernissartia*. The upper extremity of a humerus of a large individual is shown in Fig. 3. Its curvature is slight, much less than of a humerus of nearly equal size of a longirostrate form from the Hailey shales. Other smaller humeri are present, nearly complete. They are slender and nearly straight, the lower extremity scarcely differing from that of a modern alligator or crocodile. The distal end of a tibia and its distal face are shown in Figs. 6 and 7. The proximal and distal ends of two large coracoids are shown in the figure. I have outlined the connecting part between them as would seem natural. The distal extremity is also noticeable for its moderate expansion.

The numerous vertebræ preserved are of various sizes and from various places in the vertebral column. A cervical (Fig. 8) has its extremities almost amphiplatyan; the hypapophysis is small; the parapophysial articulations are not large and are situated near the end. The neurapophyses are attached by a loose suture. The length of the vertebra is 50 ^{mm}; its width, 44 ^{mm}. A dorsal centrum, of which the anterior articular surface is shown in Fig. 9, has a very smooth surface exteriorly, and is but gently concave longitudinally. The posterior central articular surface is nearly flat, the anterior rather deeply cupped. The length of the centrum is 59 ^{mm}; its width, 50 ^{mm}. Another centrum (Fig. 10) is much more compressed from side to side, presenting a vertically oval figure at the ends and in cross-section. This centrum has a length of 50 ^{mm} and a width of but 36 ^{mm}. The largest (dorsal) centrum preserved has a length of 65 ^{mm} and width of 70^{mm}.

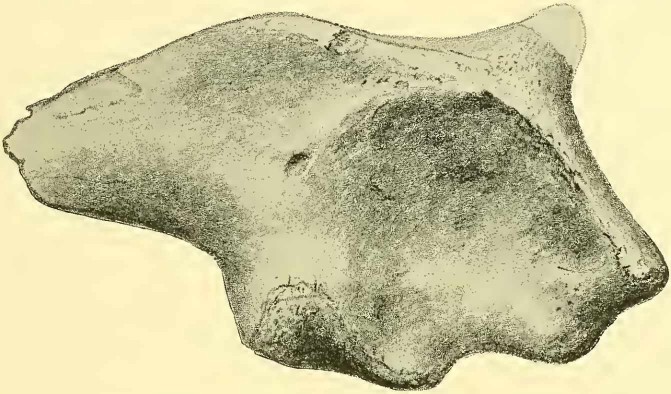

FIG. 1.—*Coelosuchus reedii.* Right ilium, one-half natural size.

Various fragments of the skull are preserved, but no teeth can be detected, though a fragment of a dentary or maxilla has numerous thecæ for their reception. The skull fragments are massive and deeply pitted, conclusively proving, it seems to me, the brachystomous nature of the face. The largest portion preserved is that figured herewith, the posterior part of the left mandible. It measures 155^{mm} in its greatest width, and resembles the corresponding part of the mandible of *Goniopholis tenuidens*, as figured by Owen.[1] If the skulls of the two species were of like proportions, the present must have measured over four feet in length. Species of *Goniopolis* have no mandibular foramen, so characteristic of the crocodiles, and its absence in the present species, together with the great width of the bone and its numerous deep pittings, indicates conclusively the brevirostrate character of the form. This is also indicated by the large size of the anterior extremities, the bones preserved showing that they were fully as large as the posterior ones, a character also seen in *Goniopholis* and *Bernissartia*, and very different from the small fore legs of the longirostrate types.

FIG. 2.—*Coelosuchus reedii.* Right pubis, one-half natural size.

The Goniopholididæ are supposed to have been denizens of fresh or brackish water, but these specimens do not necessarily imply that the Wilcox shales are of that character, since the bones may have been accumulated at the mouths of rivers or adjacent to the shores. However, some of the present Crocodilidæ are denizens of salt water, and it is not at all improbable that various extinct broad-faced species may have had similar habits. The turtle bones accompanying the remains are massive and heavy, very different from the typical marine types.

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[1] Owen, *British Fossil Reptiles,* Vol. II, Plate XLII, Fig. 2.

In conclusion, from the study of considerable material, and the attentive perusal and consideration of the facts and arguments offered, especially by Koken,[1] I share the opinion of most recent writers on the crocodilia that the separation of the amphicœlian and procœlian crocodiles by Huxley, which at one time seemed so brilliant a generalization, into the suborders Mesosuchia and Eusuchia is unnatural and artificial. I believe that the change from amphicœlous to procœlous vertebræ has been concurrent in two, possibly in all three, of the modern types of Crocodilia, the Gavialidæ, Tomistomidæ, and Crocodilidæ. In the specimens from the Hailey shales the centra may best be described as cœloplatyan, the anterior concavity deep, the posterior one shallow, if any. The change from this form to a distinctly procœlous one is not at all difficult to understand, and was brought about, I believe, by the same or similar causes in the different phyla. The true teleosaurs could not have been ancestral to any of the modern crocodiles, since the marked difference in the size of the fore and hind limbs was a specialization for aquatic habits, as was carried to a greater degree in the Thalattosuchia,[2] and could not have reverted to the more modern amphibious type, even that of the gavials. That the true crocodiles began existence as terrestrial, or at least terrestro-amphib-

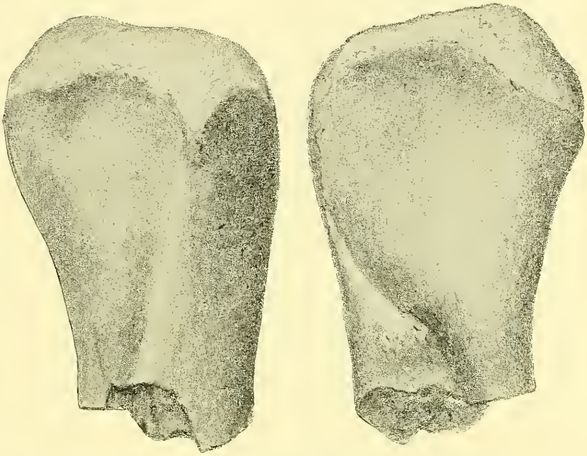

FIG. 3.—*Coelosuchus reedii.* Proximal extremity of right humerus, one-half natural size.

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[1] Koken, *Paleontologische Abhandlungen* (1887), Vol. III, p. 105; *Zeitschrift der Deutschen geologischen Gesellschaft*, 1888, p. 767.

[2] Fraas, *Paleontographica*, Vol. XLIX (1902), p. 1.

ious, animals is scarcely open to doubt, and all are agreed that the phytosaurs were not this ancestral type. That they should have become more aquatic in habit than are any now living, and again reverted to a subterrestrial habit, as in the modern alligators, is difficult, if not impossible, to believe. The true teleosaurs, like the thalattosaurs, were a short-lived branch of which no modern descendants have survived. Owen has thought[1] that the introduction and development of the small mammals was a cause of the evolution of the small, brevirostrate crocodiles, the Atoposauridæ and Goniopholididæ; but I doubt this very much, though they may have been the inciting cause of the evolution of such diminutive forms as *Alligatorellus* and *Atoposaurus*. Were more extensive land faunæ to be discovered in the middle and lower Jura, I believe that we should find the remains of real amphibious brachystomous crocodiles, much less like the structure of *Teleosaurus* than is *Teleidosaurus* even. It is hard to believe that the littoral reptiles, or semiaquatic forms, like *Pleurosaurus*, *Acrosaurus*, etc.,

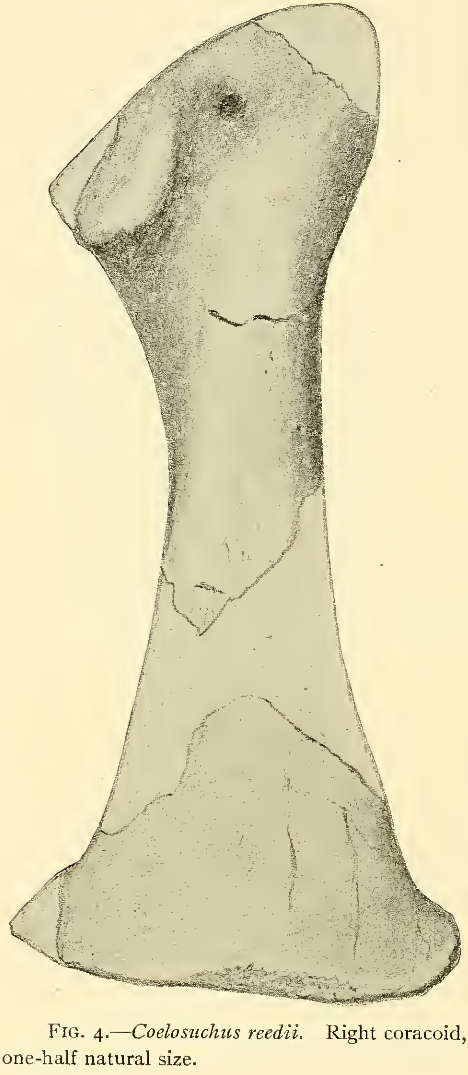

FIG. 4.—*Coelosuchus reedii*. Right coracoid, one-half natural size.

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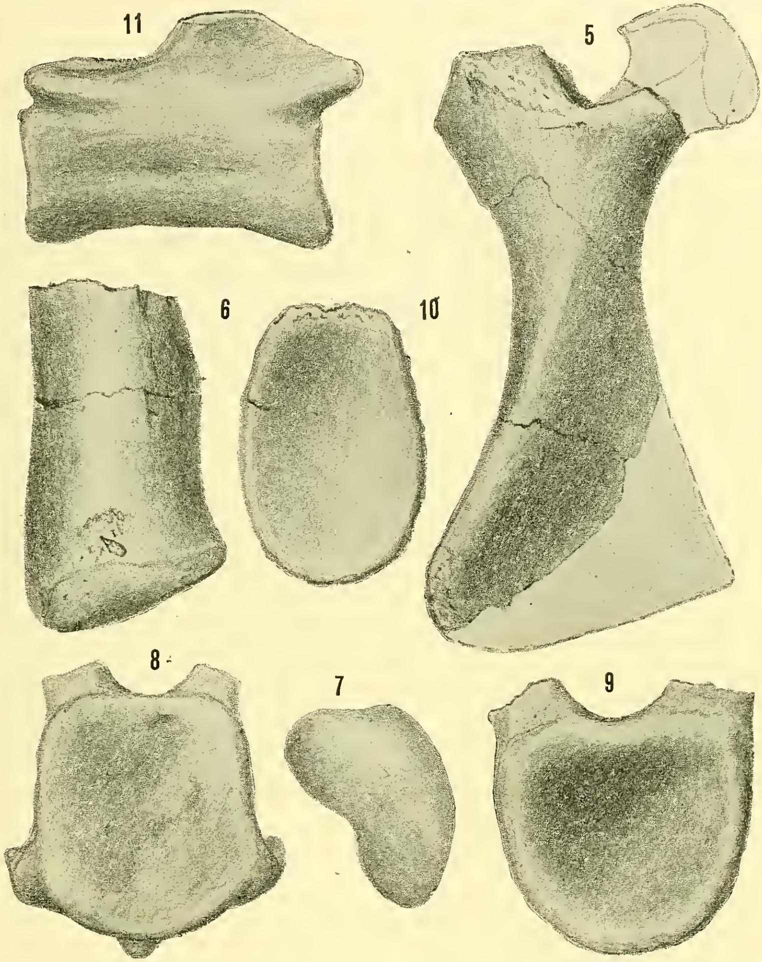
[1] Owen, *Quarterly Journal of the Geological Society*, February, 1879, p. 148.

of late Triassic and Jurassic times, were not as legitimate objects of prey for the amphibious crocodiles as were the small mammals.



FIGS. 5–11.—*Coelosuchus reedii.* All two-thirds natural size. Fig. 5, left ischium, Fig. 6, distal extremity of left tibia; Fig. 7, distal face of same; Fig. 8, proximal face of cervical vertebra; Fig. 9, proximal face of dorsal vertebra; Fig. 10, proximal face of dorsal vertebra; Fig. 11, caudal vertebra.

The terrestrial and amphibious crocodiles, with short, broad heads, are yet to be discovered in the Triassic rocks, probably as low as the Muschelkalk.

Just what has been the cause in each case of the change from amphicœlous to procœlous or opisthocœlous vertebræ may not be apparent, but it is no more difficult to believe that this change occurred in the different phyla of crocodiles than in the different orders of reptiles. We know that all procœlian reptiles cannot be traced back to a common procœlian ancestry. The earliest vertebræ of this type were apparently those of the Rhaetic or Liassic pterodactyls. Many of the squamata had changed from amphicœlian to procœlian by the close of the Jurassic times, and it is not at all improbable that the beginning of the change in the crocodiles occurred about this time; certainly so, if the vertebræ described by Seeley from the Wealden are really those of crocodiles, as seems probable.

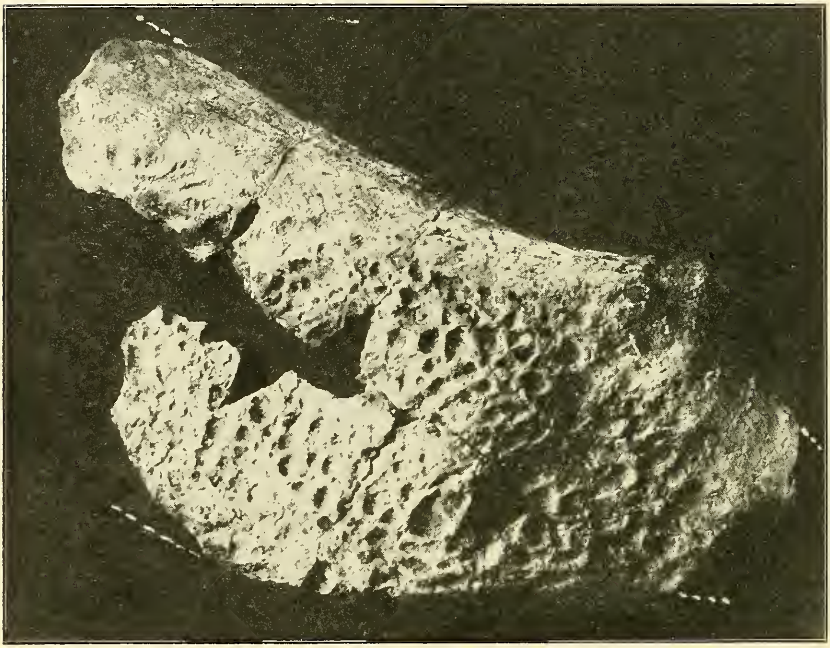


FIG. 12.—*Coelosuchus reedii.* Posterior portion of left mandible, one-eighth natural size.

The geckos among the lizards, chiefly climbing or pendent animals in habit, have retained amphicœlous vertebræ, long after their loss by terrestrial lizards—a fact which does not render their separation from other lacertilia into a distinct suborder imperative. Toads, the most terrestrial of all amphibia probably, have procœlous vertebræ.

The procœlous structure has never been attained by either aquatic or highly amphibious forms; on the contrary, the amphicœlous structure has persisted longest in such. Its attainment has always been correlated with the use of the hind limbs in the support or propulsion of the body upon land, and the amphicœlous structure has lingered longest in the tails, as in the dinosaurs and pterodactyls. The ichthyosaurs, with feeble hind limbs, retained a very primitive structure of the vertebræ, till late in Cretaceous times, until nearly all other reptiles had acquired convexo-concave vertebræ; while the plesiosaurs, equally aquatic animals, and doubtless derived from nearly as primitive ancestors, acquired in many cases truly amphiplatyan vertebræ—a fact doubtless to be correlated with the important use of the hind legs and a well-developed sacrum. The procœlous vertebræ of the mosasaurs was a character acquired by their ancestral terrestrial forbears, as was also their scaled skin. A consideration of these facts, together with the pterygoidal inclusion of the posterior nares, serving no apparently useful purpose in such purely ichthyophagous reptiles, inclines me to the belief that the modern gavials are late descendants of the more terrestrial procœlian types such as *Thoracosaurus* or *Holops* may have been. The opisthocœlous type of vertebra is of much wider distribution, and has been acquired by purely aquatic animals such as *Lepidosteus* and the true salamanders.

No form of convexo-concave vertebræ is of profound morphological significance in the evolution of the vertebrates, but I would not go quite so far as does Koken in uniting procœlian and amphicœlian crocodiles in the same family, notwithstanding the extraordinary resemblance of other parts of the skeleton.[1]

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[1] Koken, *Zeitschrift der Deutschen geologischen Gesellschaft*, 1888, p. 768.

GLACIAL EROSION IN THE FINGER LAKE REGION OF CENTRAL NEW YORK[1]

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The origin of the Finger Lake valleys was assigned by Lincoln[2] and by the present writer[3] to glacial erosion upon the evidence of hanging valleys, though this name was not then used. Later recognition of other evidence, notably the steepened lower valley slopes, the smooth, straight valley walls, and the absence of projecting spurs, characteristic of regions of marked glacial erosion, supported this explanation. When, however, quarrying operations revealed an area north of Ithaca in which pre-Wisconsin decay was preserved on the steepened slope of Cayuga valley, it seemed necessary to reconsider the question of the origin of this valley. In a paper presenting the newly discovered facts[4] the general question of the origin of the Finger Lake valleys was reconsidered and three hypotheses were proposed as working hypotheses. No attempt was made to establish either of the hypotheses, but the object of the paper, avowedly an unfinished study, was to show that the problem was less simple than formerly believed, and that there were objections to the glacial-erosion theory of sufficient force to warrant a question whether some other theory than glacial erosion might not account for these valleys. The fact that I have been quoted as an opponent of the glacial-erosion theory for these valleys, which has not been the case, is the reason for this preliminary statement.

One of the three hypotheses considered in my previous paper was stated in the following words:

> A modification of the glacial-erosion theory has been advanced during the progress of the investigation of the problem, and is still being considered. It is as follows: During its first advance the ice deeply eroded the valleys; during

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[1] Published by permission of the Director of the U. S. Geological Survey.

[2] *American Journal of Science*, Vol. XLIV (1892), pp. 290–301.

[3] *Bulletin of the Geological Society of America*, Vol. V (1894), pp. 339–56.

[4] *American Geologist*, Vol. XXXIII (1904), pp. 271–91.

> interglacial conditions the older gorges were cut; with return of glaciation the valleys were deepened still further. During as many glaciations as this region experienced this process was continued. On this basis the older gorges are interglacial; their cause is the lowering of their base level by the overdeepening of the valleys to which they were tributary. Since facts sufficient to establish or to overthrow this explanation are not yet at hand, it must stand at present merely as a working hypothesis. [1]

Work done since the publication of this paper strongly supports the theory of double glacial origin for at least the Seneca valley. In this valley there is a general condition of remarkably perfect, broad, mature tributary valleys hanging several hundred feet above the lake level, at about the 900-foot contour. They are truncated by the straight, smooth, lower steepened slope of the main valley, so that they stand out prominently, with open mouths, clearly discordant with the main valley, and about 1,500 feet above the rock floor of the Seneca valley at Watkins.

These hanging valleys are trenched in their bottoms by gorges partly buried in Wisconsin drift. The buried gorges are both broader and deeper than those of postglacial origin. Along the western shore of Seneca Lake from Watkins to the northern edge of the Watkins topographic sheet, a distance of eight miles, there is absolutely continuous rock, proving that the gorges have not cut below lake-level. Yet the rock-floor of the main valley is 1,000 feet below lake-level at Watkins. The gorges are therefore also hanging valleys, and a double period of glacial erosion is indicated, with an intermediate condition of interglacial stream erosion.

On the eastern side of the Seneca valley the evidence is almost as clear, though there are some short gaps in the rock-wall. In the Cayuga valley there are gaps in the rock which may possibly be on the sites of the buried gorges, so that the evidence from this valley is not convincing.

In my previous paper it was pointed out that there is a marked discordance in the hanging valley levels of neighboring valleys, and this fact was then considered to be evidence opposing the glacial-erosion theory. Both Salmon and Six Mile Creek valleys hang at a much lower level than their neighbors (for example, Fall, Cascadilla, and Buttermilk (Ten Mile)). I am now convinced that the interpretation that this discordance is opposed in the glacial-erosion

[1] *Ibid.*, p. 284.

theory was incorrect, and that these two valleys are really confirmatory of the glacial-erosion theory. This change of view is the result of a recent study of the valley profiles and a mapping of the moranic deposits of the valleys in question. The latter show that these valleys were occupied by actively moving ice parallel to their axes, while the neighboring higher hanging valleys were not. They were therefore open to ice-scouring. A study of the profiles shows that these discordant hanging valleys have the U-shape of glacial erosion and not the gorge-shape of a rejuvenated valley, the only other explanation that seems a possible one for such discordance. It is believed, therefore, that while the Cayuga valley was profoundly deepened by ice-erosion, the Salmon and Six Mile Creek valleys were deepened moderately, and the Fall, Cascadilla, Buttermilk, and other valleys practically not at all, since they were not occupied by ice freely moving along their axes.

There still remains some evidence opposing glacial erosion by the Wisconsin ice-sheet, but none opposing erosion by an earlier advance, unless the fact that no deposits of an earlier ice-advance are found in this region is considered opposing evidence. The most serious objection to Wisconsin ice-erosion is the presence of residually decayed rock at the Portland quarry north of Ithaca. But in view of the striking topographic evidence of ice-erosion of a double period—the condition of double hanging valleys, the steepened slope, the spurless valley wall, and the undissected valley sides—the question may fairly be asked whether even this evidence from residual decay remnant, in a single place, may not be misleading. In seeking for an explanation of the presence of this decay product in the particular place where it occurs, I have found but one hypothesis that appears possible. The Portland quarry lies just south of the junction of Cayuga Lake and Salmon Creek valleys, down both of which the ice flowed somewhat freely. It is possible that the thrust from the Salmon Creek valley pushed the ice toward the west side of the Cayuga valley, leaving the site of the Portland quarry under a wedge of ice with slight motion, and hence with slight erosive power. Too little is known about the erosive action of ice, and the direction of ice-currents under the guidance of topographic irregularities, to warrant further consideration of this question, at present.

To account for the facts briefly outlined in this paper by rejuvenation seems utterly impossible. This hypothesis will not explain the hanging gorges, nor the discordant U-shaped hanging valleys. Formation of the lake valleys entirely by Wisconsin ice-erosion is also out of the question. But the striking resemblance of the topography to that of regions of known ice-erosion seems to demand origin by glacial erosion; and, in spite of the opposing evidence from a remnant of residual decay, and of other objections of less importance, it is believed that such an origin must be assigned to these valleys, and that the apparent objection to such origin is dependent upon some local condition which permitted residually decayed rock to remain, while elsewhere in the valleys there was profound ice-erosion.

THE ICE-FLOOD HYPOTHESIS OF THE NEW ZEALAND SOUND BASINS

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INTRODUCTION

The author feels confident that the glacial explanation of the striking geographic forms in the southwestern Alps of New Zealand finds readier acceptance among those students who, until such time as they themselves have conducted careful and detailed physiographic examinations, have not so much as seen a region of former or present intense glaciation, than with those who have spent their lives amid such ice-modified surroundings. Only to such workers does the whole series of novel perceptions presented during a first glimpse at a formerly strongly glaciated region come with the startling force of a revelation. The foregoing is applicable to the case of the author, and because of it he feels warranted in presenting this glacial explanation for certain New Zealand forms. For several years prior to visiting Alpine New Zealand in the summers of 1901 and 1902, he had made numerous topographical observations in Australian New England, Monaro, The Darling Downs, northern Queensland, and Fiji. Between the latitudes embracing these localities, viz., 15° and 37° S., thousands of tributary water-courses had been inspected. All were observed to join the main river channels with non-conflicting, or but triflingly conflicting, grades. The magnificent plateaus of eastern Australia still, in great measure—when composed of felsites and acid granites—retain their individuality as to their central portions, and here, naturally, as they are traced headward, the rivers are observed to leave the wide and well-matured valleys of the uplands in gigantic waterfalls for rapidly trenching canyons. But even at this *initial* stage of canyon growth, with one or two exceptions, easily explicable by local rock variations, etc., the legions of side gulches, although insignificant in length, come in "at grade." Thence, following the canyons in their intricate windings to the points where stream corrasion has destroyed the individuality of the plateau, one finds a ceaseless repetition of contracted waterways, tortuous channels, and myriads of overlapping spurs. Above all, the absence of lakes and the wonderful constancy of the "graded" water-courses were marked features.

The first sight of the New Zealand fiords and the Alpine lakes was marvelously contrasted to Australian scenic types, where glaciation had had no part in determining the valley contours. Here (in New Zealand) were great rock basins, broad flat-bottomed valleys, with bordering walls rectilinearly disposed as to their bases, and of even dip, but of such steepness as to be inaccessible to any but daring climbers; a marked absence of spurs; and an arrangement of such valley buttresses that they appeared shriveled up to the canyon walls, their terminations ending in tremendous precipices, the bases of the same being usually in alignment. Here also one saw *lines of sentinelling domes* rising thousands of feet into the air—a prevalence of rock monuments suggestive of sitting lions—and numerous deep and fairly broad-bottomed canyons connecting with the sounds and larger valleys over gigantic walls flush with the main rectilinear ramparts. These remarkable side valleys, seen from below, appeared to spring direct through U-shaped notches in the vertical walls. In the crystalline schists these walls were at times almost monotonously majestic in their steepness and evenness of slope, as in Milford, while in the softer schists of Wakatipu the valleys were broader, the slopes less, and the "hanging valleys" a minor feature. Then again there were the gigantic moraines of the lakes; and, perhaps most striking of all, the wondrous *cirques* or amphitheaters, thousands of feet in height, which, in the denser rocks, almost prohibit the scaling of divides.

No one form just enumerated found a response in the stream-developed contours of the eastern Australian cordillera. The fact was, moreover, well established that this fiord and lake land had been demonstrated, by many workers, to have been one of former intense glaciation, and as such an attempt was made by the writer to furnish a glacial solution to the problem. While still puzzling over the "hanging valleys," Professor W. M. Davis' note on glacial forms in Norway, Switzerland, and England came under my notice, and, with minor modifications only (as will be seen in this note), appeared competent to explain the New Zealand forms. Later, Dr. G. K. Gilbert and Willard D. Johnson, of the United State Geological Survey, kindly forwarded copies to me of their notes on *cirques* and allied phenomena in northwestern America.

After the publication of the Dunedin note, the importance of the ice-flood hypothesis as explaining the *peculiar* "sound" shapes and the *present inactivity* of glaciers forced itself upon me. The present note is the result.

I desire here to mention the great help derived from a perusal of some of the glacial reports written by Professors T. C. Chamberlin, R. D. Salisbury, W. M. Davis, T. W. E. David, and James Geikie, Dr. G. K. Gilbert, Professor J. W. Gregory, Sir James Hector, Professor F. W. Hutton, Von Haast, Willard D. Johnson, Dr. Lendenfeld, F. C. Matthes, and Professor I. C. Russell. To a great deal of the literature no access has been obtainable.[1]

THESIS

The Great Ice Age marked a flood in glacial action, while the present warm conditions obtaining in these areas of former intense ice-action marks a glacial drought.

The sounds, lakes, and canyons of southwestern New Zealand were determined, for the greater part, by preglacial streams whose channels had attained to the graded stage.

During the height of the ice-flood the glaciers gouged out deep basins much below the baselevel at points near the convergence of profound canyons. Here also they ripped off spurs, aligned and even undermined the walls, thus producing double canyon-cliff slopes.

At other points, such as "broads" and other quiet spots in the preglacial canyons, the ice-scouring was not pronounced. Also at all points away from the central channels aggradation and minor scouring would be noticeable.

Recession of the ice-flood brought about obliteration of former deep groovings in the rock basins and canyon walls, aggradation was almost suspended in the later drought stages, and overriding of old

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[1] Since writing the above, I have received a glacial note supplied to the *Journa of Geology* for 1905, by Professor Albrecht Penck.

moraines and general ice-stagnation resulted, inasmuch as the old flood-scoured channels were now too broad and of too slight a grade to admit of further corrasion by the present insignificant representatives of the former glaciers.

CHARACTERISTIC TOPOGRAPHIC FEATURES OF SOUTH-WESTERN NEW ZEALAND

1. *Plateau remnants.*—Around Milford Sound, Lake Te Anan, and Lake Wakatipu there exist numerous sub-horizontal masses (Fig. 1), and long ridges attaining heights of from 5,000 to 6,000 feet. Above these again rise peaks and masses to heights of 10,000 feet. Farther south sub-horizontal masses of much less elevation are encountered (Fig. 2).

FIG. 1.—Clinton Gorge; showing dismantled plateau, spurless chasm, and wide canyon floor. In the foreground to the right lies a large *cirque*.

These are apparently survivals of a flexed surface, the upland itself representing the advanced maturity of subaerial erosion (in pre-Tertiary times), when the land was at a much lower elevation.

2. *Hanging valleys.*—These remarkable topographical features are most pronounced in the dense crystallines of Milford Sound, while in the softer Paleozoic schists of Wakatipu they are reduced almost to insignificance. They possess fairly evenly graded channel slopes almost to their point of discharge into the main stream. This they join either in cascade form or as sheer waterfalls as much as 2,000 feet in height. In the crystallines the wall which holds the notching hanging valley is generally possessed of a rectilinear base, the precipice which borders the sounds or canyons at these points being continuous across the inter-hanging valley mouths. This gives a most remarkable appearance as contrasted with typically stream-developed areas (Fig. 3). Magnificent examples of these hanging valleys are the Sinbad Valley (Fig. 4), the Stirling Falls (Fig. 3), and Bowen Falls (Fig. 5).

FIG. 2.—Preservation Inlet. Dismantled plateau at much lower level than that in Fig. 1. Also wide valleys.

3. *Rectilinear cliff bases.*—These forms are found in the Hollyford and Clinton canyons, but are even more pronounced in Milford Sound (Fig. 6), and the side valleys of the Cleddau, Arthur, and

Harrison Cove streams. The mountains composing the sides of the valleys of the Wakatipu and Milford Sound types, may be notched and broken by deep ravines reaching down to the water's edge; they may appear even as isolated *bee-hive* and *sitting-lion* shapes; yet their immense bases almost uniformly preserve a wonderful alignment.

4. *Truncation of spurs.*—All stages in apparent truncation of spurs may be found in the sounds and side canyons. The idea suggested from a study of these forms is that of a former series of overlapping spurs which have been subjected to some mighty force, whose maximum strength had been exerted along the lower and central valley channels, causing the planing off of spur ends in some cases, and utter shriveling up of spurs against the canyon walls in others. The more complete truncation of spurs would, of course, result in more perfect alignment of cliff bases.

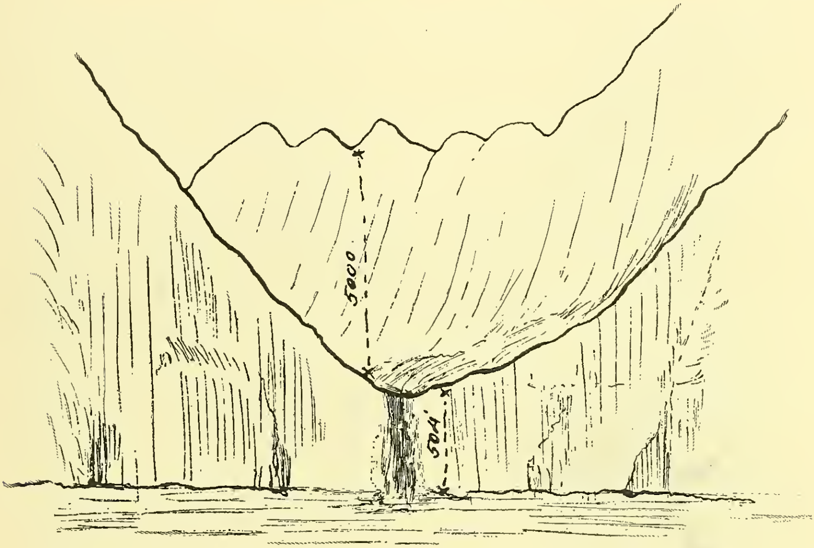

Fig. 3.—Sketch of Sterling Falls, 504 feet high. (From a photo.) Note the alignment of the canyon walls, and the steepness and evenness of the hanging valley walls.

Examples of these progressive stages in apparent spur truncation are shown by Figs. 7, 8, 9, and 6.

Sitting-lion forms and great bee-hives or domes are also the expression of this apparent mutilation of once long rambling spurs.

5. *Double cliff slopes.*—A feature characteristic of the dense crystallines of Milford and its side canyons especially. Along the bordering walls of these canyons the lower portion is often observed to be absolutely perpendicular for as much as from 1,000 to 2,500 feet. Above these rise the characteristically even, but very steep, rock slopes (Figs. 11 and 12), for other 3,000 feet. Usually the sides rise for some 4,000 or 5,000 feet in this steep fashion (slope about 50° to 60°), but in many places these tremendous lower perpendicular slopes come in. Just below the points of convergence of two steep and deep canyons the feature is much emphasized. Figs. 9, 10, 11, and 12 illustrate the point.

FIG. 4.—Mitre Peak (5,600 feet) and Sinbad Valley. Milford Sound. Note the inaccessible walls of the hanging valley (Sinbad).

CONTOURS OF SOUNDS AND LAKES

Associated with these double slopes of Milford are found deep rock basins having fairly flat bottoms and almost perpendicular sides (Fig. 12). These features are also accentuated just below points of deep canyon convergence. The central portions of these rock basins are the deepest, and sounding lines 1,700 feet in length have been employed without reaching bottom.

Generally the sound entrances are *much* shallower and narrower than portions much higher up-stream.

PREGLACIAL HISTORY

The plateau which survives now as ridges and mesas from Lake Wakatipu to Preservation Inlet probably marks the old-age stage of erosion of a surface originating in the Mesozoic folding[1] of southern New Zealand. Differential elevation then ensued, which carried the plainlike surface (developed near sea-level) of the closing cycle of erosion to considerable heights. The early Tertiary sedimentation was probably induced by this deformation. Canyons early became the expression of the cutting action of the streams on the raised area, and during Eocene times a series of anastomosing and graded watercourses were developed in the area. Subsidence ensued, closing the Eocene erosion, the valleys were deeply drowned, and thick masses of Oligocene age were deposited on the Eocene valley floors. This has, it seems to me, been admirably demonstrated by Hutton,[2] in his reply to Von Haast's[3] assertion that the canyons of the New Zealand Alps are due entirely to ice-action; for, according to Hutton, Oligocene limestones occur on the lower slopes of Lake Wakatipu, this same valley having been carved out of the schists by streams in Eocene times on the uplifted plain. Therefore, taking Lake Wakatipu as a type of these lakes and fiords, we are driven to the conclusion that deep valleys had been carved in the hard Paleozoic complex by Eocene streams, and that on subsidence ensuing at the close of that period, the lower valleys were drowned and Oligocene limestones deposited.

Afterward elevation ensued, and the forces of subaerial erosion once more came into play. Now, if stream-erosion here was com-

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[1] F. W. Hutton, *The Geology of Otago.*

[2] *The Geology of Otago*, pp. 86–94. This volume is a real treasure-house of general geological knowledge for southwestern New Zealand.

[3] *Geology of Canterbury and Westland*, pp. 177–92.

parable to that obtaining on the neighboring Australian continent, then a whole host of overlapping spurs must have characterized the headward growth of the canyons. One, however, looks for them in vain. The plunging waterfalls one expects to see are absent from their heads, being found perched along the canyon *sides* instead, while enormous and almost inaccessible *cirques* represent the initial stages in canyon growth.

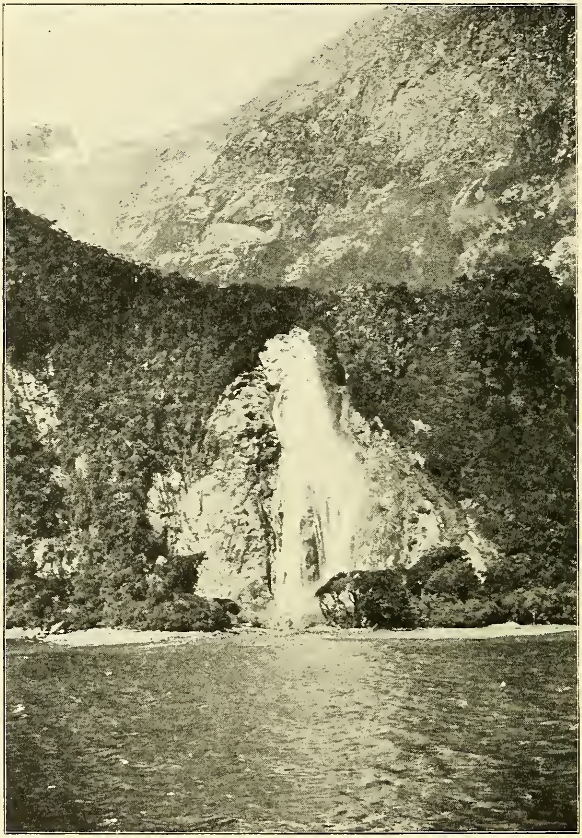

FIG. 5.—The Bowen Falls, 550 feet high. A hanging valley in Milford Sound Note the evenly steep walls of the valley.

The great glacial epoch has come and gone, and with its passing the resurrected topographic forms are seen to be totally different from forms which we know to be developed by streams in *non-glaciated* areas.[1]

Here, then, is strongly suggested a glacial origin for these forms. In the succeeding pages an explanation of these geographic features is attempted.

FIG. 6.—The northern wall of Milford Sound. Note the alignment (and double slope) of walls at Stirling Falls; also the "hanging" valley to the extreme left.

THEORETIC CONSIDERATIONS

It is here proposed to explain the peculiar topography of the southwestern New Zealand sounds, lakes, and canyons as the result of great ice-floods working along lines of preglacial drainage, developed to late youth or early maturity in lofty plateaus having rapid fall to baselevel (generally sea-surface), and to show that the present glaciers must necessarily, from analogy with ordinary stream-action, be practically stagnant.

The similarity between ice- and stream-action need not be at all

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[1] Similarly for the like features of the once strongly glaciated fiord regions of Alaska, Norway, and Patagonia.

strained in this connection. It is only necessary to assume that ice acts somewhat as a viscous body; i. e., that its surface should show a gradually curving fall from summit to baselevel. Thus we get increased velocity with increased volume of ice, as with ordinary streams, and the capacity for work exhibited by the more quickly moving mass is not related by a simple ratio to that performed by the more slowly moving one.

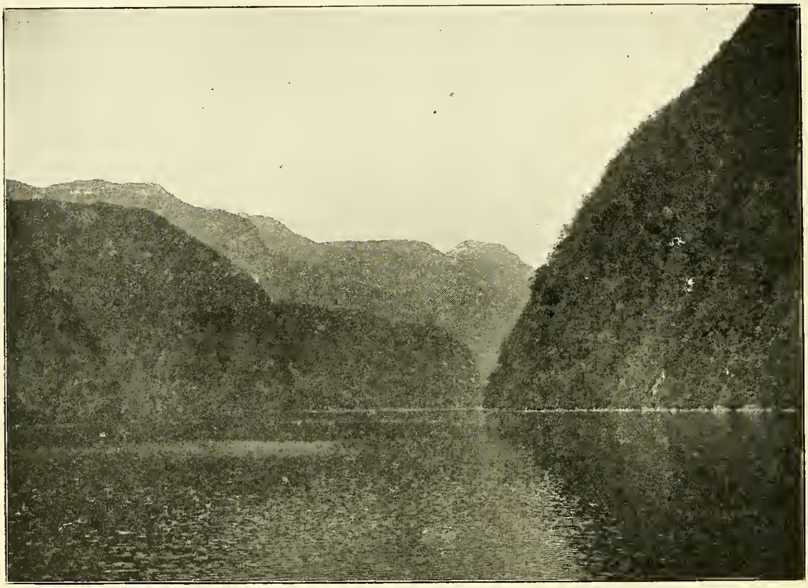

Fig. 7.—Wet Jacket Arm. Note the partial truncation of spurs resulting in precipitous facets facing the Sound.

The same idea of wonderfully increased efficiency as regards cutting, transportation, etc., is seen also during the convergence of two ice-masses into a canyon of very little greater width than either of the two feeders.

TOPOGRAPHIC CONDITIONS OBTAINING IN SOUTHWESTERN NEW ZEALAND

1. We have a much dismantled plateau in the area under consideration (Figs. 1, 2, and 7). Great convergence of these plateau remnant valleys to the later canyons is often observable.

2. The channel bottoms of the incising canyons show *gentle* grades almost to the very heads of the valleys; huge rock basins also exist, the floors of which are frequently lower than the valley bottoms, and are at times far below base- or sea-level itself.

3. Convergence of steep canyons is pronounced, and often marked by the association of huge rock basins, straightened and often perpendicular lower canyon walls (Figs. 5, 6, and 9), surmounted by steep, even slopes.

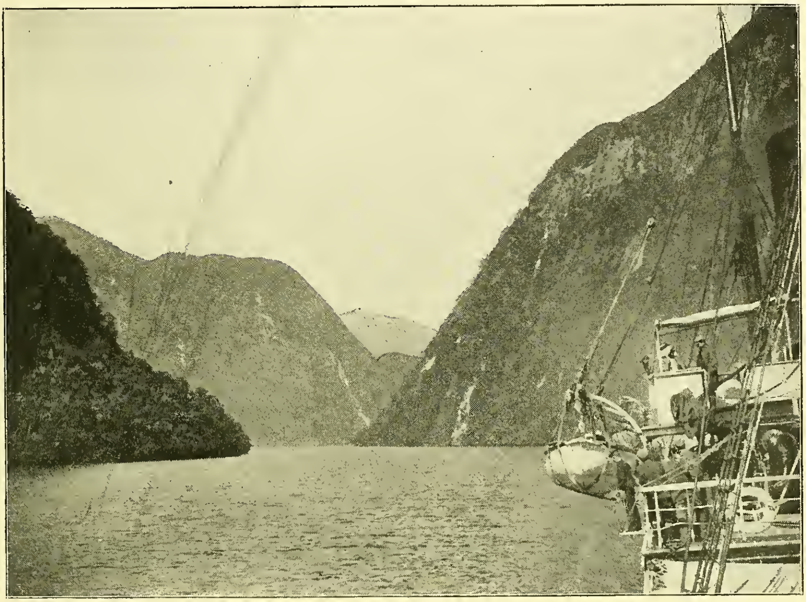

FIG. 8.—Crooked Arm. More advanced stage of spur truncation than in Fig. 7.

4. An immense precipitation is shown for this area, the average probably exceeding 150 inches per annum.

5. Whatever the nature of the agency which imposed these peculiar topographic features on the landscape, the recency of the same and the character of the rocks acted upon have permitted of no alteration in their general appearance.

The problem under discussion is a physiographic one, inasmuch as it deals with the origin of present-day surface contours.

ACTION OF FLOODS ALONG MATURELY DEVELOPED STREAM CHANNELS

The maturely developed stream channel is composed of reaches of alluvial flats, alternating with graded rocky slopes. These alluvial stretches may be regarded as fleeting baselevels. In periods of ordinary water the stream accomplishes very little cutting or transporting, its energy being absorbed in establishing a perfect adjustment of channel grade, which has been temporarily upset by a freshet or flood. Consider now the effect of a great flood on this graded channel. Along certain points of the channel—notably where convergence of streams occurs—deep holes are scooped out below the temporary baselevels. In many cases, along the lower stream courses, basins are formed whose floors lie considerably below their grand baselevel (generally the sea-surface). Every physiographer is aware of such facts. Excavation of banks also keeps pace with this scooping action. Nevertheless, on the other side of the stream aggradation is proceeding hand in hand with this corrasion. The

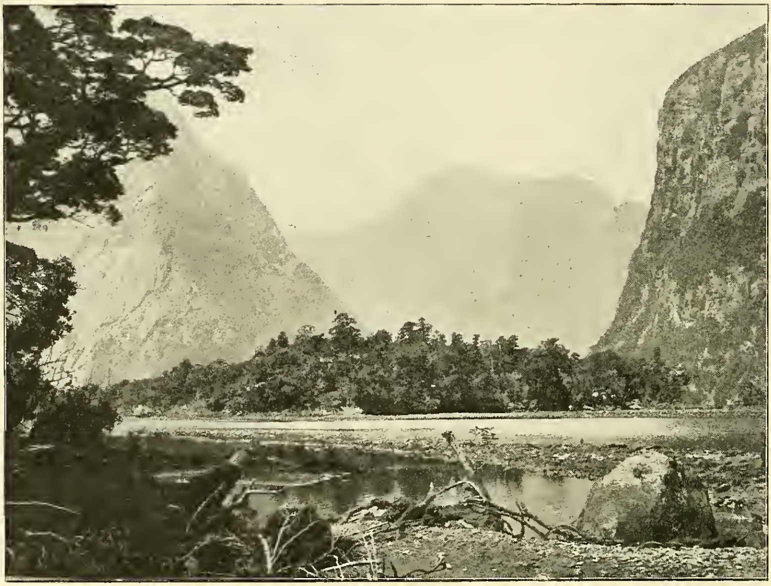

Fig. 9.—The Arthur River at its entrance to Milford Sound. Note the double cliff slope of Sheerdown Hill to the right. See also in this connection Fig. 11.

flood waters which at times surmount the stream banks and spread over the surrounding country are for the most part observed to be stagnant and to form "back-water" masses, in which some aggradation goes on. If some previous channel or natural valley is found by this trespassing mass, a considerable amount of corrosion may occur even at these higher points. This is, of course, in the broads of the stream. In the narrows there is little chance for back water, except in sheltered corners opposite the cutting curve.

FIG. 10.—Lower Milford Sound. Note the immense double slope on the left.

All this is, of course, quite natural. However high the flood, however much it overflows its banks, we expect the maximum strength to occur at or near the central channel portion, while away from the drainage channels we expect aggradation and even stagnation.

With the recession of the mighty flood, we do not expect a continuation of basin excavation below baselevel. On the contrary, we look for aggradation at these points until the normal stream-channel slope has been restored. Nor do we expect the drought-stricken stream to rouse to action the huge loads of flood bowlders littering its channel, and with them to tear away the sides and bottom, even as in times of heavy water they struck each other and the containing banks wildly until their shrieks could be distinguished above the roar of the escaping waters. On the contrary, we expect the reduced stream to gurgle *among* the flood bowlders, to override the banks of débris, or to become stagnant even in the depressions. Thus the recession of high water is seen to act in the direction of obliterating the marks made by storm waters.

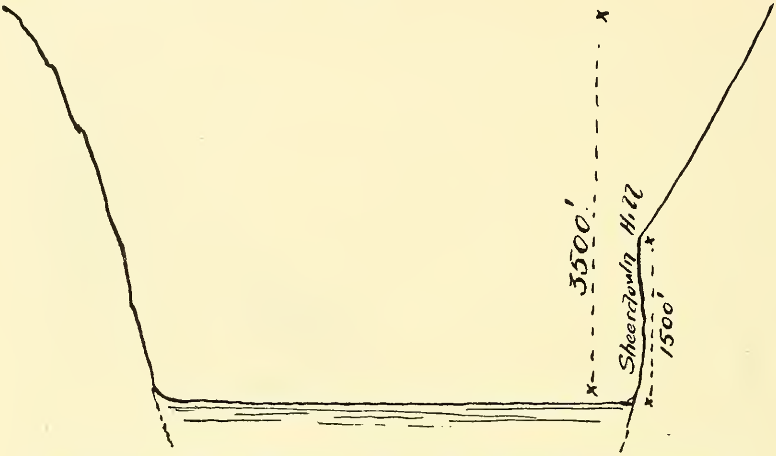

Fig. 11.—Sketch section across the Arthur River mouth. (From a photo.)

Again, in proportion to the advanced degree of stream reduction attained in any region, so are the flood forms just enumerated less and less accentuated in areas of hard, solid structures.

APPLICATION TO ICE-STREAMS

If now the writer has succeeded in stating his case for stream-action clearly, the far-reaching effects of its application to glacial studies must be apparent at once. For it is indisputable that the recent Ice Age marked a glacial flood, while the present insignificant glacial representatives of that momentous period indicate a pronounced ice-drought.

Let us review briefly the probable action of glaciers in these preglacial stream-developed canyons of southwestern New Zealand. As a type of a valley developed by stream-action to the stage of late youth or early maturity, the accompanying sketch of Moonan Brook

(Fig.13) (in New England, New South Wales), may suffice. Here a valley some 3,000 feet deep is seen, many overlapping spurs being noticeable.

We will suppose that convergence of plateau remnants to heads of canyons, as also of these deep valleys into each other, is a common feature.

With the increase in ice-volume, the valley becomes gradually filled with a glacier. With increased volume or convergence (the confluent ice-surfaces will generally keep at same level) comes added velocity. The directions of flow have been determined for it and its tributaries by the preglacial streams, and the lines of maximum depth and motion will be along the portions vertically above the old stream channels. Even should the glaciers fill the valleys, the higher

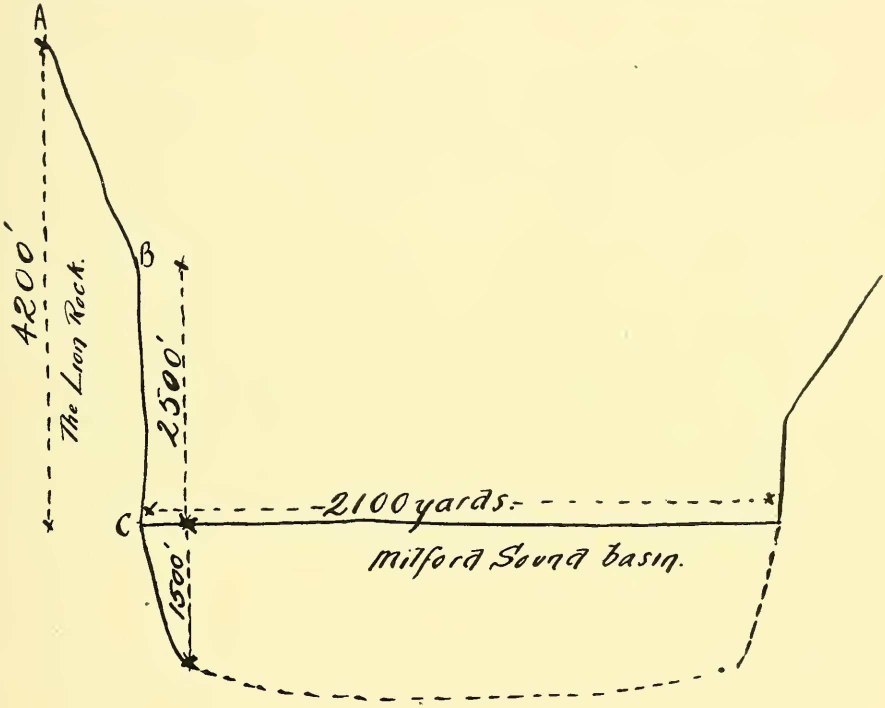

FIG. 12.—Sketch section across Milford Sound. (From a photo.) To the left are seen the effects of the heavy ice-thrusts just below the convergence of Arthur, Cleddau, and Harrison Cove streams. Fifty yards from its cliff, the Sound is 1,500 feet deep.

they rise above the canyon rims, the stronger the resultant thrusts along the central channel, as in the case of ordinary stream floods. Along the lower spur ends the maximum force will thus be early expended. The upper portions of the spurs will experience great wear and tear, but the amount will be trifling as compared with that felt by the spur portions near the base of the central channel. The rock load, as also bottom friction, will cause reduction of speed along the *lowest* portions of the glaciers, and, as with streams, we would expect the maximum velocity to occur along the central channel at some point intermediate between the surface and base of the moving ice-mass. Under the tremendous scouring action of the armed glacier, we would then expect the lower spur ends to suffer first. Fig. 7 appears to illustrate this stage of planation. Here the floating spur ends have vanished, and precipitous facets to the sound are presented by the truncated masses.

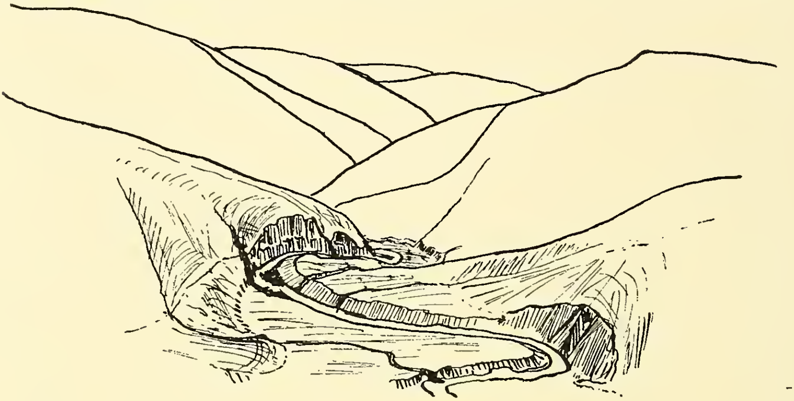

FIG. 13.—Sketch of Moonan Brook (New England, New South Wales). A typical stream-developed valley. Note the overlapping spurs, the spur-cutting and aggradation by floods. Canyon about 3,000 feet deep.

All this time the glacier is increasing its load, and, as with streams, the strong cutting action may have to be suspended (during local slackness in ice-supply) until the excess of load has been removed. Also as with streams, the degree of spur planation will depend upon their arrangement and development. Small spurs in the direct line of flow will early suffer complete removal, while large ones, favorably situated as regards their preservation (points opposite the cutting curves) will show truncation on certain sides only. Fig. 8 illustrates this well. As the ice gathers strength, it will possibly surmount the great canyon walls, and actually flow over the old, flexed upland. This stage may be considered the period of maximum ice-flooding. After the almost complete truncation of spurs in softer rocks, slopes of moderate batter will be induced in the canyon sides, as they will be too weak to resist the lateral thrusts from the swiftly moving glacier. Deep holes will also be plowed in the bottom rocks to great depths below local baselevels. But in the narrower canyons of the dense crystallines, as around Milford Sound, especially where the steep canyons are from 5,000 to 6,000 feet deep, and where marked convergence of valleys occurs, the results will be marvelous. The resultant ice-velocity is much increased as the converging masses are forced into a deep valley only slightly broader than either of its tributaries. The spurs are ripped off, but the resulting massive and aligned walls present great

FIG. 14.—Sutherland Falls, 1,904 feet high, from a hanging valley which is mature and 2,500 to 3,000 feet deep. Upper Arthur River. Note the majestic wall and notch through which stream comes. Here two deep valleys converge to form Arthur River.

resistance to the mighty ice-flood. The differential strength of the converging glaciers in their upper and lower parts will be pronounced. Undermining action will set in. The upper portions will be slowly worn back to steep, even slopes, but the cliff bases will experience such tremendous lateral thrusts that perpendicular and even overhanging slopes will be produced at points somewhat lower than halfway down the valley sides. The disposition of the converging valleys will indicate which side of the lower canyon is selected for special attack. In exceptional cases[1] bottom thrusts will also, near these points of canyon convergence, excavate rock basins possibly several thousands of feet in depth below baselevel.

Figs. 6, 9, and 10 illustrate these stages in wall and bottom excavation in the narrow crystallines.

With the *undermining* action by the heavy lateral thrusts of the lower portions of the glacier, the lower ends of many weaker tributary valleys will be shorn off, and their mouths will be left hanging along the aligned cliff bases.

Figs. 5, 6, 11, 12, and 14 illustrate these points well. The diagrams are taken from photos of Milford and the Arthur River. No one, we venture to say, could see lower Milford Sound and fail to see in it a *heavy* ice-flood working along lines of preglacial drainage.

As might have been expected, the northern wall of Milford has been selected for special attack. This is well seen just below the junction of the Arthur and Cleddau canyons, but the point is still further accentuated a little farther down, where the immense glacier of Harrison Cove was picked up. The great corrasion of the eastern wall of Harrison Cove is also noticeable as compared with that of its western one.

Beyond these points come the evidence of minor spur truncation only, the contracted sound entrances, and the shallowing of fiord waters. As we might have expected, the huge rock basins and associated "hanging valleys," double cliff slopes, etc., are seen in places like this where the ice-fall is pronounced. Beyond this plunge to baselevel we should expect comparative stagnation.[2]

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[1] The depths attained will be a measure of the thickness of the ice-sheet.

[2] From considerations of lack of gathering ground for ice, the cessation of corrasive power after fall to baselevel, etc.

But even in periods of maximum ice-flood many broads or divergences in the channels (canyons) would form spots where aggradation or partial glacial stagnation would occur. The deep fiord basins, with their associated lower precipices, steep, even upper slopes, aligned cliff bases, and "hanging" valleys, mark points of maximum ice-scour, and occur in exactly the positions where we would expect to find them; but there are other spots at which we would expect to have evidence of much less efficiency of ice-corrasion. This is even so. At these points spurs are not observed shriveled up to their containing walls, nor are rock basins found. These points correspond with the smoother waters of a stream-flood. In the canyons themselves these evidences of weakened erosive power may occur only at some *considerable height above the channel bases.*

Again, as the ice-flood in places welled over the canyon sides after the manner of a river overflowing its banks, so we could expect very little comparative scouring to occur at these points. There will be no natural drainage lines to follow at this level, and the ice-overflow will here expend most of its energy in opposing gravity as it rises above the upland irregularities. Aggradation with pronounced stagnation results from this. *Old* drainage lines may, of course, be found, and here, especially on declines,[1] ice-corrasion may be considerable; or the ice-cap may open onto the steep sea-front and set up incipient valley formation here. "Hanging" or even graded valleys may result thus, if the ice-flood be of considerable duration in time.

Consider now the effect of diminishing the ice-supply. Decrease of volume is marked by loss of speed, and this by a *wonderfully* decreased capacity for work. Long before ice-drought conditions shall have set in *active* corrasion will be suspended, and *aggradation* will be the order of the day. For during the period of flood the channel bases have been graded so as to be adjusted[2] to the heavy burdens passing over them. Now an ordinary stream[3] is wholly

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[1] The writer would insist on the idea being kept in mind that a glacier should corrade more on a *decline* than on an *incline.*

[2] A stream-flood may occupy several days only, while the glacial period (summation of ice-floods) probably lasted very many thousands of years.

[3] We should say this law applied to viscous substances generally.

or mainly functional in readjusting the grade along which a *mighty flood only* could do effective work. Until such time, aggradation at the majority of points will ensue. Thus it is with our retreating ice-stream. The deeply scored channel, the huge rock basins (between widely separated canyon precipices adorned with "hanging" valleys), marked the grade along which the ice during a maximum flood *only* could accomplish work. The least retreat of the flood would cause cessation of cutting at these points. Although the canyon ice-overflow might be stopped, yet the canyon itself might be full. Nevertheless, cutting work would be ceased along these points of maximum excavation, since pressure and speed have been reduced in the central channels. The only work the glaciers can now accomplish along the rock basins will be the partial, or at times even complete, obliteration of the deep grooves which marked their high-flood attack. Hence we should expect the rock basins to lose their deep chisel marks, and slight scratches,[1] or even smooth surfaces, to be substituted as the power of scouring became progressively feebler. Huge loads of rubbish could still be carried, and these would be dumped just below the rock-basin mouths. With still farther ice-retreat the loads would be dumped into the lower ends of the rock basins (lakes and sounds). Hence would arise great shallowing up at the sound entrances. With farther recession the glaciers would be unable to even *move* their former bottom loads, and then would ensue the overriding of moraines (formerly the tools with which the glacier accomplished its work). Still later stages would be marked by stagnant or inactive glaciers. Thus arise, in the author's opinion, the inactive glaciers of Alaskan, Norwegian, Alpine, and other canyon bases. They are enormous ice-masses, it is true, but the fact must not be lost sight of that they are but the veriest pigmies as compared with their colossal representatives during the Ice Flood. Still again, the channel grades existent at present were formed *during the flood*, and as such the channels of today at these localities are too wide, and possessed of slopes too much reduced, for corrasion to be noticeable in the present ice-drought stage.

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[1] The declines of the troughs would be more scoured in these later stages than the lower inclined floors. Nevertheless, in the Ice Period these were more deeply chiseled.

Therefore we should expect readjustment of *grades* at present. So far is this distant in point of time that the deep rock basins are still only partially filled up. Until such readjustment of stream grades be brought about, *aggradation and stagnation* with local minor corrasion will be the only expression of present-day ice-action.

In comparing these "facts of form" in New Zealand with those of other strongly glaciated regions *in areas of steep profound canyons having short runs to baselevel,*[1] such as Alaska, Norway,[2] and Patagonia(?), we are struck with the wonderful similarity between the several topographies. In all are found the same tremendous fiord depths, the steep bordering walls, the peculiarly shaped rock basins, the truncation of spurs, the wealth of domes, the magnificence of the *cirques*, and the prevalence of "hanging" valleys. In all is observable the evidence of a former widespread intense glaciation. The steep-walled canyons possess their peculiar features in the most marked degree near the points of convergence. In no formerly non-glaciated region are such features obtainable; indeed, non-glaciated New Zealand and Australia stand out in the most marked contrast. It has also, in the previous pages, been shown that, on the assumption of an ice-flood—a fact which cannot be disputed—the observed forms are precisely those which could be expected. If New Zealand forms are explicable on the hypothesis of stream canyons modified by ice-floods, so also are those of Alaskan, Norwegian, Alpine, Sierran, and similar localities.

A couple of other points might be touched on at this stage, the remainder being reserved for treatment when considering the objections raised by several leading geologists to the theory of profound ice-modification.

1. Subsidence has often been advanced to explain the depth of fiord waters. Against this the writer[3] would strongly protest, unless supported by observation. It is utterly opposed to the evidence yielded by a study of *recent* New Zealand and eastern Australian

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[1] I. e., great comparative velocity by steepness of ice-fall, convergence of canyons, etc.

[2] The Californian Sierras, the Rockies, and the European Alps doubtless fall also into line with these localities.

[3] For New Zealand.

topography. Subsidence postdating glacial times there has certainly been in New Zealand and Australia, but apparently to nothing approaching the depths required to sink these old ice-channel floors 2,000 feet or more below the sea-surface.

Furthermore, the fact of the striking depths found in the Norwegian, Alaskan, and Patagonian fiords, and the strong contrasts presented thus with associated non-intensely glaciated areas, are very suggestive.

Rock-basin excavation along old stream channels below base-level during periods of maximum ice-floods combined with *slight* later drowning is a sufficient explanation.

2. *Cirques* also appear explicable on the assumption of ice-sapping,[1] and find their counterparts in stream-action in rock basins excavated by the undermining action of water falls.

The magnificence of the glacial features (lakes, sound basins, cliff slopes, *cirques*, etc.), as compared with the holes, bank-cuttings, and flood-heaps formed by water, is due to the fact that in the case of the one the corrading agent was confined to a trifling portion only of the valley, while in the case of the other the glacier occupied the whole of its valley.

ANSWERS TO OBJECTIONS

In H. L. Fairchild's recent glacial note[2] a great number of hitherto unanswered objections to glaciation as an efficient corrader are advanced. To most of these the ice-flood hypothesis furnishes a satisfactory answer.

Thus (p. 19) Fairchild adduces the frequent presence of rock-polishing and slight ice scratches only instead of "deep groovings and cornice-like flutings" as evidence against the efficiency of ice-erosion.

Now, these smooth surfaces, slight scratches, and general absence

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[1] See also Willard D. Johnson, "The Profile of Maturity in Alpine Glacial Erosion," *Journal of Geology*, Vol. XII, No. 7 (1904); also Dr. G. K. Gilbert, "Systematic Asymmetry of Crest Lines in the High Sierra of California," *ibid.* Since writing the above, Professor Albrecht Penck has sent the author a paper on "Glacial Features in the Surface of the Alps," *ibid.*, Vol. XIII, No. 1 (1905). In this remarkable paper the author sees additional confirmation of his "ice-flood" hypothesis.

[2] "Ice Erosion Theory a Fallacy," *Bulletin of the Geological Society of America*, Vol. XVI, pp. 13–74, Plates 12–23.

of deep groovings are exactly what we should expect to find on the hypothesis of a former glacial flood and present ice-drought. For the old channel was adjusted to its ice-flood load; the ice-recession was gradual, and work now, instead of being directed toward deepening flood basins, was confined to weaker dragging of loads and minor cutting. In these processes the deep flutings, etc., must to a great extent disappear.

(P. 20) With regard to flexibility of glaciers: Water cannot hold its load stiffly up to its work; yet the observations of the author along New England (New South Wales) stream tracks prove that water can hold bowlders up so effectively that marvelous demolition of spurs and channel bottoms is soon brought about.

With regard to many roche moutonnée forms, we should look upon them as tending to produce stagnation in a viscous mass away from the main drainage lines. We should also, as with water, expect to see far more work done on the downfall side of a rock mass than on its inclined side.

(P. 21 [4]) The analogy need not be carried beyond granting apparent viscosity and flow for glaciers. It does not here concern us what causes the motion. What we feel sure of is: Increased volume gives added velocity, and with flowing masses this gives wonderfully increased efficiency of transportation and corrasion.

Page 21 (5) does not carry weight, in the face of the fact that the present Muir glacier is indisputably a drought-glacier stagnating in its old *broad and more than baseleveled* valley.

(Pp. 22, 23 [7 and 8]) These objections are answered later.

(P. 26) Fairchild claims that rapid corrasion by ice is a self-checking process. If one watches a stream, he will see all the stages of bank-cutting, aggrading, and load-shifting in progress at the same time. Streams, either of ice or of water (or any viscous matter whatever), must adjust themselves to their burdens. If a flood is on, the stream will cut vigorously in one place and aggrade in another. With diminution in volume, transportation sets in until the excess of load is removed. Yet all the time the material is surely being carried to the grand baselevel. This is the way the glacial saw clears itself for cutting.

(P. 27) In areas removed from the centers of drainage lines ice must override obstacles, even as the back waters of a high flood must. Corrasion is here reduced to a minimum, for the simple reason that these areas are not situated along graded channels.

The overriding of drumlins by ice-masses is what must be expected *at any stage* succeeding to the *high floods* which produced them. The drumlins are analogous to the great masses of débris piled up along the banks or along the channels of a stream during high flood. With the recession of the flood the load is dropped, and the babbling brooklets of subsequent dry phases must either trickle through or override the débris. But as for water, so for ice, the drumlins owe their existence to former floods.

(P. 27) "Could not a very deep glacier, having great pressure on its bed, along with a steep gradient, giving high velocity, rapidly abrade its bed?" Fairchild says "No!" But why not? It is only *along* these old preglacial lines, whether belonging to the newer canyon stage or to the older valleys of the flexed upland remnants converging into the canyons, that we claim such erosive power. We do not even need steep channel grades. A sharp convergence of two canyon glaciers into one very little larger in cross-section, especially if the walls are strong and deep, will furnish the velocity needed to give the increased efficiency of erosion needed.

But, as before remarked, over the bulk of the area—i. e., in inter-stream channel areas—we do not expect much cutting work to be done.

(P. 28) Fairchild states that basin excavation is less probable than valley-widening. We maintain that in New Zealand sounds the evident aim of the glaciers *is* to widen and flatten their floors. At certain points of convergence, however, especially when the high and strong walls are confined, the thrusts find partial expression during high floods in basin excavation the while undermining operations are going on. (See *ante*, also diagrams and photographs.) We are thoroughly acquainted in New Zealand with the tendency to widen valleys by ice.

(P. 31) These points have all been answered in other parts of the report on the ice-flood hypothesis. Similarly the peculiar basins of the Sierras, Cascades, Alaska, Norway, and New Zealand have been shown to result from ice-floods along channels of *profound* preglacial canyons, especially just below points of canyon convergence.

Of course, in an area of preglacial drainage carried to late maturity or early old age, especially in areas of gentle or moderate relief only, we would expect comparatively little action to be manifest even during the height of the ice-flood. This point should always be kept in mind by anyone comparing such widely varying regions as England, the Canadian plains, or Norway.

Where the stream-flood dashes its load angrily along the torrent tracks of a youthfully dissected plateau, there should we expect to see the vigorous thrusts of converging canyon glaciers. Now, Alaska, Norway, New Zealand, and Patagonia (?) are countries having young profound canyons intrenched in high plateaus. New England and many other places appear to have had their preglacial drainage well advanced. Apart, then, from certain minor features in their canyoned plateaus, we should expect to see evidence only of comparatively sluggish glaciers. This also applies to Fairchild's criticism on p. 33.

(Pp. 34, 35) Greenland has passed through its ice-flood phase as well as other regions, and therefore *its glaciers should now be stagnant as compared with their ice-flood representatives.* The *main* work was accomplished along the centers of the preglacial drainage lines, and the swarming of the ice-cap over areas of irregular hills and hollows is analogous to the "backing-up" action of ordinary flood waters against obstacles. During the height of the flood the grades of the old drainage were altered to meet the requirements of the heavy ice-cap. Now, of course, heavy as the ice-masses are, they are hopelessly incompetent to the task of corrading these old channels.

Even during the maximum ice onslaughts the ice in inter-stream areas could only corrade strongly if it discovered (or formed) a drainage line. Otherwise it would simply override hills and aggrade here and there.

(Pp. 37, 38) Referring to Professor A. C. Lawson's description of the Kern Valley, we venture to suggest that the previous notes explain these features.

(Pp. 39, 40) Without having seen Lake Chelan, we venture to suggest that it may be analogous to certain apparently non-strongly glaciated valley portions in New Zealand. Yet this is to be expected, since some portions of a stream bed are preserved, while others are deeply corraded during flood stages. But in every instance in the New Zealand fiord region where lake basins, etc., occur, we could have predicted the same from the peculiar conformation of the associated canyon structures. Lake Chelan should be studied with this in view.

(P. 41) To the objections raised on this page it can only be again said that ice-action in infantile, youthful, mature, and other phases of plateau-dissection must not be confounded.

(P. 42) This present condition of the Muir and other glaciers is what *must* result on the assumption of a former efficient ice-flood. The glaciers are now in their drought stages, and lack all capacity for corrasion along their old *basined* channels.

(Pp. 42–46) Fairchild, in criticising Dr. Gilbert's report, apparently considers that physiographers claim the *general* deepening of fiords, etc., to the extent of thousands of feet. Now, in New Zealand, these rock basins, although immense, are yet only a portion of the canyon lengths, and mark the points of convergence of deep canyons. Along the upper canyons for many miles the floor may be flat or exist as a series of terraces.[1]

Thus Wakatipu arises from convergence of the Dart and Rees canyons; Milford Sound arises from convergence of the Arthur and Cleddau valleys; while these valleys themselves are fairly flat, and their bases are probably nearly 2,000 feet above the lake and sound floors.

With respect to the differential erosion *along the fiords* (i. e., preglacial drainage *channels*), and on Annette Island, it must always be remembered that, as a rule, *in the converging narrows the streams scour, while on the associated broads they aggrade.*

As for the view, held possibly by some, that the fiords are wholly the product of ice-scour, all the physiographic evidence in New Zealand points to the fact that the ice-action was confined to working fiercely along the central drainage lines, with production of *local* spurless chasms, rock basins (sounds and lakes), and double wall slopes, alternating with comparative stagnation of glaciers at points where one would expect stream-action to be expended in aggrading.

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[1] See also Willard D. Johnson, "The Profile of Maturity in Alpine Glacial Erosion," *Journal of Geology*, Vol. XII, No. 7 (1904).

One would thus naturally expect to get islets remaining after the glacial flood occupation of a wide fiord, since this is the *stagnant* divergent, as opposed to the *rock-basining* convergent, canyon stage.

SUMMARY

The problem is a physiographic one, since it deals with the origin of present-day rock contours. It is analogous to the study of stream channel and bank contours.

Southwestern New Zealand was in pre-Tertiary time dissected by subaerial agencies to the early old-age stage.

In early Tertiary(?) time this so-developed surface was flexed, attaining a height of about 6,000 feet in the northern portions. Massive residuals of this plateau attained heights of 10,000 feet above sea-level.

During preglacial times the canyons of this area were determined by stream-action. The channels of these water-courses possessed harmonizing grades.

Their present contours are the result of marked modification by ice-action during the period of maximum glaciation.

The Great Ice Age marked a flood in ice-action, while the present much warmer conditions obtaining in formerly intensely glaciated regions are significant of a glacial drought.

The action of this ice-flood is best illustrated by comparing with the stages of an ordinary stream in flood.

In the case of ordinary streams, mighty floods along alluvial flats are frequently observed to *scoop out* holes many feet below these temporary baselevels, especially at points where marked stream convergence occurs. Along either the broads or the bank opposite to that where active cutting is in progress, *aggradation* also occurs during the very height of the flood. With the rising of the stream above its banks, masses of *stagnant back water* also are produced, whose principal function is aggradation as opposed to degradation.

Recession of the flood waters brings about aggradation at the points where maximum excavation was carried on during the flood. Especially does this occur at spots where scooping out *below baselevel* occurred.

Similarly for the ice-streams of the Glacial Period in New Zealand along the lines of preglacial drainage. Just below the point where two profound canyons junction to form one deep valley, comparable only in width with each of its feeders, the ice-masses converged, and, by analogy with viscous fluids, would thereby have their velocity increased. Thus during the height of the ice-flood, they ripped off spur ends, straightened the canyon walls, finally undermining the sides and *scooping out deep rock basins thousands of feet below base-* (sea-) *level.*

During the height of the glacial phase (flood stage), aggradation would progress hand in hand with canyon lowering and widening. Thus, wherever "narrows" in the canyons opened out into "broads," glacial action—so strong just below the points of canyon convergence—would here receive a decided check. This would also be very noticeable even during the rock-basining stage in the narrows. Again, as in the case of ordinary streams, we should, on this theory of ice-action, expect practical ice-stagnation at the majority of points at distances from the centers of the main drainage lines. Thus ice-masses swarming over the canyon rims, and flooding the stream-dismantled plateau, would find their counterparts, in stream-action, in the "back-water" of a flooded river. It might be, of course, that, in the case of ice, some old, deserted plateau channel might be found along which corrasion could be effected; or it might be that the mass would start corrading some steep sea declivity and form "hanging" valleys, the return of warm conditions checking ice-corrasion at this stage.

After the ice-flood came recession of the glaciers. As with ordinary streams, *aggradation* and *smoothing* (along declivities) now became the work of the ice-drought glaciers.

Along the rock basins, undercut walls, etc., which marked the work accomplished by the ice-flood near and below baselevel, the rapidly diminishing glaciers would be mainly employed in obliterating the traces of their former handiwork.

1. They would partly or wholly efface and smooth over their original deep rock groovings, formed during vigorous ice-thrusts.
2. Smoothing of rocks would later practically cease and aggradation commence.
3. Ice-stagnation or overriding of gravels would finally ensue.

For a little reflection will show—as with ordinary streams—that at these points the valleys are too broad, and their grades have been too reduced, to permit of work other than aggradation.

As with streams, again, so with the retreating glaciers. On the least reduced slopes a little cutting will be still accomplished, but aggradation, moraine-overriding, and general ice-stagnation will now characterize these *old* channel grades which formerly expressed *the slopes in which the glaciers of mighty ice-floods only could effect corrasion.*

Hence, in my opinion, arise the present stagnant, although possibly large, glaciers of regions such as the Alaskan and Norwegian fiords; for along the *old flooded channels* of such localities, before they can again resume cutting, they must readjust their channel grades. Until such time they will be engaged removing excess of load, in filling up of rock basins. Even a slight ice-flood at the present stage would have its operations mostly confined to aggrading.

"Hanging" valleys mark the differential erosion of main and tributary channels during the *height* of the ice-flood. Undermining of canyon walls and truncating of spurs near convergence of narrow valleys would cause recession of tributary graded channels, and at these points one would naturally look for fine examples of "hanging" valleys. A magnificent example for study is afforded by Milford Sound along its northern wall. Here, just below the junction of the Arthur and Cleddau canyons, the "hanging" valleys, double wall slopes, and aligned walls are pronounced. A little lower down, the Harrison Cove canyon comes in, and immediately below this the deep rock basin, actually overhanging lower wall, and magnificent "hanging" valley occur. On the more protected southern side these resultant thrust forms are not nearly so pronounced.

Subsidence as an explanation of the great depths of the southwestern New Zealand sounds is utterly opposed to the evidence yielded by topographic studies in non-glaciated Australia and New Zealand. Rock-basin excavation *below baselevel* by thrusts from convergent ice-masses[1] is a sufficient explanation, and accounts also for the disposition and shapes of all the associated forms.

Cirques arise from ice-sapping action, as with ordinary waterfalls.[2]

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[1] Of course, here, as in New Zealand and eastern Australia generally, a postglacial subsidence to the extent of several hundreds of feet must be admitted.

[2] See also A. Penck, and W. D. Johnson, *ante*.

The magnificent basins, lower cliff slopes, *cirques*, etc., due to ice-action as compared with basins, banks, etc., cut by water, are due to the fact that in the case of the latter the corrading agent occupied an insignificant portion only of the canyon, while in the case of the former the glacier occupied the whole of its valley.

Too great emphasis cannot be laid on the fact that these features are those which might be expected in areas of former high plateaus in which profound canyons had been excavated during *preglacial* times, and in which valleys marked convergence is a characteristic. Such areas as the Alaskan, Norwegian, Patagonian, and New Zealand fiord and canyon regions, the Rockies, the Sierras, the Alps, etc., appear to answer this description. *In these localities occur the forms predicted on the theory of modification by an ice-flood.*

But in areas belonging to the late-maturity or early old age of stream-erosion, also in areas of very unstable structures the resultant forms will be less strongly marked.

The influence of a continental ice-sheet during the ice-flood is not here discussed, the writer not having visited such a region. The resultant forms, however, could be predicted according to the degree of stream development attained in preglacial times, and to the length of time occupied in ice-cutting.

APPENDIX

AN APPEAL TO "GRADING" AS AN EXPLANATION OF THE PRESENT NEW ZEALAND FIORD, LAKE, AND CANYON CONTOURS

It may now be confidently asserted, as shown in the author's earlier reports, that the fiords, lakes, and canyons in New Zealand—as doubtless also those of Alaska, Norway, Patagonia, etc.—were due, in the main, to preglacial stream-action, and have since been profoundly modified by some mighty agent. The problem then reduces itself to: What is the origin of such striking dissimilarity of topographic contours in fiords and typical steam-developed canyons? The present note ascribes "fiord" topography to ice-streams in high flood (i. e., glacial period) flattening their grades, and excavating deep holes at points of marked canyon convergence.

All streams, of whatsoever material composed, seek to approximate to main baselevel as quickly as possible, but in so doing they are compelled to establish channel grades along which to do *efficient* work. This follows immediately from gravitative considerations, and is illustrated by the grades of *all* stream channels as known to the author. The ultimate result of this continual approximation to baselevel is a complete flattening of channel grades. Flattening or lowering of channel grades is directly proportional to the strength of the eroding agent, and is a common fact of observation. A normal stream may possess a certain grade; a flood finds this so steep that it is enabled to reduce the grade locally, and *yet* maintain great efficiency as regards transportation. Thus at certain points, notably those of stream *convergence*, floods excavate holes below local or even *main* baselevel. These holes show *undercutting* of stream banks and reversal of channel grade down-stream. Stream studies show the amount of this excavation below baselevel to be directly *proportional* to the stage of stream development (i. e., steepness of grade) and the strength of flood. Thus a stream 5,000 feet deep working along a young channel would altogether overshadow the work accomplished by a stream 50 feet deep flowing along an excessively broad (i. e., a very flattened grade) valley.

Now, the glacial period was an *ice-flood*, the streams of ice, in the canyons (young channels) of southwestern New Zealand being more than 5,000 feet thick.

The action was evidently that of a viscous stream, there being a continuous slope in the mass from summit to baselevel. Therefore, from gravitative considerations, the ice-floods would find the channel grades of the insignificant preglacial streams so steep that they could induce in them excessive local flattening and *yet* maintain great efficiency of transportation; i. e., their general velocity, as shown by their still steep surface curves above baselevel, would still be considerable. The disparity in volume between ice- and stream-floods, even allowing for loss in velocity of ice, would induce, at certain marked canyon convergences, such flattening of grade as would (by analogy with stream studies in New England, New South Wales) be commensurate even with the *depth of the ice-stream.* Thus would here arise basins thousands of feet deep, showing reversed grades lower down stream; also the undercutting of canyon sides, and alignment of cliff bases.

Upon the retreat of the ice-flood or floods, one would expect—as with ordinary streams—to find the flood grade altogether *too flat* for either efficient corrasion or transportation. The diminished glaciers would now be compelled to cease corrading at these points of flood scour and aggrade here until a working grade could be set up or another flood return to carry on its work.

Glaciers of the present ice drought should, therefore, lie inactive or stagnant along these flood-holes (i. e., fiord, canyon and lake basins), while overriding of moraines without transportation and aggrading of flood-holes would set in.

Such were among the theoretical conclusions[1] of the author after a preliminary tramp through New Zealand and a comparison with eastern Australian stream channels. This idea suggested the possible existence of "facts of form" unnoticed during the first short excursion to the Sounds, but nevertheless absolutely necessary to the success of the theory.

Opportunity was found later to examine Milford Sound while the idea was framing itself, and the forms sought were found. Thus in the *strong* crystalline schists of the famous fiord, the canyon walls, just below the convergence of the magnificent Cleddau and Arthur valleys, 5,000 feet deep, show steep upper slopes with marked *undercutting* up to great heights above the fiord base, an alignment of walls, absence of spurs, and an enormously deep rock basin. Just here a third and fourth canyon enter the narrow main channel, and the undercutting, with production of hanging valleys cut off by a great *rectilinear* wall, is very pronounced. Nothing could be more suggestive of rock basins excavated by ice-floods at canyon convergences than the old steep lateral channel grades of these "hanging valleys" now separated by vertical cliffs, due to undercutting, from the flattened grade of the main channel. Still lower down no side canyons come in, and the fiord soon shows a decided *reversal* of channel grade.

All this points to the work of a *flood* or of floods during the *youth of glacial attack.* This idea of youthful ice-attack, exemplified by fiord and canyon contours in strongly glaciated regions was first advocated by Professor W. M. Davis.

Subsidence thus appears to be *practically* negligible in forming present fiord depths.

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[1] Other deductions made were the necessity for absence of this tremendous excavation at marked canyon *divergences;* and other points noted in main report. All these appeared to be satisfactorily seen at Lake Wakatipu, Preservation Inlet, etc. Dr. G. K. Gilbert's observation of lack of glacial erosion in Annette Island, Alaska, appears to be a case in point.

STRETCHED PEBBLES FROM OCOEE CONGLOMERATE[1]

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Assistant State Geologist

The stretched pebbles here described occur in the vicinity of Ellijay, Gilmer County, Georgia, about seventy-five miles north of Atlanta. They are well exposed in a railroad cut on the Louisville & Nashville Railroad a few hundred yards north of the Ellijay station, and are also to be seen at various points both north and south of this place, along the public highway. They seem to be confined chiefly to a narrow belt less than one-half mile wide and about fifteen miles long, lying immediately west and parallel with the Louisville & Nashville Railroad. There are several other points outside of the belt here named where stretched pebbles are occasionally met with, but at no place do they reach such a remarkable stage of elongation. The region in which the conglomerate pebbles occur forms the western margin of the Crystalline rocks of the state. The surface is hilly and rough, but not so mountainous as farther to the east or west. The prevailing rocks of the region are slate, mica-schist, gneiss, marble, and conglomerate, all much folded and contorted. These rocks belong to Safford's Ocoee Series, a group of rocks of great thickness and of unknown age, but apparently older than the Lower Cambrian rocks lying farther to the west.

The beds of stretched pebbles, which at some places are several in number, vary in thickness from eighteen inches to five feet. They are invariably interbedded with mica-schist, and always dip at a steep angle. The beds differ from one another chiefly in the size of the pebbles of which they are formed, and in the extent of elongation of the individual pebbles themselves. In some instances the pebbles have been only slightly flattened or elongated, while in other cases they have been elongated more than twenty times their

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[1] Published by permission of the state geologist.

original diameter. The matrix or binding material, which constitutes only a small percentage of the pebble beds, consists mainly of mica. Where the mica is absent or nearly so, the quartz pebbles are frequently found welded together for the greater part of their length; however, a slight pressure is usually sufficient to break the bond without injury to the individuals. Each of the several pebble beds examined consists of two kinds of pebbles, namely quartz pebbles and feldspar pebbles. The former are by far the more abundant and and are always greatly elongated. The feldspar pebbles, on the other hand, are never elongated, but still retain in a more or less perfect degree their original rounded shape. The feldspar pebbles, which are partially kaolinized, are well shown in Fig. 1, where they appear as rounded white spots.

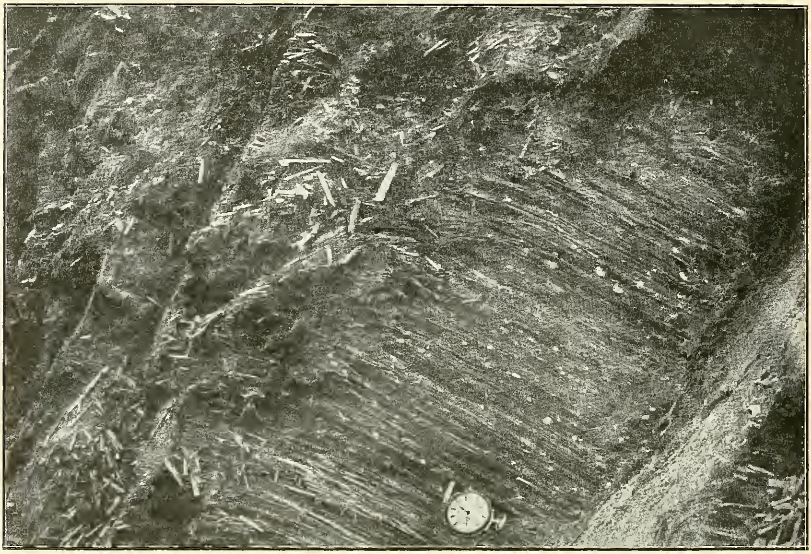

Fig. 1.—Bed of stretched pebbles near Ellijay, Gilmer County, Georgia. White spots show feldspar pebbles not elongated.

The chemical analysis of one of the pebbles by Doctor Edgar Everhart, chemist to the State Geological Survey, here given, shows it to be orthoclase feldspar:

Soluble silica	3·59
Insoluble silica	59·57
Total silica (SiO_2)	63.16
Alumina (Al_3O_2)	21.04
Ferric oxide (Fe_2O_3)	1.02
Lime (CaO)	none
Magnesia (MgO)	trace
Potash (K_2O)	14.44
Total	100.19

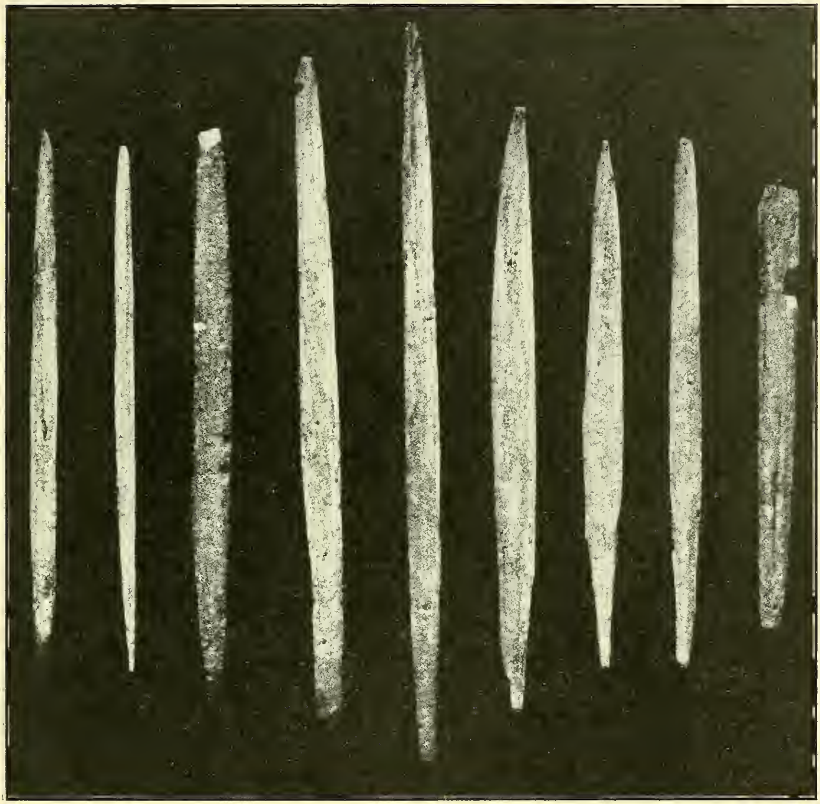

Fig. 2.—Stretched quartz pebbles, three fourths natural size. Pebble at the extreme left has been pierced by a feldspar pebble.

The elongated quartz pebbles are always small, rarely weighing more than a few ounces. Their greatest diameter is generally near the center, from which point they gradually taper to a point at both ends. In a tranvserse section they are ellipsoidal, with sharp, knife-like edges. Their sides are often striated, and occasionally indented by depressions, or in some cases even pierced by the feldspar pebbles (see Fig. 2). The color, when unstained by foreign material, is that of milky quartz. The texture is granular, and the larger pebbles are slightly elastic. The latter property seems to be most

FIG. 3.—Micro-photograph of transverse section of stretched quartz pebble.

pronounced when the pebbles are first taken from the bed. After drying they become somewhat brittle and have to be handled with more care. The individual pebbles appear to have no cleavage, but break as readily in one direction as another. The following analysis by Doctor Edgar Everhart shows that they are almost pure silica:

Soluble silica	1.29
Insoluble silica	97.84
Total silica (SiO_2)	99.13
Ferric oxidee (Fe_2O_3)	0.77
Alumina (Al_2O_3)	0.16
Total	100.06

Microscopic examination of thin sections of the pebbles shows that they are made up of interlocking quartz granules containing numerous small inclusions. Some of the granules exhibit a banded appearance somewhat like, but different from, plagioclase feldspar. It has been suggested that these bands are possibly due to striæ made by grinding; but this explanation hardly seems plausible, as such irregular surfaces would probably be rendered invisible by the Canada balsam. In sections tranverse to the long axis of the pebbles the granules are elongated; but in sections parallel to the long axis, and in the short axis of the ellipse formed by the cross-section, as well as in sections parallel to the long axis, and in the long axis of the ellipse formed by the transverse section, the elongation of the granules is not so pronounced. The degree of elongation of the individual granules in the tranverse section is about sufficient to account for the flattening of the pebbles in that direction. The mechanical effect of strain or stress shown by wavy extinction was not observed in any of the sections.

PRE-CAMBRIAN NOMENCLATURE

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The report of the committee of American and Canadian geologists appointed by the surveys of the two countries to compare notes in the field and decide upon a suitable nomenclature for the pre-Cambrian formations of the Upper Lakes, forms an important landmark in the geology of that region. While it is evident from the report itself that the results attained represent a compromise, not perhaps altogether satisfactory to either party, in the long controversy which has been waged over the relationship of these complex and difficult formations, yet it is to be hoped that, at least in its broad lines, the proposed nomenclature will be accepted by future workers in the region, putting an end to the confusion which has reigned. The position and reputation of the members of the committee give their decisions great weight, and doubtless their nomenclature is the best that could be framed to reconcile the two points of view.

Accepting it as such it may still not be amiss to discuss certain features of the report, as they appear to one who has worked over much of the region on the Canadian side.

The brief summing up of the results of their field-work in the various districts visited is of use as showing the ground covered by the committee, and the materials which they brought to bear on the solution of the problems of the pre-Cambrian; and in general their conclusions seem quite justified, in spite of the short time which could be devoted to any one place. Several members of the committee had of course previously done a large amount of work in the critical localities and were thoroughly familiar with the field relationships. It is to be regretted, however, that so few of the characteristic sections of the Rainy Lake region were visited, and that the important Michipicoten district was not visited at all. In the latter case Professors Van Hise and Leith had, however, acquired some first-hand knowledge of the field relations.

The locality visited for a study of the Rainy Lake Couchiching was, however, decidedly unfortunate, since characteristic Couchiching is not displayed at Shoal Lake.

It must be remembered that Lawson's admirable work in the region was devoted to mapping the rocks on a lithological basis, since the time relationships were obscure. Finding a series of sediments distinct from the prevailingly eruptive or pyroclastic rocks which he had previously studied on the Lake-of-the-Woods, he gave them the name Couchiching, and mapped all the sedimentary gneisses and schists under the same color. He considered the Couchiching to be lower than the Keewatin, and in general he was correct in this; but the significance of the conglomerates occurring in various parts of the region was evidently not clear to him. The mica schists which overlie the basal conglomerate at Shoal Lake should really be excluded from the Couchiching, on account of their much later age, though lithologically very like the typical rocks. The greater part of the rocks mapped as Couchiching lie far below the conglomerate, often at the base of the series of schists, through which, as Lawson proved, the granite and gneiss have pushed eruptively, though similar bands occur at higher levels among the Keewatin ash rocks and volcanics. The later schists above the conglomerate clearly belong to the Huronian and not to the Keewatin.

If the committee had examined the region about Rice Bay, a few miles west of Shoal Lake, they would have found a thick series of Couchiching schists and gneisses associated with banded silica and graphitic slate of the iron formation, undoubtedly more ancient than the Shoal Lake conglomerate since the latter incloses many pebbles of the same banded rocks. Similar associations occur at Fair's farm, about two miles west of Fort Frances, where the iron formation is intimately connected with typical Couchiching. A still better example of the same relation is found at various places to the north; for instance, along the Canadian Pacific Railway near Dryden, where an iron range has been traced for several miles, everywhere parallel to and interfolded with characteristic Couchiching schists.

In the American pre-Cambrian regions south of Lake Superior the amount of sedimentary material associated with the Keewatin pyroclastics and eruptives is insignificant, so that, not unnaturally, the basement complex is looked on by American geologists as overwhelmingly eruptive in origin. This is by no means the case, however, in the Rainy Lake and Wabigoon regions of Ontario, where in some places the Couchiching sediments cover many square miles and are thousands of feet thick.

Logically the basal formation should be called the Couchiching, since our time subdivisions in all later formations are founded on sedimentary rocks, the eruptives being looked on as, in a sense, accidental. Still we may follow the committee in using the pleasant-sounding name Keewatin, which was given first and has been widely used by other writers since Lawson introduced it, in place of the uneuphonious Couchiching.

Turning to another point, the suggestion of the committee that the name Laurentian should preferably be confined to granite and gneiss older than the lower Huronian will not commend itself to many Canadian geologists. As shown by Professor Willmott and the present writer in the Michipicoten and other districts of northern Ontario, this would cut out the majority of the areas of gneiss and granite named and mapped by Logan and his successors as Laurentian. As they are in some cases the actual rocks which received the name from Logan, and as they occupy an enormously greater area than the similar rocks in the United States, one fails to see why the recognition of the later age of most of these granites and gneisses should be so grudgingly allowed. Why should it be permissible only "in certain cases" and "preferably with an explanatory phrase" to call these rocks Laurentian? Should not the usual relationship be accepted as typical, and the explanation be applied to the older granites and gneisses found in the comparatively insignificant basal complex south of the Great Lakes?

This question of the relative age of the Laurentian and the basal sedimentary rocks is evidently rising in other quarters also, as may be seen from Professor Keyes's article on "The Fundamental Complex of the Southern End of the Rocky Mountains,"[1] where he evidently looks on all sedimentary rocks as necessarily later than the Laurentian or Archaean. Now that it has been proved that water-formed sediments, sometimes in large amounts, belong to the basal complex and

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[1] *American Geologist*, Vol. XXXVI, No. 2, p. 116.

are older than the Laurentian eruptives in the Great Lakes region, where these rocks have been most widely studied, should not the western geologists revise their point of view and drop either the "Proterozoic" or the "Azoic," or both, from their nomenclature?

A third point in the report requires comment, viz., the separation of the Keweenawan from the Huronian as an upper pre-Cambrian formation. The break between the Keweenawan and the Animikie is certainly not more important than that between the Animikie and the next lower formation, the Middle Huronian of the new classification, Logan's Upper Huronian. If the Animikie, which was not included by Logan in the Huronian, is now placed within it, why not close up the gap and include the Keweenawan also as a provisional fourth division of the Huronian? Probably most geologists who have studied the Keweenawan would be inclined to place it with the Cambrian, and some have suggested that the Animikie also is early Cambrian. Certainly the two formations should go together.

Since the Huronian as mapped by Logan and Murray included some areas now called Keewatin, the new definition has shifted the use of the term upward, omitting part of the lower rocks, but adding the Animikie above. Logan intended that the Huronian of the upper Lakes should include all the rocks between the base of the Cambrian and the Laurentian, since he suggests that the two divisions of the upper copper-bearing rocks (now known as the Animikie and the Keeweenawan) are probably equivalent to the Potsdam and the Chazy.[2]

If the Huronian is defined as including all between the Cambrian and the Keewatin, the term "Algonkian" becomes unnecessary and should be dropped, at least in the Lake Superior region. Possibly its use might be continued in the west, where the equivalence of the pre-Cambrian beds with those of the east is not certainly proved, but the law of priority should undoubtedly reinstate the name Huronian in the east. However, the term Algonkian is carefully omitted from the committee's report, perhaps in order not to raise a fresh subject for controversy. It may be taken for granted, I suppose, that Canadian geologists will continue to use the name Huronian instead of Algonkian; and it is to be hoped that if American geologists prefer to retain

[2] *Geology of Canada*, 1863, p. 86.

in the future the term Algonkian, now so widely in use in their literature, they will explain that in the Lake Superior region it is equivalence to Huronian.

In conclusion, it should be made clear that the writer has no desire to criticise captiously the conclusions arrived at by the committee, but merely wishes that all points should be thoroughly considered before we are finally committed to a nomenclature which presents some marked differences from the one usual in Canada. Perhaps the American members of the committee have conceded to the Canadians as much as could be expected when one considers what an important and powerful organization they represent—the greatest, and in the main the most ably manned, survey in the world.

The committee are certainly to be congratulated on reaching conclusions with which all geologists working in the region can agree, so far as the broad lines are concerned at least—a result which seemed very distant only a few years ago. Their report should do much to aid in the settlement of difficulties in pre-Cambrian geology in other parts of the world, as well as in the region of the Great Lakes.

EDITORIAL

THE ILLINOIS GEOLOGICAL SURVEY

The organization of a new geological survey is always an occasion for congratulations both to the profession at large and to the state which takes up the work. Illinois is the last to assume the burdens and to reach out for the benefits to be derived from such work, and in many particulars the opportunities in this great central state are unique. The present organization is not the first survey which the state has had. In 1857 $3,000 was appropriated for the making of a complete geological survey of the state—a rather small appropriation for so ambitious a program. The next succeeding assembly, recognizing the inadequacy of the funds, appropriated $5,000 annually for geology and $500 annually for topography, and these appropriations continued till 1872, when the new state constitution prohibiting all continuing appropriations went into effect. At that time $2,000 was appropriated for the expenses of the survey for one year, and in 1873 $7,200 for the succeeding biennial term, with a special appropriation of $1,500 for illustrating Volume VI. The Twenty-fifth General Assembly made a special appropriation of $20,000 for the work, and when the survey was abandoned, funds amounting to $4,000 to $5,000 a year were provided for the maintenance of the succeeding State Museum of Natural History.

The first state geologist, Dr. J. G. Norwood, was appointed in 1851 and served six years. The only published result of his work was a study of the lead and fluor-spar mines near Rosiclare, found in Volume I of the survey reports. His successor, Dr. A. H. Worthen, was appointed March 22, 1858, and served until his death in 1888. His name is the one most closely associated with Illinois geology, since he directed and carried out the work of thirty years, resulting in the publication of the eight well-known volumes relating to the geology of the state. The last of these was published after his death by his successor in the curatorship, Dr. Joshua Lindahl, by courtesy state geologist. Dr. Worthen associated with himself, in the early years of the survey, such well-known men as J. D. Whitney, Henry Englemann, Leo Lesquereaux, F. B. Meek, and J. S. Newberry, and while the personnel of the corps changed somewhat in the course of years, the roll included always well-known and honorable names.

The work of the Worthen survey was largely directed to a study of the general geology and paleontology of the state, and was carried out by counties, the entire state being covered. It resulted in a general geologic map, on the scale of six miles to the inch, and, in addition to the county reports, individual papers on the various formations and groups of fossils. There were, however, no economic reports, as that term is now understood, and when the legislature directly ordered a report on the economic geology of the state, the law was nominally complied with by making a scissors-and-paste compilation from the general volumes and publishing separately three small octavos. In those days the close relations of geology to industry and to technology were not so well understood as now, and geologists considered work on paleontology and pure science more in keeping with the dignity of their profession. The older survey none the less laid broad and deep foundations for future work and very greatly stimulated the development of the mineral resources of the state. When it was discontinued—and field-work seems to have practically stopped in 1872—the curator of the museum took up the work of a bureau of information, and, despite the fact that that office soon became part of the political spoils of the state, this work at least was well done.

Feeling the need of a modern re-study of the state, and particularly the completion of the economic work left by the older organization, the last General Assembly appropriated $25,000 annually for the field-work during the biennial term, and provided for a further draft of $5,000 a year on the printing funds of the state, if necessary. The credit for this move belongs largely and directly to Governor C. S. Deneen who, when the matter was brought to his attention, saw at once its importance and devoted himself to bringing the matter about. The co-operation of many others was of course very important, but the active interest of the state administration was essential, and is significant of the new creed that the best government is the best politics, and that reform means as much doing new things as correcting old abuses; it must be dynamic, not static.

Of the funds of the new survey $10,000 per year is by agreement alloted to topographic mapping in co-operation with the United States Geological Survey, which duplicates this allotment. The remainder is devoted entirely to geology, since Illinois provides separately for the study of its soils, water, natural history, and for engineering experiments. In order to promote close co-operation with these various surveys, the director of the State Geological Survey has his office at Urbana at the university, though the control of the organization is vested in an independent commission. This consists of the governor and the president of the State University *ex officio* and, by appointment, Professor Chamberlin of Chicago. In September this commission met and elected as director Dr. H. Foster Bain, of the United States Geological Survey and formerly, as was true of Dr. Worthen, assistant state geologist of Iowa. The remainder of the corps has not yet been announced, except that it is understood that Professor C. W. Rolfe, who is in charge of the department of ceramics at the State University, is also to be in immediate charge of the investigation of the clay resources. Field-work on this has already been begun by Mr. Ross C. Purdy, lately connected with Dr. Edward Orton in his investigation of Ohio clays.

It is understood that for the present the work of the new survey will be centered mainly on the study of coal and clay, but that the broader problems of the geology of the state are to be re-investigated in the light of the advances made in general knowledge and theory in the quarter of a century which has elapsed since the old survey ceased work. In this work, and in its general activities, geologists both in America and elsewhere extend to the new organization best wishes, and to the state of Illinois congratulations upon having provided the means for such work.

R. D. S.

REVIEWS

The Aftonian Gravels and Their Relations to the Drift Sheets in the Region about Afton Junction and Thayer. By SAMUEL CALVIN. (*Proceedings of the Davenport Academy of Sciences,* Vol. X, 31 pages, 1905.)

In this small brochure Dr. Calvin presents the results of an excellent and much-needed re-study of the type locality for the Aftonian. It will be remembered that, when Chamberlin in 1895 proposed a classification of American glacial deposits, he named one of the important interglacial epochs from certain beds occurring at Afton in southwestern Iowa. These beds were correlated with others in eastern Iowa and in Minnesota, and assigned to the interval between the Iowan and Kansan glacial periods. When the Iowa Geological Survey took up the study of the drift deposits, it was very shortly determined that the lower drift of eastern Iowa was the upper drift of southwestern Iowa, and presumably the one to which the term "Kansan" should be applied. This being so, the beds at Afton must represent a pre-Kansan rather than a post-Kansan period of deposition; and if they were truly interglacial, any drift below them represented an earlier glacial interval than any at that time recognized in the region. Ten years ago, belief in the complexity of the glacial period was not so unanimous as now, and there was some hesitancy in taking so radical a step as was involved in the recognition of an additional glacial advance. In the years which have since passed, the pre-Kansan has been widely recognized, and its existence is now fully established.

In 1898, when the reviewer studied the Aftonian localities, certain of the exposures were obscure, and the evidence was confusing, so that it was thought wiser to make no certain deductions as to the exact relations of the Aftonian to the Kansan. Professor Calvin has been so fortunate as to be able to study new exposures which completely explain the puzzling irregularities noted before, and which leave no doubt of the Aftonian marking a true interglacial interval separating the pre-Kansan from the Kansan by a notable period of time. Mr. Savage had already shown from paleo-botanic evidence[1] that the correlation of the beds at Afton with

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[1] *Proceedings of the Iowa Academy of Sciences,* Vol. XI, pp. 103–9.

those at Oelwein in northeastern Iowa was correctly made, so that now there is satisfactory evidence for almost the whole of the story. Whether the pre-Kansan drift is entirely covered by the Kansan, or at some point has a surface development beyond the margin of the latter, is not entirely settled, though the observations of recent years tend to support the view that the pre-Kansan represents only an incomplete advance of the ice and was wholly overridden by the Kansan, representing the maximum advance.

H. Foster Bain.

Economic Geology of the Bingham Mining District, Utah. By John Mason Boutwell. With a Section on Areal Geology by Arthur Keith, and an Introduction on General Geology by Samuel Franklin Emmons. (Professional Paper No. 38, U. S. Geological Survey.) Pp. 1–413, 49 plates, 9 figures.

General.—The sedimentary rocks, which are all of the Upper Carboniferous system, consist of 10,000 feet of quartzite containing eight limestone beds aggregating 2,100 feet in thickness. They are cut in many places by intrusive monzonite and younger extrusive andesite. The ores of the region occur in veins cutting all rocks, in beds in the limestone, and disseminated through the monzonite.

Genesis of ores.—The ores may be grouped into three classes: copper ore in monzonite, the lode ores, and copper sulphides in limestone.

1. Copper ore in monzonite.—A relation appears between the amount and quality of the ore, and the degree of alteration of the including rock, suggesting a secondary origin for the ore. Microscopic examination showed the ore to be imbedded in secondary quartz and sericite, proving its secondary origin. The conclusion follows that the copper was deposited from hot solutions in the monzonite after its solidification.

2. The lode ores.—These are confined to fissures. Hot aqueous solutions rose through great northeast-southwest fissures, altered the country rock somewhat, and deposited the lode ores in largest bodies between limestone walls, mostly by filling, but slightly by replacement. The solution was rich in carbon dioxide and sulphur, and a slight solvent of limestone, as shown by the presence of much calcite in connection with the ore, by the great bodies of sulphides deposited, and by the displacement of some of the limestone by the ore. Deposition was aided by decrease in pressure, by the varying slope of the fissures, by contact with limestone, and probably by the material displaced from the limestone.

3. Copper sulphides in limestone.—These ores occur only in fissured regions of limestone marmorized by the contact with monzonite. Inasmuch as it retains the bedded structure of the limestone, and shows every conceivable stage of replacement when observed microscopically, the conclusion is that it was deposited by a molecular replacement of the limestone. The source of the copper was the intrusive monzonite, while the transporting agents were hot solutions or vapors emitted from the intrusives either from the top or from great depths.

The district is a steady producer of low grade ore, and is the foremost camp of Utah in the production of copper. More of the sulphide ores are being found continually, and progress is constantly being made in the production of low-grade copper, which seems likely to prolong the mining activity of the region indefinitely.

The report is clearly written, and betrays systematic and thoroughgoing work. A. C. T.

Geology of the Tonopah Mining District, Nevada. By JOSIAH EDWARD SPURR. (Professional Paper No. 42, U. S. Geological Survey.) Pp. 295, 24 plates, 78 figures.

Ore deposits were discovered in the Tonopah district in April, 1900, by James L. Butler. The geologic structure is complex. The rocks are of volcanic origin, probably Miocene-Pliocene, except for a series of water-laid tuffs. The successive flows have been named earlier andesite, later andesite, five recognized rhyolite-dacite series, the Siebert tuffs, and finally a little basalt. The region has been profoundly faulted. It is concluded that the faulting was initiated chiefly by the intrusion of the dacitic rocks. After the intrusion there was a collapse, a sinking of the various vents. "The still liquid lava, in sinking, dragged down with it adjacent blocks of the intruded rock."

The veins occur principally in the earlier andesite, and do not extend into the over-lying rocks. Less rich veins are found in the later andesite and one of the rhyolite-dacite series. These veins are formed by replacement in fissured zones. Transverse fissures have determined the position of cross-walls and ore shoots by limiting and concentrating the circulation.

The ores contain silver sulphides, silver selenide, gold in an undetermined amount, chalcopyrite, pyrite, some galena and lead, with a gangue of quartz, adularia and some carbonates. Oxidation has occurred to varying depths, but has not reduced the amount of gold and silver.

The earlier andesite has suffered extensive alteration, near the veins to quartz, sericite, and adularia; farther away to calcite and chlorite. The principal work of the altering waters was the formation of the veins. A detailed account of these changes is given, and a study of typical specimens leads to the conclusion that these waters were charged with an excess of silica and probably potash, with gold, silver, antimony, arsenic, copper, lead, zinc, sodium, sulphur, some chlorine and fluorine; but were notably deficient in iron. By comparison and microscopic studies of the later andesite it is concluded that these altering waters were charged with carbonic acid and sulphuretted hydrogen, and contained magnesia, iron and lime.

The composition of the waters indicated above does not seem to correspond to the composition which waters descending through the rock would have had. An eruption of andesite, followed by highly siliceous and potassic waters, deficient in iron, and an eruption of rhyolite followed by waters rich in lime, magnesia, and iron, present an antithesis which may give, according to the author, some clew to the origin of the waters. Two hypotheses of this origin are considered, an atmospheric and a magmatic. The author favors the latter view.

Besides a detailed discussion of the above-mentioned facts, Mr. Spurr has chapters on the descriptive geology of the several mines and prospects; the increase of temperature with depth in the mines, and concludes the report with a comparison of similar ore deposits elsewhere. F. D. M.

Stratigraphy and Paleontology of the Upper Carboniferous Rocks of the Kansas Section. By George I. Adams. (Bulletin of the U. S. Geological Survey, No. 211, 1903, pp. 1–72.)

Tabulated List of Invertebrate Fossils from the Carboniferous Section of Kansas. By George H. Girty. (Bulletin of the U. S. Geological Survey, No. 211, 1903, pp. 73–83.)

Summary of the Fossil Plants Recorded from the Upper Carboniferous and Permian Formations of Kansas. By David White. (Bulletin of the U. S. Geological Survey, No. 211, 1903, pp. 85–117.)

Notes on the Permian Formations of Kansas. By Charles S. Prosser. (*American Geologist*, Vol. XXXVI, 1905, pp. 142–61.)

Several important contributions have been made lately to our knowledge of the much-debated section of the Upper Carboniferous of Kansas.

The standard Carboniferous Section for America may be regarded as the one which is so fully displayed in the Mississippi valley. It is in Kansas that the most complete development of the upper part of the Carboniferous is found. In this locality the Upper Carboniferous limestones and the so-called Permian beds appear in unbroken sequence. It is unnecessary at this time to go into any of the details that have been for so many years the subject of lively debate. Professor Prosser has recently admirably summarized opinions expressed. What has been really needed in all this prolix discussion has been greater attention to critical data. The entire subject has been lately reviewed by Dr. G. I. Adams.

A most succinct and concise account is the recent memoir on the *Stratigraphy and Paleontology of the Upper Carboniferous Rocks of the Kansas Section.* In the main, Mr. Adams records the results of an attempt after extensive and direct work in the field, to rectify the confusion regarding the stratigraphy and the consequent interminable synonomy which has in Kansas arisen unchecked during the last decade. While it would have been very desirable to have had the same careful inquiry extended over Missouri, Iowa, Nebraska and Arkansas, the fact that it was not does not detract from the memoir under consideration. A comparison of the Kansas formations with their representatives of the region lying to the eastward would have proved of great value, and would have removed a considerable part of the synonomy which still remains in the Kansas area.

Not the least noticeable feature of the Adams bulletin is the nearly complete elimination of the classifications and the nomenclatures of Prosser and of Haworth. Whether or not the author has not gone too far along this line remains to be seen. The same question may be asked regarding the work of the pioneers in the Kansas region.

Dr. Adams recognizes, upon lithologic grounds, four main divisions of the Upper Carboniferous of the region. In order to avoid complications in nomenclature of the Carboniferous, he has thought it advisable not to give names to these divisions. There are: (1) lower shales and sandstones; (2) interstratified limestones, shales, and sandstones; (3) limestones interstratified principally with shales; (4) bluish and purplish shales. These four subdivisions are based wholly upon lithologic characters as determined by the writer mentioned. Critical examination of the data upon which he has founded his groupings shows that, although unnamed, they do not differ essentially from those previously recognized by other investigators who have been in the region, and who have based their determinations, not only on lithologic, but upon broad stratigraphic, faunal, and historic grounds.

Adams' main contention is to draw for the major subdivisions of the section lines that are slightly different from those previously recognized.

Data which he presents appear to give results quite diverse from what he manifestly intended. For the major subdivisions they militate strongly against his conclusions rather than support them. Moreover, Girty's elaborate tables showing the detailed vertical ranges of the fossils clearly not only do not strengthen Adams' position, but very greatly weaken it; and, on the other hand, furnish the strongest evidence yet published that the main divisions previously recognized are very nearly the proper ones. For Adams' chief conclusion the introducing of the faunal evidence is very unfortunate.

The relationships of the so-called Permian of Kansas to the Red Beds are of great significance. Mr. Adams states that—

> the distinctions which have thus far been outlined in Kansas do not hold when the rocks are followed southwestward along their strike into the Indian Territory. Approximately along the Arkansas River, or a little south of that stream, the interstratified limestones disappear from the section, and the formations are accordingly shales and sandstones. Moreover, the rocks in the Indian Territory gradually assume a red color in the higher portion of the section, the line of transition to this color being diagonal to the strike. The Red Beds of Kansas belong to this phase.

Regarding the biotic characters Dr. Girty aptly observes that—

> the constituents of the Kansas section consist of alternations of limestone and shale, the latter sometimes containing more or less sandstone. During limestone-making periods invertebrate life was varied and abundant; but few of the mud beds, however, appear to have supported animal life. With some exceptions, therefore, only alternate formations are represented by fossil faunas. The youngest fauna obtained is that of the Marion formation, the Wellington having so far proved devoid of marine fossils. The oldest fauna occurs in the Cherokee shales. It is rather meager, so far as known, but it is probable that numerous additions to our list of species can be obtained at favorable localities. Many of the faunas in the section are large and varied, and while all are not equally extensive, I believe that their uniform excellence is far above the average in sections of equal length.
>
> The value attaching to tables such as the one given depends upon the consideration of several factors. The most important among these appear to be the following:
>
> 1. The precision with which the collections are located in the generalized section.
> 2. The consistent accuracy of the determination of species.
> 3. The variety and abundance of the formational faunas, and the uniformity maintained in these particulars throughout the section.
> 4. The completeness with which the faunas are represented in these particulars by the collections.
>
> With all these elements favorable, the sequence of faunas and the range of

species shown by this table should be applicable to a considerable area. Its applicability should, indeed, be limited only by facts of identity of horizon and of basinal boundary.

The tabulation of the species according to their occurrence in the minor formations, some fifty of which are recognized in the 2,000 feet of strata, is essentially a repetition, though perfectly independent, of a similar attempt made a decade ago. It is mainly valuable in substantiating the conclusions arrived at at that time regarding the serial grouping of the various lithologic units of the region.

Mr. White's record of the fossil plants, while necessarily meager, is important as the most complete list of species yet published. It affords many suggestive considerations. The author states that—

> nearly all the specimens here discussed are of Coal Measures (Pennsylvanian) age. But very little plant material from beds of the supposed Permian of Kansas has yet been described. The University of Kansas, in connection with its geological survey of the state, has accumulated more or less fossil plant material in its paleontological collections. This paleobotanical material, which has been sought with especial regard to the Permian problem, is now being studied by Mr. E. H. Sellards, and will probably receive systematic treatment and illustration in one of the proposed volumes of the state university survey. The writer is under obligation to Mr. Sellards and to the university for specimens, particularly of Permian types, submitted for examination or donated to the collections of the United States National Museum. This material, so far as it has anywhere yet been published, is included in this summary; but such species in the material communicated by Mr. Sellards as are new to science or have not previously been discovered in the state obviously could not be included without unfairly anticipating their full description by him and impairing the originality of his publication. Accordingly, in dealing with the supposed Permian flora in particular, which he has been so successful in discovering, all paleontological discussion of the material is here omitted.

The plant remains throw no light on the possible subdivisions of the section; and the whole Lower and Upper Coal Measures are merely said to represent the Allegheny section of Pennsylvania.

Professor Prosser's article on the Permian, while adding nothing new to the subject, is important as affording a connected review of all that has been written on the Kansas Permian beds during the past few years. A considerable portion of the paper is taken up in defending former positions this author has taken. Concerning the retention of certain names the author mentioned, without bringing out any additional reasons, quotes a final rule of the Federal Survey. Without questioning the good taste of such proceeding, or the fact that it adds no weight whatever to a logical conclusion, it is not probable that any organization on the face of the earth can fix nomenclature until all evidence has been thoroughly sifted.

In discussing the nomenclature of the Upper Carboniferous system, Professor Prosser falls into the same error that he has previously, notwithstanding the fact that his statements have been corrected, and he furthermore does not appear to have yet grasped the points of that contention. However, as these are taken up in another connection, they need not be considered in detail here. If he recognizes, as he states, the uppermost series of the Carboniferous as the Permian, it seems wholly unnecessary to say the least, to enter into a prolix argument as to whether Oklahoman series and Cimmaron series are correctly determined or not. Taking the first-mentioned position, most persons would pass the second over without argument. The fact that the last-named terms are re-argued by him at length would appear to indicate that the author is not so sure, after all, that they are not valid.

As to the dividing line between the Permian and Upper Carboniferous it is stated that—

> it is clearly shown by Beede and Sellards that the Wreford limestone is a conspicuous formation which may be readily followed from southern Nebraska across northern and central Kansas, at least into the southern part of the latter state. This is fortunate in case the Wreford limestone be considered the base of the Permian, because it will afford a marked lithologic break for the line of division between the Permian and the Carboniferous.

Summing up the main features of these papers, it appears (1) that in Kansas there are recognizable in the Carboniferous section, which is more than 2,000 feet thick, four well-defined subdivisions; (2) that the lines of separation of these major members are essentially those which have been located before and generally agreed upon by those who have worked in the Kansas field during the past decade; (3) that the only matter to be now settled is one of nomenclature—the application of simple geographic names to provincial series. There have been a sufficient number of titles already proposed, which cover very closely, if not quite, the subdivisions recognized. The time is ripe to do away with all petty technicalities, and adopt permanent names. This may easily be done even at the risk of modifying somewhat the original meanings; such a course is far more preferable than the proposal of a new set of titles, which in the end are likely to become synonyms.

In the articles mentioned above numerous references are made to the general Carboniferous section and to sections so widely separated as Pennsylvania and New Mexico. Without intervening sections or some description of them the comparisons are of small use as elucidating Kansas geology. However, it brings up the question of general classification of the American Carboniferous deposits. If we parallel these provincial sections as types—(I) western Texas, and southern New Mexico, (II) eastern Kansas and Missouri and (III) West Virginia and Pennsylvania—we get something of the following arrangement:

	Time-Divisions	Provincial Series		
		I	II	III
Carboniferous	Late......	Cimmaron	Cimmaron	
		Wanting?	Oklahoman	Permian
	Mid......	Maderan	Wanting ?	
		Manzanon	Missouran	
		Wanting?	Des Moines	Pennsylvanian
		Wanting?	Arkansan	
	Early.......	Socorran	Mississippian	(Poconoan ?)

On the whole, it seems advisable not to attempt the impossible by stretching any one provincial series over the entire continent. A general continental section based upon the somewhat elastic time divisions is about as far in the present state of our knowledge as exact paralleling can go.

Charles R. Keyes.

Revised Nomenclature of the Geological Formation of Ohio. Bulletin No. 7, Fourth Series, Geological Survey of Ohio; November, 1905. By Charles S. Prosser. Pp. xv+36.

This bulletin is prefaced by the state geologist, Professor Edward Orton, Jr., giving a refreshing account of the Ohio Legislature setting aside a definite appropriation for purely stratigraphic work, realizing that the proper development of economic resources is directly dependent upon the accurate knowledge of the formations and geological structure of the state. Another feature of the introduction is the statement of an excellent method of dealing with the various requests made to the state geologist to undertake local and private investigations, analyses, etc.

The body of the bulletin is a further elaboration by the author of his article in Vol. XI of the *Journal of Geology*, bringing the subject up to date, but which will receive further attention as the work of the Ohio Survey continues. The author gives a table of the old and new classifications of the formations of the state, and in characteristic manner reviews the literature on the subject and adds the results of his own field studies.

Prior to Prosser's work Ohio stood well in the quantity and quality of the work done by its state surveys. However, owing to the intricate nature of many of the formations and the difficulty of properly interpreting them, much remained to be accomplished. Prosser's work has thrown much additional light on these formations, as the tables of formations show. The revised list of formations is as follows: Alluvium and Glacial, Dunkard formation, Monongahela formation, Conemaugh formation, Allegheny formation, Pottsville formation, Maxville limestone, Logan formation, Black Hand formation, Cuyahoga formation, Sunbury shale, Berea grit, Bedford shale, Ohio shale (consisting of the Cleveland shale, the Chagrin formation, and the Huron shale), Olentangy shale, Delaware limestone, Columbus limestone, Monroe formation (consisting of the Lucas Limestone, the Sylvania sandstone, and the Tymochtee member?), "Niagara group" (consisting of the Hillsboro sandstone, the Cedarville limestone, the Springfield limestone, the West Union limestone, and the Osgood beds), Clinton limestone, Belfast bed, Saluda bed (which is regarded as probably forming the upper part of the Richmond), Richmond formation, Eden shale, and Trenton limestone.

The priority, synonomy, correlation, and application of these names are fully discussed in the *Bulletin*. J. W. B.

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THE FORMER LAND CONNECTION BETWEEN AFRICA AND SOUTH AMERICA

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There are two lines of inquiry which lead to a common conclusion, namely, that in former ages there was a notable land area where now the waters of the Atlantic lie. The first is concerned with the evidence afforded by islands in mid-ocean, and the second makes use of the character and conditions of deposition of the rocks on the continents bordering the ocean, and the distribution of animals now living on either side.

The bulk of the evidence is naturally accumulated in the second line of inquiry, because the continents are more accessible to observation and investigation; but even a little testimony from oceanic islands is of very great value, for these are formed by the piling-up of lavas, and the vents penetrate the ocean floor and bring up fragments of the solid crust beneath, so that we can actually handle and examine the constituent rocks of the submerged land.

In setting out the arguments on the first line of inquiry, it is necessary to define what is meant by a continental type of rock. Sir John Murray's list of continental types is gneiss, schist, sandstone, and compact limestone; and generally the term seems to be applied to any rock formed from the detritus of a land-mass, bearing in mind that it is generally accepted that sediments are deposited within two hundred miles of the coast. The inclusion of schists and gneisses seems to imply, in addition, that rocks may be included in the list of continental types which have been subjected to deformation, the underlying idea being that earth-movements, such as those which produce mountain-folds, are confined to the regions of the globe that have been, or are, above the level of the ocean. The average specific gravity of continental types of rock is taken to be 2.68. We owe this term to the theory of Dana, Wallace, and others, that the oceans and continents have remained pretty much in the same places during geological time. The opposite of continental rock is, obviously, an oceanic rock, though this term is never actually used, the meaning being conveyed by various phrases, such as "the rocks forming the ocean floor," or "the sub-oceanic crust." Now, since the continents as a whole are less elevated above mean sea-level than the ocean floors are depressed below it, and since the density of water is less than half that of rock, it is obvious that if the densities of the continents and ocean floors were the same, the water would be attracted by the land-masses and heaped up along the shores. Such is actually assumed to be the case by Suess in the introduction to his *Antlitz der Erde*, but Fisher adduces very strong arguments in favor of the view that, setting aside rotational effects, the sea-level is sensibly spherical. In the latter case, the rocks of the sub-oceanic crust must be denser than the continental types to keep the water in place, and it is assumed that they are composed of basic original magma, and of basaltic flows from submarine volcanoes, which were more dense than the material of the continental crust.[1] The specific gravity of the rocks composing the ocean floor is taken to be 2.96. Thus it appears that in respect to the density of the sub-oceanic floor and the consequent form of its hydrosphere we have two rival schools, the one maintaining that the ocean surface forms a series of troughs between the continents, the other that the hydrosphere is sensibly spherical. This point must be settled before we can arrive at any comprehensive and satisfactory explanation of the geology of the earth as a whole; and, as far as I know, the materials at present available are not sufficient to enable one to give an irrefutable answer one way or the other. Even if Stokes, Pratt, and Faye, quoted by Fisher, go too far in one direction, and Fischer, Hann, and Listing, quoted by Suess, go too far

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[1] Fisher, *Physics of the Earth's Crust*, chap. 25, and Appendix, p. 16.

in the other, yet the work of v. Drygalski[1] shows that there are factors which render both to a certain extent reconcilable. A great advance will have been made if it can be sufficiently proved that there was once a land surface where now the Atlantic Ocean or some notable part of it, lies; and I will now present the arguments n favor of this view.

Evidence from Ascension Island.—Ascension Island, like the Tristan group and St. Paul's rocks, lies in the mid-Atlantic ridge. Composed chiefly of volcanic rocks, there are abundant traces of the substructure being granitic in nature. Darwin states that in the neighborhood of the Green Mountain fragments of extraneous rocks are frequently met with imbedded in the midst of scoriæ.[2] Professor Renard confirms this, and mentions as occurring in this manner, granite, granitite, diabase, and gabbro, "torn up from the depths by eruptions."[3] There is no record of the granite basis appearing above the water-line; but if one takes these observations and considers them in the light that Woolnough has thrown on the Fiji Islands, another group which until recently had been thought to be purely volcanic, the true significance of these ejected blocks is made clear. In Fiji, Woolnough found that the whole group was underlain by a basis consisting of granite, quartz-diorite, quartzite, slates, and old sedimentary rocks of an indeterminate age,[4] and I confidently look to the results of his second expedition for affording still more striking evidence for the continental origin of these islands.

Evidence from St. Paul's rocks.—A great deal has been written on the ultra-basic rocks from this small mass of land in mid-ocean, and the opinions as to whether they are igneous or metamorphic have been equally balanced. The deformation of crystals imbedded in the matrix is such, however, that we must assume that the rock has been subjected to earth-movements, and in spite of the islands lying in a region of active submarine volcanic action, such a careful author as Neumayr was satisfied that this ultra-basic

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[1] *Zeitschrift der Gesellschaft für Erdkunde* (Berlin, 1887).

[2] *Geological Observations on Volcanic Islands*, 1851, p. 40.

[3] Challenger Reports, *Physics and Chemistry*, Vol. II, Part 7, p. 62.

[4] *Proceedings of the Linnean Society of New South Wales*, 1903, Part 3.

rock—serpentine, peridotite, or sherzotite, whatever we choose to call it—was a metamorphic and not an eruptive rock.[1]

Evidence from Tristan d'Acunha.—In the Tristan d'Acunha group one block of gneiss was obtained by Mr. Hammond Tooke on a voyage thither in H. M. S. "Odin." Further specimens from Nightingale Island showed fragments of an earlier consolidated rock imbedded in a glassy matrix; the fragments were very minute and had the appearance of having been derived from a felsite or microgranite.[2] Both these cases would have been too small evidence on which to build any theory of the rock substructure of the islands, did not the description of Ascension Island support them. In Carmichael's account of the ascent of the peak on Tristan d'Acunha we read that the plain from which the central cone rises "is encumbered with large detached masses of porphyritic stone, and with others, inclosing crystals of sulphur or augite, which seem to have been ejected in their present state from the interior of the mountain."[3] Latter-day petrologists may smile at a man who cannot distinguish between crystals of sulphur and augite, but Carmichael was sound on general geological questions, and his description of Cape Town, with the sandstone resting on slate and granite with dolerite dykes,[4] is far better than many of the later accounts.

Volcanic ejectamenta as indices of deep-seated formations.—It is a remarkable fact that we can thus sample the deep-seated rocks, far below the zone of direct observation, by the ejectamenta of volcanoes. In South Africa I have made use of them in the Drakensberg, where many thousands of feet of Permian, Triassic, and perhaps Jurassic strata lie upon an Archæan base,[5] and in the central Karroo portions of the Palæozoic floor are brought to the surface in this manner. Often enough, in South Africa especially,

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[1] *Erdgeschichte* (Leipzig, 1890), p. 199.

[2] *Transactions of the South African Philosophical Society*, Vol. XVI (Cape Town, 1905), p. 49.

[3] *Transactions of the Linnean Society*, Vol. XII (London, 1817), p. 491.

[4] Biographical sketch, *Hooker's Botanical Miscellanies*, Vol. II (London, 1831), pp. 1–59, 259–89.

[5] "The Volcanoes of Matatiele," *Annual Report of the Geological Commission* (Cape Town, 1902), p. 39.

the fragments torn from the throats of volcanic pipes have been rounded by attrition, and assume the characteristics of water-worn bowlders. In crush-breccias at Kuysna I have found rounded bowlders of exactly the same shape formed on the very spot from which they have been broken. The accounts of crush-breccias from the Isle of Man and Canada bear out the same view, namely, that rock-fragments can be rounded by simple dry friction. This point is important as the presence of apparently water-worn bowlders in volcanic agglomerates, such as those of the Kimberly diamond pipes, has frequently been adduced as evidence of water-action.

The comparative coolness of these volcanic eruptions is remarkable, and is such that in some cases, where fossiliferous strata contribute to the fragments in the volcanic pipe, the structure of the remains are as fresh as in the parent rock. In Scotland Sir A. Geikie records a vent at Elie Neck in which there are fragments of crinoidal limestone which show no trace of metamorphism, and their crowded organisms are as clearly recognizable as in pieces of limestone from a quarry.[1] In Kimberly the fragments of shale in the blue mass are quite fresh, and blocks containing fossil fish are as unaltered as if they had been procured from their original resting-place.

The temperature, however, was greater in other cases; for instance, Branco records blocks of middle Lias marly clay from the agglomerate in the Schleursbach volcano in Swabia, which have been baked and the included belemnites turned to white marble.[2] In the far south, Phillipi[3] describes blocks of granite entangled in lava on the top of the Saussberg; the ferro-magnesian minerals are melted, and the lava occupies the space they once filled by a sort of pseudomorphism, while the quartz and felspar remain intact. These blocks may have been derived from the surface of the ice-cap which once extended over the Saussberg, but the prolonged heating of the blocks, sufficient to melt

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[1] "Geology of Eastern Fife," *Memoirs of the Geological Survey of Scotland* (Glasgow, 1902), p. 241.

[2] *Swabiens 125 Vulcan-Embryonen* (Stuttgart, 1894), p. 546.

[3] *Veröffentlichungen des Instituts für Meereskunde*, Heft 5, 1903, p. 126.

the hornblende, seems rather to indicate that the blocks came up in the lava from below.

I cannot forbear in this connection from drawing attention to a similar result which was obtained in the earliest experimental work which was carried out on the melting-points of rocks. Sir J. Hall, in heating some blocks of basalt from Arthur's Seat, near Edinburgh, found that at 100° of Wedgwood's pyrometer the whole was changed to a pure black glass, but at 60° the felspar remained unchanged while the hornblende disappeared, and formed a glass along with the basis of the stone.[1]

The further action of heat in volcanoes is shown in the Nightingale rocks, where fragments have been included in the liquid magma and in part remelted. And a still further stage, possibly, is exhibited in the rocks of Tristan d'Acunha, where sphene occurs in great abundance.[2] This mineral, together with perovskite, occurs in certain eruptive rocks, which, as far as I have observed them personally, suggest that sedimentary rocks have been absorbed in the molten magma. Perovskite is an accessory mineral in the melilite basalts of the Karroo volcanic pipes, and also in the mass of melilite basalt which occurs in the faulted Cretaceous rocks of the south coast of the Cape Colony;[3] it can be regarded, in fact, as an alteration product of the ilmenite in the original magma, from being brought into contact with limestone in the zone of intense pressure. The extraordinary abundance of sphene in the Tristan d'Acunha rocks I am inclined to view as the result of the interaction of a rock magma containing titanium acid and a limestone.

The final stage of the temperature gradient is that in which the rock is entirely molten, and the molecules of the various elements left to sort themselves into groups to form minerals without any influence from the inclusion of extraneous solid materials. If we could know the whole history of igneous rocks, perhaps these too might tell us something about the substructure of the earth beneath the volcanic vents, for it is not an entirely untenable theory that

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[1] "Experiments on Whinstone and Lava," *Transactions of the Royal Society* (Edinburgh, 1798).

[2] *Transactions of the South African Philosophical Society*, Vol. XVI, p. 46.

[3] *Annual Report of the Geological Commission*, 1898, p. 62; *ibid.*, 1903, pp. 43–67.

they are derived from the fusion of pre-existing rocks, sedimentary and otherwise, which have been subjected to dynamical stress.

I have spoken hitherto mostly of the large fragments torn off from the throat of the volcano, but the inclusions in the Nightingale rock are more of the nature of fine dust. Such volcanic dust aggregated into beds would be known as a tuff, but it has not been generally recognized till recently that such tuffs may be built up entirely of non-volcanic materials. In the peperino of Italy we have a leucite tuff with many inclusions of non-volcanic rocks, such as limestone, sometimes in large blocks, at others in the form of fine dust. In the cave sandstone of the Drakensberg we have a tuff which is composed entirely of non-volcanic dust, grains of quartz, microcline, plagioclase, tourmaline, epidote, etc., with only an occasional ash-bed. I suspected its origin, when first studying it in Matatiele, from the fact that it was found thickest near the volcanic vents. Its nature, also, showed clearly that it was not an ordinary sediment; for there are beds of this rock 800 feet thick without a trace of stratification. Sometimes there is stratification; either a plane passes slantingly through the mass from top to bottom, or it is curved and twisted as if the whole material had been stirred about in a gigantic pot. The structure of the rock was such that I finally decided that it must have been ejected as a liquid mud exactly like the Italian peperino, and that the constituent grains had been blown from the substratum of granite and Archæan schists by explosions. Von Knebel has described similar tuffs composed of disrupted granite from the Ries in Germany.[1]

In 1845 Ehrenberg described a remarkable tuff from the Island of Ascension containing infusoria, which he called a pyrobiolith.[2] Prestwich surmised that these "diatoms" had lived in subterranean caverns which the explosion had traversed,[3] but the *Challenger Reports* state that the organic remains are the siliceous particles of grasses. It seems probable that this tuff was erupted as a boiling liquid mud, which, traversing a plain covered with grass, tore off by rolling action and incorporated grass fragments in the

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[1] *Zeitschrift der Deutschen Geologischen Gesellschaft*, Vol. LV (1903), pp. 236–95.

[2] *Berichte der Königlichen Akademie der Wissenschaften* (Berlin, 1845), p. 140.

[3] *Proceedings of the Royal Society*, 1886, No. 246, p. 156.

substance of the mud. In view of the presence of granite blocks in the lavas, it is quite possible that some of the tuffs on these volcanic islands will turn out to be of the same nature as the granitic tuffs such as are found in the Drakensberg and the Ries in Germany.

In the Atlantic islands that do not stand on the central ridge continental types of rocks are also found, as, for instance, in the Canary Islands, where gneiss occurs; in the island of Mayo, in the Cape Verde group, Doelter found compact limestones and crystalline schists—traces, he maintains, of an ancient continent.[1]

On the whole, therefore, the evidence of a land connection between Africa and South America, afforded by the islands in mid-ocean, is suggestive, but far too little investigated to be worth much at the present time. The oceanic islands are not favorably situated for lengthened research; yet a very serious lacuna will exist in our knowledge of the geology of the earth as a whole, if they are not systematically studied. The surprising results of Woolnough in the Pacific makes one expect similar results from the Atlantic islands; and then there are the islands in the Indian Ocean, about which we know very little indeed, and the Aleutian Islands in the north Pacific, which are similarly unexplored. I urge, therefore, that these oceanic islands can and do afford evidence of the sub-oceanic crust, and if we are to understand the relation of our present continents to the waters that encompass them, we must not rely solely on the facts as presented to us in the most convenient places, round our homes, but we must put off from our shores and seek knowledge in isolated rock-masses of the ocean.

In the second line of inquiry we can consider the evidence from the American or the African side where the land bridge is supposed to have emerged.

In South Africa in Silurian times we have a remarkable band of sandstone 5,000 feet thick, coarsely false-bedded throughout, stretching from the west coast at a point about midway between the mouth of the Orange River and Cape Town, to Port Elizabeth, and then coming in again at St. John's River, quite similar in constitution, and passing eastward to Natal. This was succeeded by deeper water deposits containing characteristic Ameri-

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[1] *Verhandlungen der K.-K. Geologischen Reichsanstalt* (Wien, 1881), p. 16.

can forms of life, such as *Leptocœlia flabellites*, *Vitulina pustulosa*, *Spirifer orbignyi*, *Ambocœlia umbonata*, *Grammysia chemungensis*, *Bellerophon reissi*, and many others. Following these Bokkeveld Beds come the sandstones of the Witteberg Series (the Cauda-galli grits of North America). And after this the Dwyka conglomerate, a glacial bowlder-clay with a peculiar assortment of inclusions, all of which have been now traced to rocks *in situ* in the north of the Colony and Transvaal. The whole series is plainly indicative of the existence of a land-mass in Palæozoic times whose shores ran through the south of the Transvaal and the north of the Cape Colony. The conglomerates in the Table Mountain sandstone in the west show that the land was near at hand there. But after Silurian times there is no evidence in South Africa that the sediments were derived from the west; they seem all to have been derived, as far as the Cape Colony is concerned, from the north.

Quite otherwise is it in South America. Katzer finds there the most complete evidence for the existence of a land-mass on the east, whence the sediments that now go to form the mainland were derived,[1] and this continent existed up to Tertiary times. The long residence of this author at Para and his wide acquaintance with the literature of South America make his conclusions peculiarly valuable. In Devonian times the existence of the *Leptocœlia flabellites* fauna in South Africa, the Falkland Islands, South and North America, has led many to suppose that the European seas were separated from the waters under which the Devonian sediments were being laid down containing this fauna, by a land bridge; Katzer has called it the Atlantico-Ethiopic Continent,[2] and I, Flabellite Land, after the characteristic fossil *Leptocœlia flabellites*. From a review of the Jurassic faunas Neumayr came to the same conclusion as others have come to, from considering the extension of the Devonian faunas.[3]

Finally, if the bridge lasted as late as the Tertiary period, we must expect the distribution of land animals to have been affected

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[1] *Grundzüge der Geologie des unteren Amazonasgebietes* (Leipzig, 1903), p. 239.

[2] *Bol. d. Mus. Paraense*, Vol. II (1895), plate, p. 237.

[3] *Denkschriften der K.-K. Akademie der Wissenschaften*, Wien, Vol. II (1885), p. 132.

by it, and such we find to be actually the case. The late Dr. Blanford, in his anniversary address to the Geological Society of London in 1890, went thoroughly into the question in regard to the fresh-water fishes and batrachians. In a subsequent letter I received from him he wrote:

> I have long been aware of the extraordinary connection between the faunas of Africa and South America, only a very few examples of which were known when I wrote about ancient continental connections in 1890. For instance, the fresh-water crustaceans have been examined by Dr. Ortman,[1] spiders by Pocock,[2] and several other groups by Dr. Scharff.[3] I have heard of an amphisbæna (belonging to the family of lizards, chiefly confined to Africa and South America) turning up at one of the South Atlantic islands (Trinidad, off the Brazilian coast I think), but I cannot now find the reference.

Boulenger, in his presidential address to the zoölogical section of the British Association at the South African meeting, stated that, although it was possible to get the present distribution of fresh-water fishes without a land-bridge between Africa and South America, yet a connection would immensely simplify the explanation of their dispersal.

There are many naturalists who do not think that the evidence from living forms of life is sufficient to bring into existence in past ages such a tremendous rearrangement of the land-surfaces, but if the geologists from their side can adduce satisfactory reasons for such a submerged land connection, most of their opposition would vanish, for the connection does help to explain matters very considerably. If geologists rely on elaborate arguments to prove their contention, zoölogists are not likely to take the trouble to examine them; and this brings me back to my former statement, that even a little evidence from oceanic islands is of very great weight. A block of slate containing *Leptocœlia flabellites*, found in Tristan d'Acunha or similar Atlantic islands, would prove more by itself than any attempt to reconstruct the direction of sedimentation in past ages, no matter how sound the arguments were. I have shown that such a find is by no means impossible, and I have endeavored to make clear what important issues hang on the proper investigation of oceanic islands.

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[1] *Proceedings of the American Philosophical Society*, Vol. XLI (1902), pp. 267–400.

[2] *Proceedings of the Geological Society*, 1903, Part I, p. 340.

[3] *Proceedings of the Royal Irish Academy*, Vol. XXIV.

SOLIFLUCTION, A COMPONENT OF SUBAËRIAL DENUDATION

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According to the theory of river development, as it has been worked out in its full modern form by a number of eminent American morphologists, the occurrence of narrow *v*-shaped valleys in a region indicates that the region in question has passed only the very first stages of the cycle of erosion. This type of valleys, considered by older European geologists as the most important feature of river-action, is, according to the modern American school, only an immature stage in the development of river valleys.

In the course of time the blocks of land left between the principal valleys will be dissected by secondary streamlets, the valleys will be broadened, and their slopes will get more and more gentle. At last, if the subaërial denudation has time enough to fulfil its work under unaltered conditions, the hills are wholly consumed, the region is base-leveled, and the land once deeply dissected is turned into a slightly undulating plain with broad and shallow, faintly insected river valleys.. Not till then has the process reached the final stage of its cycle, the "peneplain."

This theory of subaërial denudation is based upon the premise that river-erosion works all over the *areas*, and not only *linearly*, as was supposed by an older school of geologists. This assumption looks at first somewhat startling. Evidently the main stream and the principal tributaries of a river form only a branching system of erosive *lines*. Only when the innumerable rivulets and feeders, all the transient small waters washing hillsides and slopes at rainfalls and snow-meltings, are taken into consideration, does the erosive system present a network so close that it can be said to cover all the area.

In its finest embranchments, in the region of the primal feeders, the erosive system is highly supported in its work by the weathering of the rock and by *a slow movement of the waste-sheet down the slopes*

The latter process, generally little estimated, has been clearly sketched by the master of the American "base-leveling" school, W. M. Davis:

> The movement of land-waste is generally so slow that it is not noticed. But when one has learned that many land forms result from this removal of more or less waste, the reality and the importance of the movement are better understood. It is then possible to picture in the imagination a slow wasting and creeping of the waste down the land slopes; not bodily or hastily, but grain by grain, inch by inch; yet so patiently that in the course of ages even mountains may be laid low. . . . . Every change of condition between cold and warm, dry and wet, melted and frozen, that causes a gain or a loss of volume in the rock-waste aids its slow movement down-hill. With countless minute changes every particle is led, slowly but surely, from higher to lower ground.[1]

It seems to me that it is in the removal of the waste, by which the undecayed rock is again exposed to the attack of the weather and the débris is carried to the primal streamlets, that this process, in its more or less rich development, chiefly determines the effectiveness of river-action in peneplaining. Professor Davis supposes that the removal of the waste may continue also underneath a cover of vegetation, and he points out that "the growth and decay of plant roots aid the downward creeping of the waste." But experience has taught us that in regions covered by a rich vegetation the removal of the débris must be very slow, as the unaltered rock is, in most cases, hidden by a deep covering of decayed material. In those lands where the climatic conditions are unfavorable for the removal of the waste the material carried away by river transport must be comparatively scarce and the subaërial denudation only very slow in its advance toward its final end, the peneplain.

But, on the contrary, in regions where the vegetation, because of the hostility of the climate, is all too scarce to fix the detritus, but when the precipitation is still abundant enough to cause effective action by running water, a quick removal of the waste and a plenteous feeding of the streamlets with detritus highly accelerate the subaërial denudation.

During the last few years I have had opportunity of studying,

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[1] Davis, *Physical Geography*, pp. 263, 267.

under high northern and southern latitudes, regions where the removal of the waste is now going on under peculiar conditions, and in another case was working during a bygone climatic depression in a most effective manner almost all over the area of the islands under consideration.

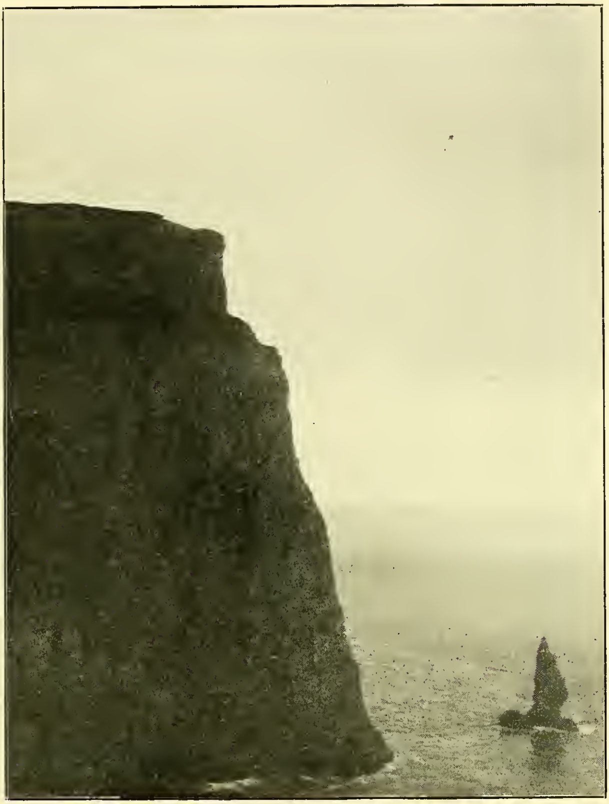

Fig. 1.—Bear Island. Sea cliff, 400 meters in height.

I have thought it possibly useful to publish a short preliminary review of my observations, as they may add to the understanding of an important component of subaërial denudation. The phenomenon I am going to describe is by no means new to science; on the contrary, it has been noticed and clearly described by many skilled observers from different parts of the world, where the conditions are favorable for its development. But it seems to me that there has been a tendency to depreciate its importance as a link in the series of denudative agents, and to look at it as only a curiosity of mere local nature. No one, as far as I know, has collected the scattered material, as I will try to do in the following pages, and probably few have had an opportunity like mine to study the phenomenon in its fullest development.

SOLIFLUCTION IN BEAR ISLAND

This islet situated in 74½° N. L., in the Atlantic part of the Arctic Ocean, is a small remainder of a once larger stretch of land. Sea cliffs, in some places rising to the height of 400 meters and fringing the island almost all around, tell us of the destructive action of the abrasion. The northern and larger part of the island forms a lowland plateau rising very slowly from the recent coastal outline to the interior and cut out through slightly dislocated Devonian and Carboniferous beds. Several reasons, among others the occurrence of old, somewhat obliterated coastal cliffs at the inner margin of this plateau, incline me to consider it as worked out by marine abrasion.

The southern part of the island is mountainous, with tops rising to 460–539 meters. In this region the ground is composed of a great variety of sedimentary rocks from Silurian to Triassic age, and the older strata are cut up by vertical dislocations into a few parallel blocks. In some cases the denudation has laid bare parts of the precipitous surfaces of the faults, but as a rule the land-sculpturing agents show a marked tendency to smooth the tilted blocks to rounded hills and broad river valleys with gentle slopes. Thus the land forms of the interior of the island are in a striking contrast to the perpendicular cliffs on the sea side.

On the hill-slopes and valley sides of Bear Island there are almost everywhere clear indications of a moving of the waste from higher to lower ground. Many of the small hills show a very marked streakiness of surface, which is due to the peculiar arrangement of the detritus; sometimes the flowing soil forms real streams which have much likeness to a glacier in miniature, and often in the depressions between the hills there are numerous small circular or semicircular walls composed of rock fragments and including a patch of muddy material, often hardened through desiccation. Evidently all these phenomena only represent different facies of the displacement of the waste.

It is not very difficult to find out the mode of formation of the "mud-glaciers" mentioned above. When in summer time the melting of the snow has reached an advanced stage, often the bottom of the valleys are free from snow, while big masses still rest in sheltered places on the valley sides. Every warm and sunny day new quantities of water trickle from these melting drifts into the rock-waste at their lower edge. As the masses of detritus are composed not only of coarser rock fragments such as blocks, slabs, and gravel, but also of finer particles filling the interspaces between the coarser material, they are able to absorb considerable quantities of water. When once saturated, they form a semifluid substance that starts moving slowly down-hill. This process, the slow flowing from higher to lower ground of masses of waste saturated with water (this may come from snow-melting or rain), I

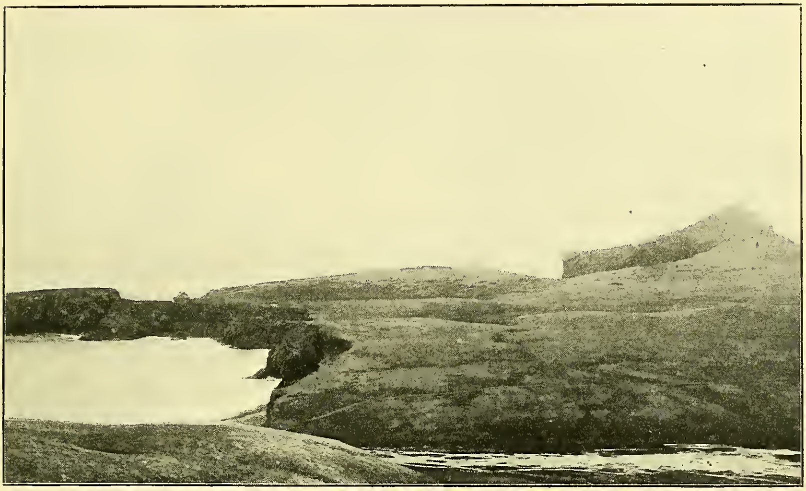

Fig. 2.—Scenery from the southern part of Bear Island, showing the contrast between the rounded land-forms caused by subaërial denudation and the perpendicular coastal cliffs caused by marine abrasion, dissecting the island.

propose to name *solifluction* (derived from *solum*, "soil," and *fluere*, "to flow").

As the snowdrifts of Bear Island diminish in the course of the summer, new ground is exposed, its waste is thawed, and then, saturated with water, it follows the slow downward movement. The flowing detritus does not generally move as a "sheet-flood" with a broad front, but more often flows in some slight depression of the slope, taking the form of a narrow tongue, offering a most striking parallel to a glacier. The névé region is represented by the area of water-saturated detritus at the lower edge of the melting snowdrift, and the flowing tongue of mud is the glacier proper that moves down the valley. The terminal moraine even is often to be seen in the shape of slabs and pieces of rock that the mud-stream has pushed together in front of its lower end.

These mud-streams do not consist of finer particles only, but also of coarse material, gravel and blocks, frequently intermixed with, and also carried on the top of the muddy substance.

Small mud-glaciers of the type just described are very common in Bear Island, and sometimes they reach noticeable dimensions. On the slope of Oswald Hill I measured such a tongue of detritus that had a breadth of 35 meters and a depth (thickness) of at least 2.1 meters. In this case "the terminal moraine" was represented by a zone of sandstone plates, pushed together so that they were all standing edgewise beautifully concentric to the rounded front of the detritus tongue, and this piled-up zone had the rather startling width of 17 meters! This example may give some idea of the considerable quantity of detritus that can be removed in a single stream, as well as of the energy which such a mud-glacier can develop before its movement is arrested.

My companion in the voyage to Bear Island, Dr. G. Swenander, during his botanical researches made an observation that was highly illustrative for a proper understanding of the extent and importance of the solifluction.

Bear Island looks very barren also when compared with more northern Arctic islands, and its sterility is proved not only by the small number of species of higher plants, but also by the complete barrenness of large areas

Swenander gave an explanation of this scantiness of the flora: All the phanerogamic plants of Bear Island—with the exception of a single species—are perennial, and these forms cannot endure upon the flowing soil, where they are easily drowned in the moving mud. The sterility of the areas of solifluction is quite a striking feature of the island. On many slopes small hills of the solid rock crop out of the covering of moving waste, and, though the soil is very scant in the small fissures and crevices of the rock, here the plants grow more willingly than upon the perfidious flowing ground. Thus these small rocky hills form cheerful verdant patches scattered over the barren slopes. In the rare cases when Swenander found single plants growing upon the moving waste, he could demonstrate a remarkable adaptation to this mode of life. The root system of these specimens was exceptionally developed in order to keep the plant afloat on the moving medium. These roots were stretched out in the direction of the movement of the soil, and in some cases where the slope was very steep it was noticed that the proximal part of the root system, carried by the more rapid flowing of the superficial layer of the mud-stream, had reached a *lower* level than the distal branches, which, joining the slower movement of deeper parts of the stream, were left behind in the displacement down-hill. These facts, which I owe to my friend Dr. Swenander, illustrate better than anything else the mode of progress and the importance of solifluction in Bear Island. Evidently, then, this process is a chief agent of the denudation. Every summer large masses of detritus in this way flow down-hill into the bottom of the valleys, where the streamlets undertake the work of transport. It is characteristic for this hitherto undervalued component of subaërial denudation, which I have named "solifluction," that—in contrast to the wind and the running water—it does not lift its material, but like the glacier-ice—with which it has been already compared—it removes blocks and gravel almost as well as the fine mud.

THE STONE-RIVERS OF THE FALKLAND ISLANDS

This island group, situated in 52° S. L. in the South Atlantic, consists of two large and a great number of small islands. The East Falklands, and to some extent also the western large island, present an undulating land surface built up by slightly folded Devonian beds and evidently subjected for a long time to subaërial denudation. With the exception of some resistant quartzite ridges, they, and especially the eastern island, are far advanced toward the peneplain. The land is woodless over large areas, and occupied by peat-bogs, the drier places forming grass steppes and the very driest heaths covered by *Empetrum rubrum.*

This landscape, as bewildering through the monotony of its outlines as deterring through its ugliness, boasts a natural phenomenon that may be unparalleled in the world. The "stone-rivers," which form a beloved object of the fancy of the population, were lucidly described by Charles Darwin, though he could not find a satisfactory explanation; but a later visitor, Sir Wyville Thomson, got very near to a proper understanding of the thing. In order to demonstrate the process in question, I quote the condensed description given by the eminent naturalist of the "Challenger:"

> In the East Island most of the valleys are occupied by pale gray glistening masses, from a few hundred yards to a mile or two in width, which look at a distance much like glaciers descending apparently from the adjacent ridges, and gradually increasing in volume, fed by tributary streams, until they reach the sea. Examined a little more closely, these are found to be vast accumulations of blocks of quartzite, irregular in form, but having a tendency to a rude diamond shape, from two to eight or ten or twenty feet long and perhaps half as much in width, and of a thickness corresponding with that of the quartzite bands in the ridges above. The blocks are angular like the fragments in a breccia, and they rest irregularly one upon the other, supported in all positions by the angles and edges of those beneath.[1]
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> There can be no doubt that the blocks of quartzite in the valleys are derived from the bands of quartzite in the ridges above, for they correspond with them in every respect; the difficulty is to account for their flowing down the valley, for the slope from the ridge to the valley is often not more than six to eight degrees, and the slope of the valley itself only two or three, in either case much too low to cause blocks of that form either to slide or to roll down.
>
> The process appears to be this: The beds of quartzite are of very different hardness; some are soft, passing into a crumbling sandstone; while others are so hard as to yield but little to ordinary weathering. The softer bands are worn away in process of time, and the compact quartzites are left as long projecting ridges along the crests and flanks of the hill ranges. When the process of the disintegration of the softer beds has gone on for some time, the support

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[1] Thomson, *The Atlantic*, p. 245.

> of their adjacent beds is taken away from the denuded quartzites, and they give way in the direction of the joints, and the fragments fall over upon the gentle slopes of the hillside. The vegetation soon covers the fallen fragments, and usually near the sloping outcrops of the hard quartz, a slight inequality only in the surface of the turf indicates that the loose blocks are imbedded beneath it. Once imbedded in the vegetable soil, a number of causes tend to make the whole soil-cap, heavy blocks included, creep down even the least slope. I will only mention one or two of these. There is constant expansion and contraction of the spongy vegetable mass going on, as it is saturated with water or comparatively dry, and while with the expansion the blocks slip infinitesimally down, the subsequent contraction cannot pull them up against their weight; the rain-water trickling down the slope is removing every movable particle from before them; the vegetable matter on which they are immediately resting is undergoing a perpetual process of interstitial decay and removal. In this way the blocks are gradually borne down the slope in the soil-cap and piled in the valley below. The only other question is how the soil is afterwards removed and the blocks left bare. This, I have no doubt, is effected by the stream in the valley altering its course from time to time, and washing away the soil from beneath.[1]

This explanation given by Sir Wyville Thomson, referring the formation of the stone-rivers to the slow removal of the waste down the slopes, must be willingly accepted by everyone who has studied the "stone-runs" in nature. The only objection, and that a very essential one, is against the idea of the phenomenon as a product of present conditions and of the process as still working with full effectiveness underneath the vegetation that now partly covers the stone-rivers. It ought to be noticed that long before I visited the Falkland Islands and studied in detail one of the stone-rivers, James Geikie, knowing these tracts only from the descriptions of Darwin and Thompson, had already expressed the opinion that the stone-runs were comparable to the rubble-drifts of England, or otherwise that they were formed in a bygone period, characterized by a climate more severe than the present.[2]

When I came to the Falkland Islands in 1902, I did not know of the ingenious comparisons made by James Geikie, but with my earlier experience from Bear Island it was easy to go straight to a full understanding of the thing.

Solifluction, in its quite typical form, is still at work in the Falkland Islands, but only on a small scale in favorable localities where

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[1] *Ibid.*, pp. 246–48.

[2] Geikie, *The Great Ice Age*, 3d ed. (London, 1874), pp. 722, 723.

the hillsides are steep, the vegetation scarce, and the trickling water saturates the soil.

On the slope of Stephens Peak, a conical sandstone hill on the south coast of West Falkland, I found a recent mud-stream extending almost from the top of the mountain to its base, with a breadth of 32 meters where it was widest. The fall of the stream was 11–19°. Its material was a kind of stony clay charged with big blocks, the whole having much resemblance to some types of the glacial till. Also on the surface of the stream there lay numerous blocks, the largest having a diameter of 1.5 meters. I removed several of these big blocks to examine their bedding, and I always found them to rest upon the stony mud, never upon a basement of other blocks or solid rock.

In other parts of the same slope I found ancient mud-streams which were bordered by vegetation and evidently fixed at the present time. In some places the fine material was washed away by surface water, only to leave a residuum of sandstone blocks, a copy in miniature of the large stone-runs. Between the latter and the recent mud-streams of Bear Island my observations on the slopes of Stephens Peak gave all the transitional stages.

But although the solifluction is still working in exceptionally favorable places in the Falkland Islands, it seems to me quite evident that the large stone-runs, which are covered with vegetation in all places where the fine material is not washed away, were formed in an earlier period, when the solifluction was working in this region upon a much larger scale than today. Apparently several changes in the level of the land and in the condition of the climate have passed over these wonderful, timeworn giants.

I have studied in detail, and surveyed in the scale of 1:20,000, the big stone-river (possibly the largest in the islands) south from Port Louis, which was originally described by Darwin. In a coming paper I will publish this material *in extenso*, but for the present purpose the following brief remarks may be sufficient.

The open areas and strips consisting only of a chaotic accumulation of large blocks of quartzite evidently have been formed by a secondary washing away of the finer material that once filled all the interspaces between the big blocks or carried parts of them on its surface. As will be demonstrated by my map, the contours of these vegetationless block-fields, with all their embranchments, give the rude outlines of a small river system, and, as has been mentioned already by Darwin and Thompson, in many places the purling of running water is heard far down below under the blocks, indicating the recent course of a stream in the depth of the stone-river.

But the real extent of the ancient *flowing slopes* is much larger than that indicated by the open vegetationless block-fields. In all places where running water has not washed away the fine material the old detritus flows remain in their original composition and offer a soil which is able to carry a covering of vegetation. Where there is a small cut of any kind in such an unaltered part of the slope, it is easy to recognize that the mass underneath the mantle of vegetation is the same as in the waste-streams on Stephens Peak, large blocks imbedded in fine rock detritus.

The large old stone-runs of the Falkland Islands evidently were formed in a period of the past with a climate more severe than the present, with heavy snowfalls in winter, but also with summers characterized by active snow-melting, causing an intensive solifluction which was ever victorious in the fight with the then poor and scattered vegetation. I fancy that in these days the state of the Falkland Islands was very much like that which I have actually studied on the Bear Island of today.

It is very inviting to connect this birthtime of the Falkland stone-rivers with the great climatic depression of a bygone time that has been demonstrated in the adjacent southern lands.

In Tierra del Fuego and the south part of Patagonia Darwin, Agassiz, and O. Nordenskjöld have studied the moraines of an old land-ice extending to the Atlantic Ocean, in South Georgia I have traced a complete glaciation of the island, and in the Antarctic region, in Graham Land, Arctowski, Nordenskjöld, and myself have found full evidence of an earlier, much larger extension of glaciers and land-ice.

To the west, east, and south the Falkland Islands are surrounded by lands deeply furrowed by an old ice age. In our islands, on the contrary, there are no traces of an old ice-sheet, no grooving of the rock-surface, no moraines, and some very characteristic relief forms are directly incompatible with the hypothesis of an earlier ice-action upon the islands.

But, on the other hand, it seems impossible that the great wave of cold, which has set its mark so severely upon the surrounding lands, should have left no traces on the Falkland Islands. Nothing is then more natural than the presumption that the birth of the stone-rivers is a facies of the ice age of the southern lands. In the Falkland Islands the climatic depression was not severe enough to cause a glaciation, but only an intensive frost-weathering and flowing slopes, quite as today in Bear Island we have no glaciers, but only a marked solifluction.

The stone-rivers certainly are the most striking feature of the inland scenery in the Falkland Islands. Never did I feel them more imposing than in a voyage along the southern coast of East Falkland. Then, behind the lowland forming the south part of the island, I saw in the distance the Wickham Heights, the principal watershed, in its full extent. Every transverse valley of the low mountain range was filled by the gray mass of a stone-river extending to or upon the lowland at the mountain's foot. The resemblance to a region crowded by valley glaciers was really amazing.

The unsurpassed grandeur of the Falkland stone-rivers was sufficient to provoke the idea that in this island group the solifluction has been at work on a larger scale than anywhere else on the present earth surface. But I think that this effect of the solifluction, that we meet with in the stone-runs, is rather exceptional, depending upon the petrological character of the rock yielding the material to them.

As already cited, Sir Wyville Thomson has clearly described how the mountain ridges, from which the stone-rivers flow, consist of hard, thick quartzite-bluffs, with intercalations of more soft material. The last-mentioned softer bands are successfully attacked by the weathering and turned into a muddy mass forming the matrix of mud-streams. The quartzite bluffs, thus deprived of their footing, break down in big blocks, and these are carried down-hill by the mud-streams. In the bottom of the valley the fine material is removed by running water, and there is left a very abundant residuum of huge, hard quartzite blocks, almost unattackable by weathering. Such a result of the combination of solifluction and river-action will be reached only with rocks com posed of an alternation of soft and extremely unattackable material. In other cases also the big blocks will gradually succumb to the weathering, the river will be able to clear its course. and new mud-streams will follow those already washed away by the running water.

Also in this respect a comparison with the conditions of Bear Island is highly instructive. In the southern, mountainous part of the island, where I have studied the solifluction in its most varied development, and where the ground is for the larger part composed of rocks (slates, limestone, dolomite), which are through all its mass almost uniformly attackable by weathering, I have found, in the course of the small rivers, no accumulations of big, irregular blocks like those of the stone-rivers. But as soon as one enters the areas of the Ursa sandstone—a rock in parts much like the sandstone of the Falkland Islands, and consisting of alternating hard quartzites and soft intercalations—the aspect of the ground is quite altered. The vast Ursa sandstone area on the flat land in the north of the island is all densely covered over with huge, edged blocks, the whole forming a regular Gehenna for the wanderer—quite as the stone-rivers.

I feel sure that these immense block-fields of Bear Island are formed in quite the same manner as the Falkland stone-runs: by weathering of the rock; by solifluction (though this is very slow and hardly perceptible in the great plain of Bear Island); finally also by the action of running water. The only differences between the two occurrences are differences of topography and of age: in Bear Island a great plain forming a *stone-field*, in the Falkland Islands valleys filled at the bottom by *stone-rivers*—the former a recent, the latter a fossil occurrence.

According to the relation given above, the Falkland Islands are characterized not so much by the extreme intensity of the solifluction in a past time as by an exceptional abundance of the residuum left by the running water that has sifted the material of the old mud-streams. Under other petrological conditions the result of the combination of solifluction and river-action will be, not the formation of stone-rivers, but—if the time of their action has been long enough—the leveling of the land to peneplain.

REGIONAL EXTENSION OF THE SOLIFLUCTION

From Bear Island in the arctic and from the Falkland Islands in the subantarctic regions I have described in the previous pages two occurrences of solifluction—one recent, the other fossil—where in both cases the phenomenon is developed in rather exceptional dimensions. But, if often only in a moderate scale, this mode of waste transport works in many parts of the world. In the geological, geographical, and botanical literature there are to be found many notes on mud-streams and flowing slopes, illustrating the process here in question. In the following pages I have collected, partly with the assistance of helpful friends, some descriptions of of soil-flowing, but the list of them is given without any pretentions to completeness. Surely many a valuable note on processes of this kind has escaped me, and I hope that colleagues in different lands, after having read this article, will kindly call my attention to observations still unknown to me.

South Georgia.—This subantarctic island is a ridge of folded land, deeply indented by transverse fiords between which the mountains rise steeply to 1,000–2,000 meters. Small glacier caps of varied type occupy a large part of the mountains, and in many of the valleys splendid glacier streams extend into the fiords. But the narrow lowland strips and much of the mountain slopes were free from ice-covering, and here frost-weathering, solifluction, and running water are the chief agents of destruction. Slowly moving slopes and small mud-streams were frequently seen, and the forms of the detrital masses offered many a striking parallel to my earlier experiences on Bear Island.

Graham Land.—The ice-covering of the antarctic lands is all too complete to leave any place for solifluction on a large scale; but on the very limited areas where the land was exposed we could trace almost everywhere this mode of transport working in the summer. On the plateau above the winter station on Snow Hill, Nordenskjöld kindly pointed out to me a locality where the land surface showed the same streakiness that I had seen before in Bear Island, beautifully developed, and which was evidently due to displacements of the soil.

North America.—I have had no time for looking into the immense American literature for notes indicating observations on solifluction, and shall be most thankful for any information on this subject relative to that continent where the land forms are so splendidly developed and so admirably surveyed.

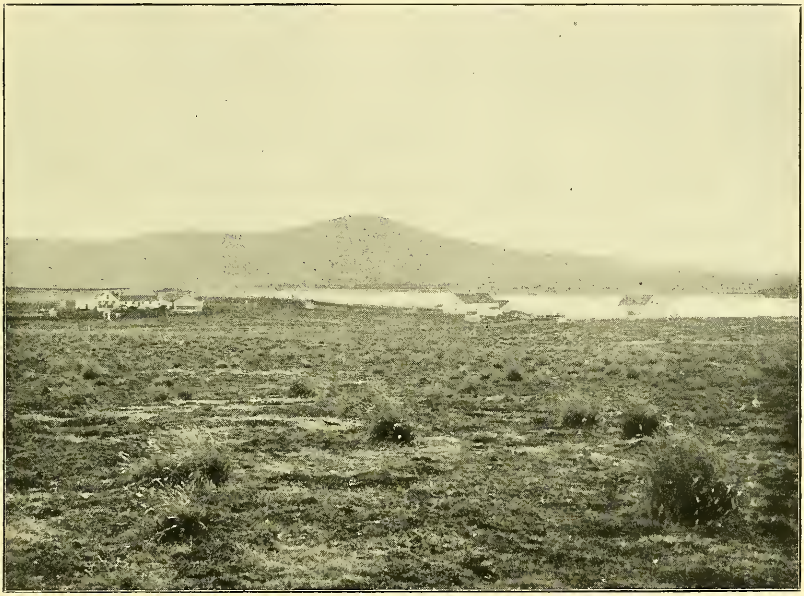

Fig. 3.—Fox Bay, West Falkland. Scenery showing the vast plains and the low, rounded mountains.

The only observation from the United States that I am able to mention here is cited by James Geikie in *The Great Ice Age*, and is taken from Hayden, who has given a very illustrative description of solifluction in some valleys in the Rocky Mountains. These valleys are

> covered thickly with earth, filled with more or less worn rocks of every size, from that of a pea to several feet in diameter. The snow melting upon the crests of the mountains saturates these superficial earths with water, and they slowly move down the gulch much like a glacier.[1]

[1] *Geological and Geographical Survey of Colorado*, 1873, p. 46.

A note on "flowing soils" is also cited by James Geikie[1] from the arctic part of the American continent. The observation was made by Sir Edward Belcher on Buckingham Island in 77° N. L. He ascended a hill 200 feet above the sea to make observations, and found the soil well frozen and firm and covered with a slight crust of snow. But as the power of the sun increased toward noon, the snow disappeared.

> As noon passed the soil in all the hollows or small watercourses became semifluid, and very uncomfortable to walk on or sink into. At the edge of the southern bank the mud could be seen actually flowing, reminding one more of an asphalt bank in a tropical region than our position in 77[1] 10′ N. The entire slope, in consequence of the thaw, had become a fluid moving chute of débris for at least one foot in depth.[2]

Spitzbergen.—During the arctic expedition of 1898, under the command of Professor A. G. Nathorst, when I made my first acquaintance with the solifluction in Bear Island, I also had opportunity to see some phenomena of this kind in Spitzbergen, where they were studied somewhat more in detail in the neighborhood of Hecla Cove, in Treusenberg Bay by my companions G. Andersson, H. Hesselman, and A. Hamberg. The following year, 1899, Dr. Th. Wulff made some observations on the same phenomenon in the first-named place and in Green Harbor in the Ice Fiord.[3]

Recently Professor DeGeer has given a brief account of his researches on moving slopes made during several expeditions to Spitzbergen, partly long before the observations mentioned above.[4] DeGeer has noticed the phenomenon in several localities in the Ice Fiord region, as at the Wahlenberg glacier, at Temple Bay, where the cover of vegetation had got dispersed by a mass of moving soil, and at Cape Thordsen. At the last-mentioned place a small railroad was built many years ago (1872) for mining purposes. Ten years later the railroad could still be used, but in 1896 De Geer found it to be greatly distorted by the effect of the moving soil.

De Geer points out that the waste-sheet generally moves over a bedding of frozen soil, and that also regelation may act in the displacement of the moving masses.

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[1] *Op. cit.*, pp. 387, 388.

[2] *The Last of the Arctic Voyages*, Vol. I, p. 306.

[3] Th. Wulff, *Botanische Beobachtungen aus Spitzbergen* (Lund, 1902), pp. 85, 86.

[4] *Geologiska Föreningen i Stockholm Förhandlingar*, 1904, pp. 465–66.

Scandinavia.—From the mountainous region of Valders in Norway H. Reusch has given a very interesting description of solifluction.[1] To judge from his sketches and verbal testimony, the phenomenon here is very similar to what I have studied in Bear Island, though not so largely developed.

FIG. 4.—Recent mud-stream charged with big blocks. Stephens Peak, West Falkland.

From Sweden a considerable number of notes on solifluction have been published quite recently, after my lectures on the flowing slopes of arctic and sub-antarctic islands had directed the attention of our geologists to the problem.

R. Sernander has given some very important observations from Häijedalen, commenced in 1895 and largely supplemented in the summer of 1904.[2] In the places studied by him, and as a rule in all parts of the mountain regions of Sweden where the process has been noticed, it has given origin only to small narrow terraces, not to far extended mud-streams—a difference possibly indicating

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[1] *Norges Geologiske Undersögelse, Aarbog*, 1900, pp. 75, 76.

[2] *Geol. Fören. i Stockholm Förh.*, 1905, pp. 42 ff.

that the solifluction here works with less intensity than in the tracts studied by me.

Detritus terraces of the type mentioned have been noted by De Geer on the Ovik Mountains in Jämtland, and by Svenonius at Sitasjaure and Vassijaure in Swedish Lappland.[1]

All these observations are made in the high mountain regions, but Professor Högbom has, in a very interesting paper, called attention to the fact that under favorable conditions solifluction can work on a rather large scale also in the woody lowlands of Norrland, and in some rare cases also in more southern parts of Scandinavia. Högbom describes from Lule River how forest trees growing on slowly moving ground are deformed, and he clearly demonstrated that in the fine fluviatile sediments, filling the lower parts of the large river valleys in Norrland, soil-flowing in some places is a very important transporting agent.[2]

Tibet.—In the vast Tibetan highlands Dr. S. Hedin during his last expedition underwent most trying experiences of solifluction. For days and weeks his caravan struggled through a terrible quagmire of water-saturated detritus. Many a time the animals were brought out of the treacherous soil only with the utmost difficulty, and once a camel got lost in such a morass. "The poor beast was literally swallowed up in the mud, and all attempts to get him out failed."[3]

The descriptions by Hedin clearly show that the saturated soil actually moves down-hill, and that the solifluction in those far-extended highlands works on a very large scale, lowering the mountains and filling the valleys:

> I could not help thinking that the whole bunch of hills would, like a viscous fluid or thick porridge, gradually flatten themselves out to a uniform level. This conformation was caused by the incessant precipitation searching into the ground and making it like a sponge; for only a very small quantity trickled into the superficial brooks and rivulets, and so flowed away. The absence of vegetation with its interlacing roots also contributed to the same result. In two or three places *the shales stuck up edgewise* and cut the camel's feet.[4]

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[1] *Geol. Fören. i Stockholm Förh.*, 1904, p. 466.

[2] *Ibid.*, 1905, pp. 19–36.

[3] S. Hedin, *Central Asia and Tibet*, Vol. II, p. 288.

[4] *Ibid.*, Vol. I, p. 519. Italics are mine.

> The slope consisted of a gigantic sheet of mire, of the consistency of porridge, and to judge from the cracks which ran across it and all round it, the entire mass was slipping slowly, though imperceptibly, down the mountain-side.[1]

All the notes collected in the preceding pages deal with regions of *recent* solifluction. But of *fossil* occurrences of the same kind indications are to be found in the literature.

In the southmost part of England, outside the area of maximum glaciation, there is widely distributed a peculiar kind of deposit known by the name of "rubble drift," "head," etc., and consisting "of a more or less coarse agglomeration of angular débris and large blocks set in an earthy matrix."[2] This kind of soil is described from Cornwall and Devon, from the South Downs and from Guernsey, one of the Channel islands. According to the opinion of James Geikie and other English geologists, these beds were formed principally by solifluction as an extra-marginal facies of drift at the time of the maximum glaciation.

A deposit of the same kind is the massive breccia of Gibraltar, described by Sir A. C. Ramsay and James Geikie. It is a rude accumulation of angular fragments of limestone, of all shapes and sizes, imbedded in a calcareous grit and earth. As to its formation Geikie writes: "When the snow melted in summer, the rubbish, becoming saturated, would move forward *en masse*, like the so-called earth-glaciers of the Rocky Mountains, as described by Hayden."[3]

It is remarkable that there are two different horizons of limestone breccias at Gibraltar, indicating two separate epochs of severe climate.

After hearing my description of the Falkland stone-rivers and the explanation of them as a facies of the ice age, Professor Högbom called my attention to occurrences of the same kind in the Ural Mountains.

They are mentioned by Tschernyschew in *Guide des excursions des VII. Congrès géologique international*, Vol. III, pp. 28, 29, when describing the quartzite mountains in the environments of the mines of Bakalsk:

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[1] *Ibid.*, Vol. II, p. 286.

[2] Geikie, *The Great Ice Age*, p. 389.

[3] Geikie, *op. cit.*, pp. 599, 600.

> Leurs versants sont couverts d'énormes éboulis des mêmes grès et quartzites, rendant très possible l'accès du sommet. Les amoncellements de grès d'un blanc de neige et de quartzites qui descendent dans les vallées latérales, offrent un aspect très original; de loin ces trainées, de pierres ressemblent de vrais cours d'eau, tant le caractère de leurs sinuosités rappelle les véritables torrents.

One of these Ural stone-rivers is figured in Ratsel, *Die Erde*, Vol. I, p. 479, this figure showing a complete resemblance to the Falkland stone-runs, only with the exception that the Ural stone-river is bordered, not by a grass steppe, but by pine forest. According to a communication given by Högbom, the region of the Ural stone-rivers lies outside the area of earlier glaciation. Nothing is then more natural than to explain also these formations as an extra-marginal equivalent to the ice-sheet.

To this account of fossil occurrences of solifluction we must add that Sernander in the mountain region of Härjedalen has found evidence of a considerably larger extent of the flowing soil in a bygone past of the postglacial epoch.[1]

The study of the traces of solifluction in earlier times is highly attractive, and of great importance for the understanding of the climate of the past and for the explanation of the chronology of the Quarternary period in extra-glacial regions. But these are problems which lie outside the scope of this article, and which, moreover, I will treat in detail in a paper on the geographical development of the Falkland Islands.

CONCLUSIONS

From the evidence given in the preceding pages it is easy to recognize the climatic features which form the optimum of the solifluction. In the polar and subpolar regions, where the ground is not covered with ice, we find this process working with more or less intensity almost everywhere, and in the same manner, the alpine tracts of lower latitudes are favorable for the development of this phenomenon. In these regions, characterized by a "subglacial" climate with heavy deposits of winter snow melting in summer, solifluction is a chief agent of destruction. The unceasing succession, summer after summer, of mud-streams and

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[1] *Geologiska Föreningens Förhandlingar*, 1905, pp. 42–84.

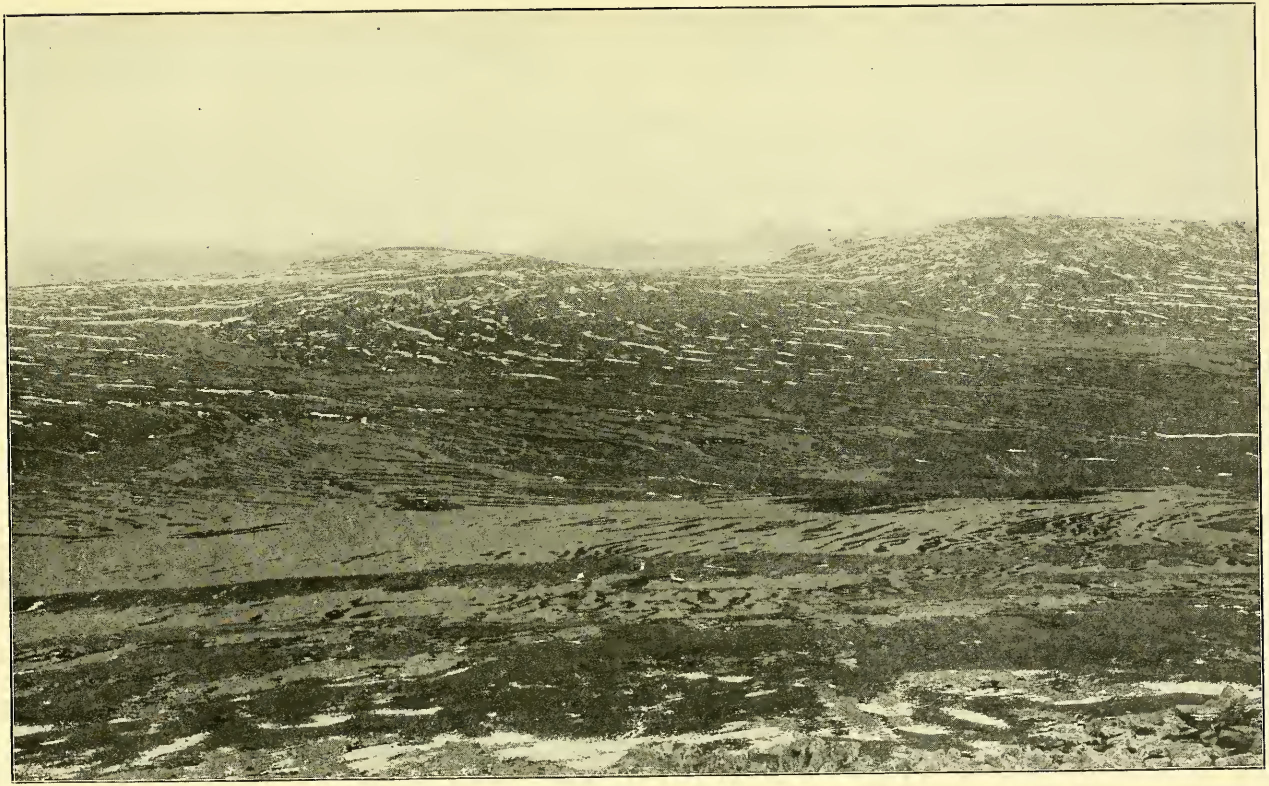

FIG. 5.—Part of the large stone-run south from Port Louis, West Falkland.

The light-gray mass in the bottom of the valley is the open block field, consisting only of a chaotic accumulation of big blocks. The dark narrow strips are covered by a vegetation of *Empetrum rubrum*. In these strips, as well as in the areas (dark gray on the photograph) covered by grass vegetation, fine material still fills the interspaces between the big blocks. The maintenance of unaltered strips in the largely washed block-field must be due to the original arrangement of the once slowly moving masses. Thus these strips of *Empetrum* and grass give clear indications of the direction of the movement in the old flowing slopes. From small transverse valleys in the background minute stone-runs descend into the principal valley, and here a real network of open block areas and grass patches gives to the eye in the distance a most wonderful imagination of a semi-fluid mass investing the valley. The photograph being taken in winter, the mountain hills are partly snow-covered.

moving slopes indicates that here the removal of the waste runs on at a rate that may be unsurpassed in other parts of the earth's surface—except in the deserts.

But this effective removal of the waste must be balanced on the one hand by a rapid production of new waste, and on the other, by an effective clearing out of valley bottoms by running water. The "subglacial" climate is most favorable for both these processes. In the extra-glacial regions the frost-weathering works with an intensity well known to every student of polar lands and alpine mountains, and the violent summer floods caused by the melting of the winter's snow give to the rivers of these regions an erosive power that is quite surprising.

When all these conditions are taken into consideration, the "subglacial" climate must be looked on as an optimum of destructive action. In fact, the high mountains, the large folded ranges, where all the agents mentioned work in high intensity, are found to be short-lived features in the earth's surface. In fact, one might be tempted to raise the question whether complete peneplanation is possible in regions where the action of running water is not supported by an effective removal of the waste, such as is produced by solifluction. With this premise, every peneplain found a climatic token of the same kind as the stone-rivers of the Falkland Islands and the limestone breccias of Gibraltar. Still I think that such a presumption hides a dangerous exaggeration. It is very possible that in many cases, under other climatic conditions of less erosive power, the process has had time to reach, though at a very slow rate, the end of the cycle of erosion.

But, on the other hand, it seems certain that solifluction has often been an important agent toward peneplanation. The importance of the process, because of its humbleness, has been much undervalued. But I feel sure that it is not until we get a knowledge of all the contributive agents that we can reach a full understanding of all the varied and complicated forms of land-sculpture.

LOCAL GLACIATION IN THE CATSKILL MOUNTAINS

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The Catskills, next to the Adirondacks, are the highest mountains in New York state. Several peaks rise well above 4,000 feet, while the great majority of the mountains in the central part of the area have an elevation exceeding 3,000 feet. Such an elevation naturally produces greater precipitation and a climate considerably colder than that of the surrounding country, as the following extracts from the report of the New York Weather Bureau plainly show. Five stations have been selected for comparison: Griffin's Corners, in the heart of the Catskills; Oneonta, in the foothills to the north; Albany, Binghamton, and Ithaca. Mean temperature for the years 1901–4: Griffin's Corners, 42.8°; Oneonta, 45.6°; Albany, 47.5°; Binghamton, 45.9°; Ithaca, 46.0°. Normal annual precipitation: Catskills, 40″–50″; Binghamton, 35″–40″; Albany, 35″–40″; Ithaca, 30″–35″. Winter conditions prevail there two or three weeks earlier, and persist two or three weeks longer, than in the lower parts of the state. This comparatively cool climate is an important factor, which must be taken into account in a study of the former glaciation of the region.

Comparatively little detailed work has been done on the glacial geology of the Catskills. Studies of a reconnaissance nature have, however, disclosed evidences that, in the higher mountains local glaciers persisted after the withdrawal of the continental ice-sheet. Such a condition is known to have prevailed to a greater or less extent in the Adirondacks, the White and Green Mountains, and the Katadn region of Maine. In New England, especially during the earlier study of glacial geology, considerable attention was given to the question of local mountain glaciation. A brief outline of the results of this work is given in the following section.

PREVIOUS ANNOUNCEMENT OF VALLEY GLACIERS

As early as 1856 Edward Hitchcock[1] described striæ and moraines showing a movement of ice down valleys in a direction different from

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[1] *Smithsonian Contributions*, Vol. IX (1856), Art. III, pp. 135–44.

that of the principal ice-movement. Later C. H. Hitchcock,[1] Packard,[2] and Vose[3] brought forward further evidence of the same nature. Dana,[4] in view of the results of his study in the Connecticut valley, attributes most of these so-called evidences of local glaciation to the work of valley tongues from the margin of a waning ice-sheet. In a later paper[5] he suggests the probability of local glaciers having remained in the White Mountains after the ice-sheet had withdrawn. Agassiz,[6] having found a terminal moraine containing bowlders transported *northward* from their parent ledges on Mount Washington, was the first to show definitely that glaciers had moved out from the White Mountains in a direction opposite to that of the general ice-movement. C. H. Hitchcock[7] has repeatedly called attention to evidences of valley glaciation among the mountains of New England, and in his later papers[8] suggests that ice from the higher mountains, in the form of a local ice-cap, pushed outward in every direction, reaching as far north as Canada. Tarr[9] has shown that local valley glaciers existed on Mount Katadn, Maine, and suggests that further study of that region is likely to show that valley glaciers descended from several of the mountains in the vicinity. Upham[10] believes that "at the close of the glacial period, the Adirondacks, the Green and White Mountains, with probably the greater part of Maine, continued ice-covered after the glacial blockade was melted through along the Hudson, Champlain, and St.

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[1] *Proceedings of the American Association for the Advancement of Science*, Vol. XIII (1859), pp. 329–35.

[2] *American Journal of Science*, Vol. XLIII (1867), p. 42; *American Naturalist*, Vol. I (1868), pp. 260–69.

[3] *American Naturalist*, Vol. II (1868), pp. 281–91.

[4] *American Journal of Science*, Series 3, Vol. II (1871), pp. 233–43.

[5] *Ibid.*, Vol. V (1874), pp. 198–211.

[6] *Proceedings of the American Association for the Advancement of Science*, Vol. X (1870), pp. 161–69.

[7] *Geology of New Hampshire*, Vol. I (1874), pp. 539–44; *ibid.*, Vol. III (1878), pp. 181–340; *Proceedings of the American Association for the Advancement of Science*, Vol. XXIV, Part II (1875), pp. 92–96; *Report of the Vermont State Geologist*, 1903–4, pp. 67–85.

[8] *Journal of Geology*, Vol. IV (1896), p. 60; *Bulletin of the Geological Society of America*, Vol. VII (1896), pp. 3, 4.

[9] *Bulletin of the Geological Society of America*, Vol. XI (1900), pp. 433–48.

[10] *American Geologist*, Vol. XXI (1898), pp. 169, 170, 380; *American Journal of Science*, Series 3, Vol. XLIX (1895), pp. 1–18; *Twenty-third Annual Report of the Geological Survey of Minnesota*, 1894.

Lawrence valleys." He has shown[1] that the moraine described by Agassiz, to which reference has already been made, is a part of a morainic belt encircling the White Mountains, and was formed at the margin of the local ice-cap which once covered them. At a later stage small local glaciers persisted in the mountain valleys.

FIG. 1.—View of a lake and its inclosing moraine built by a local glacier which descended from one of the higher ranges of the Catskills. This photograph was taken from the steep mountain valley down which the ice moved. In the foreground is a hummocky deposit representing later stands of the ice.

In the Adirondacks, Cushing[2] mentions evidence of the existence of valley glaciers either during or shortly after the retreat of the ice. Tarr, to whom I am indebted for references and helpful suggestions in the preparation of this paper, informs me that the Ausable lakes show evidences of having been formed by deposits from valley glaciers.

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[1] *American Geologist*, Vol. XXXIII (1904), pp. 7–14.

[2] *Sixteenth Annual Report of the State Geologist*, New York (1896), p. 8; *New York State Museum Bulletin*, 95, 1905, p. 437.

Chamberlin[1] suggests that, in the Catskills, some of the minor moraines scattered through the mountain valleys may be due to independent local glaciers. Of this region Smock[2] writes:

> The valleys are essentially of erosive origin, obscured, however, now by glacial débris in many places. In some of them, as that of the Batavia Kill at Windham, the Stony Clove, and Woodland valley, there are very plainly marked moraines indicating the existence and retreat of local glaciers. The larger valleys of the Schoharie Kill, the East branch of the Delaware, and the Esopus Creek, also have their moraines, though not so well defined. Subsequent to the retreat of the great mass of the continental glacier these valleys were no doubt occupied by detached glaciers.

The above summary shows that the former existence of local glaciers in the mountains of New England and New York has been recognized, in some places as certain, in others as very probable. It is the purpose of this paper to describe a definite instance of local glaciation in the Catskills.

Location and topography.—The region covered by this paper lies in the northern part of the Catskills, roughly speaking at the junction of Schoharie, Greene, and Delaware Counties, and includes a part of each.[3] The Schoharie Creek, flowing northward, is the principal stream. It occupies a rather narrow, deep valley whose floor at Gilboa has an elevation of 1,000 feet, and at Prattsville, four miles south, 1,100 feet. South of Prattsville the mountains rise directly up from the valley to elevations varying from 3,000 to 4,000 feet, while north of that village is a dissected plateau with a general elevation of about 2,000 feet. All the mountains south of Prattsville, and the higher portions of the plateau to the north, are made up of Oneonta-Catskill red and gray sandstones and red shales, which give to the soil a very characteristic red color, easily distinguished from the bluish or yellow color of the northern drift.

About three miles west of Prattsville, at the head of Fly Brook, a tributary to the Schoharie is a large U-shaped amphitheater in the mountains, with the open side toward the northeast, and with a breadth of about two miles from crest to crest of its inclosing rim. On the south and southwest portions of the rim are the two highest peaks—Round-

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[1] *U. S. Geological Survey, Third Annual Report*, p. 373.

[2] *American Journal of Science*, Series 3, Vol. XXV (1883), pp. 346–50.

[3] Gilboa sheet, U. S. Geological Survey.

top Mountain, 3,448 feet, and Bloomberg Mountain, 3,360 feet. Three spurs from the mountain divide the amphitheater into four minor basins. It is within this amphitheater that the evidence of valley glaciers may be seen.

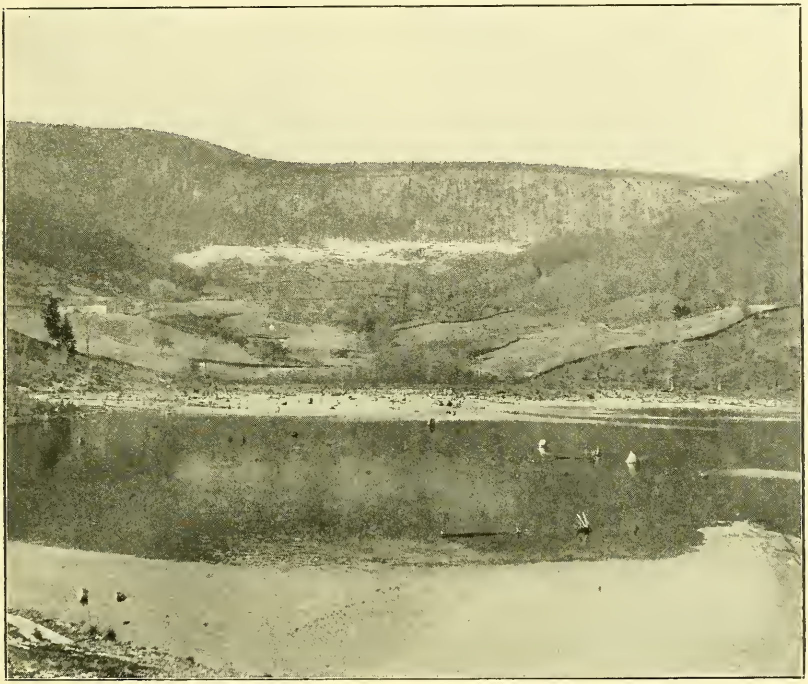

FIG. 2.—Looking up the valley from the terminal moraine. In the center is the hummocky moraine formed by the retreating glacier. One distinct loop may be seen in the middle of the valley. On the extreme right the lateral continuation of the terminal loop is shown running diagonally up the hillside.

VALLEY GLACIERS

In the central and largest of the four basins there lies a small lake[1] held up by a morainic loop which swings in a crescent across the valley, then diagonally up the hill slope on either side. (Fig. 1), taken from the mountain a little below the snow, shown in Fig. 2, shows the lake and moraine as they appear from the mountain side down which the ice moved. It also clearly shows the hummocky surface in the fore-

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[1] The lake has been enlarged by a dam across its narrow outlet.

ground, and on the left the moraine loop curving diagonally up the hillside.

The moraine, which forms an irregular ridge at least 60 feet high in places, has a rather abrupt slope on the down-stream side, and from its terminus a somewhat gravelly deposit, evidently of outwash origin, stretches away down-stream. Above the lake, for a distance of half a mile, is a thick, hummocky morainic deposit showing one or two fairly distinct ice-stands. This feature is shown in Fig. 2, taken from the terminal loop looking up the valley down which the ice came. On the extreme right of this picture the lateral continuation of the loop is shown running diagonally up the hillside (see also Fig. 1). Figs. 3 and 4 are nearer views of the lake and moraine seen from opposite sides of the lake.

FIG. 3.—A nearer view of the terminal loop. Its semicircular form is well shown.

The evidences of extinct valley glaciers in this amphitheater are not confined to the one basin just described. East of it are two basins each of which had its glaciers. The first of these has a morainic loop just as perfect, though not so large, as the one which holds the lake. It shows even better the lateral moraines on each side running diagonally down the hill and joining in the terminal loop. Within this moraine, and concentric with it is another smaller, though very distinct, loop. Between these moraines and the mountain, the bottom of the basin is moraine-filled like that of the larger valley already described.

FIG. 4.—A view along the moraine front from the point where the loop joins the hillside. Above this point the lateral moraine continues for nearly half a mile up the hillside. Below, it swings in a beautiful crescent across the valley.

The second basin is less pronounced than the first, and contains, consequently, a less conspicuous, though perfectly distinct, moraine.

Between the terminal moraine and the mountain is a hummocky topography resembling that in the other basins.

The remaining basin, lying west of the lake, I did not examine closely. It is thickly wooded, and may or may not contain local moraines.

These morainic accumulations are composed almost exclusively of local material. In the course of a half-day spent in tramping over them, during all of which time a constant lookout for foreign rock fragments was maintained, I found only one stone, a small piece of gneiss, of other than local origin. This strictly local nature of the morainic débris, taken in connection with the fact that all the terminal loops are convex down-stream and all have distinct lateral moraines leading down to them from the hillsides, shows conclusively that for an explanation we must look to local valley glaciers, and not to the continental ice-sheet, or tongues from it, pushing up toward the mountain from the north.

The valley of Fly Brook, all the way from the lake to its junction, with the Schoharie Creek, a distance of three miles, suggests strongly the idea that it was once occupied for its entire length by a valley glacier. One and one-half miles below the lake, and about 20 rods below the schoolhouse, are exposures of rock by the roadside showing striæ running in a northeast and southwest direction parallel with the axis of the valley. Patches of moraine along the valley sides, the U-shape of the valley bottom, and a peculiar morainic deposit where Fly Brook joins the Schoharie, all suggest a valley glacier.

PROBABLE EXTENDED LOCAL GLACIATION

There is some evidence that south of Gilboa the Schoharie valley and its tributaries were for a long time occupied by ice moving northward and outward from the higher Catskills. The reconnaissance nature of my visit to this region did not permit me to gather evidence enough to fully substantiate this hypothesis, but there are many facts which strongly suggest it. The following show the nature of the evidence: (1) The local nature and red color of the moraines are very conspicuous. At Gilboa, in the Schoharie valley, is a deep morainic accumulation of distinctly northern drift, containing numerous pebbles and bowlders of limestone and crystallines, and having a decided yellowish color entirely characteristic of the northern drift, and very different from the red of the local rocks. Overlying this is a thick deposit of lake clay of the same yellowish color. At Devasego Falls, three miles farther south in the same valley, is a moraine of an entirely different character. It is convex down-stream; it consists largely of local, red débris, and is overlain by several feet of *red* lake clay. South of Devasego Falls, in the Schoharie and its tributaries, the moraines are composed very largely of this local red material. (2) Moraines across the Schoharie valley and its tributaries are, apparently in every case, convex down-stream. This is especially well shown at Devasego Falls, along the Manor Kill west of Conesville, and along the Batavia Kill between Prattsville and Ashland. (3) There are lateral moraines leading into these loops in a direction indicating ice-movement, out from the mountains.

SUMMARY

The elevation and consequent low temperature of the Catskills would enable them to support glaciers while the surrounding lower lands were entirely deserted by the ice. In one valley at least, local glaciers *did* exist for a period of time long enough for the building of a morainic loop 60 feet high in places. Evidences in the Schoharie valley point toward quite an extensive movement outward and northward from the mountains.

TERTIARY AND RECENT GLACIATION OF AN ICELANDIC VALLEY

HENRY G. FERGUSON

During the summer of 1905 I had the opportunity of accompanying Dr. Helgi Pjetursson, the well-known Icelandic geologist, on his trip through the west and north of Iceland. Our primary purpose was the study of the sedimentary beds included between the lava flows of the Tertiary basalt plateau of the island. Dr. Pjetursson has made some remarkable discoveries concerning these sedimentary beds, the most interesting of which is the finding of glacial deposits—apparently indurated ground moraines—between the older lava flows. Dr. Pjetursson has already described these formations,[1] but as they are little known to American geologists, I propose to describe one of the areas where these beds are best developed, the Botnsdalr valley at the head of the Hvalfjord, about 30 miles northeast of Reykjavik.

The basalts forming the walls of the valley dip eastward at an angle from 5° to 10°, this eastward dip being constant for the whole western part of the island, except occasionally near the west coast, where the boundary faults of the island cause a westerly dip. These tilted basalts are called "regional" by Dr. Pjetursson, as being common to northern Scotland, the Orkneys, the Shetlands, the Faroes, Iceland, and western Greenland; in distinction from the "insular" basaltic lavas, peculiar to Iceland. These "regional" basalts are roughly divided into a lower or black group, which contains the "Surturbrandur" lignite and ash deposits, with Miocene plant remains; and the gray group, which, like the gray group of Ben More[1] in the Mull plateau, is the upper group in the Icelandic plateau. The latter is equally deformed, but is separated from the black by an erosional unconformity. The basalts of the Botnsdalr region seem to belong high up in the black group.

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[1] Helgi Pjetursson, "Om nogle glaciale og interglaciale Vulkaner paa Island," *Det kgl. Danske Videnskabernes Selskabs Forhandlinger*, No. 4, 1904.

Except for this erosional unconformity, there is no evidence, such as any large unconformity or discordance of dip, to indicate any marked

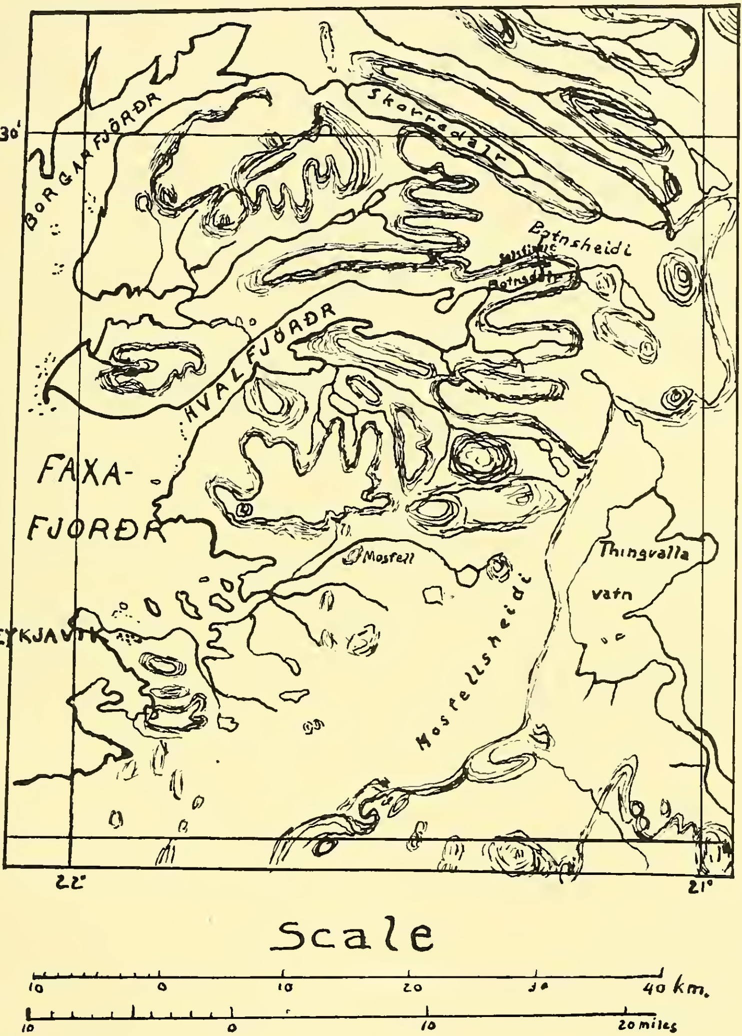

FIG. 1.—Hvalfjord and vicinity. From Thoroddsen's Map of Iceland, 1900.

pause in the volcanic activity which built up the plateau. After the building of the plateau, and before the later glacial periods, came the movements which tilted these older basalts, forming a synclinal trough across the center of the island, where the most active of the present volcanoes are now found. This seems to have been accompanied by a certain amount of subsidence, and the present top of the plateau is in reality an old peneplain surface, the truncated edges of the tilted lava flows reaching about the same level. In regions where the dip is steeper than in the Botnsdalr, this gives a very noticeable serrate appearance to the sky-line. Whether this peneplain is tilted through later movements cannot be ascertained until better topographic maps are available, but the surface is much broken by later faulting. During this period came the extensive faulting, which greatly reduced the size of the island, and later the erosion of the fiords, these in part due themselves to faults. After the island had assumed roughly its present shape came the flat-lying lavas noted on Thoroddsen's map as "Doleritic lava (pre-glacial and glacial)," and several glacial periods. The time required for the peneplanation of the plateau, its uplift, and the present erosion seems to furnish additional evidence that the regional basalts are Tertiary in age.

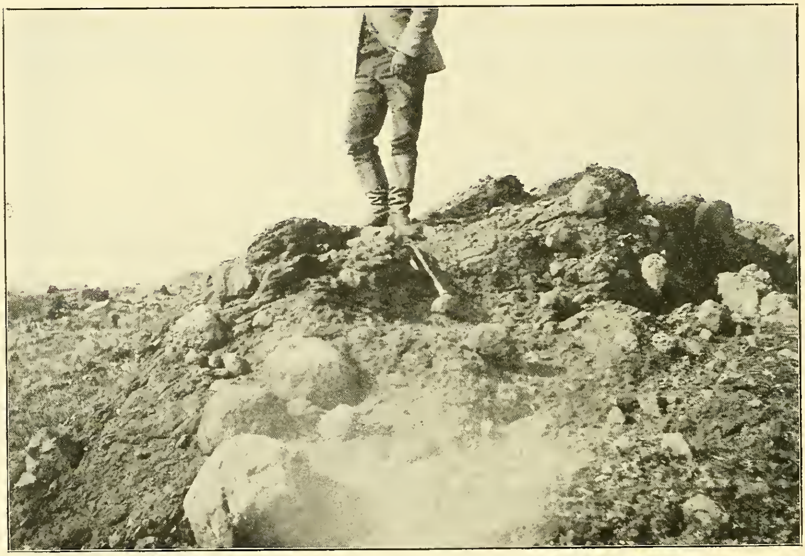

Fig. 2.—Indurated moraine on the south shore of the Hvalfjord.

[1] A. Geikie, *Ancient Volcanoes of Great Britain*, Vol. II, p. 215.

The Botnsdalr is a glacial valley, a continuation of the northern branch of the Hvalfjord, one of the east-west fiords of the Faxafjord. It is some 10 miles in length, east-north-easterly in direction, has a gentle grade from sea-level, and a width of a mile at its mouth, widening somewhat up-stream. The cliffs where the indurated ground-moraines occur rise very precipitously to a maximum elevation of some 1,200 feet, the lower 300 or 400 feet being largely masked by talus. As it was impossible to climb the cliff on the southern side of the valley, the section here described is on the northern cliff, known as the Selsfjall.

The indurated moraines[1] contain subangular pebbles and bowlders of all sizes up to 2 or 3 feet in diameter, which often show distinct striations. The cementing matrix is fine and sandy, all the grains showing some abrasion, differing in this from the

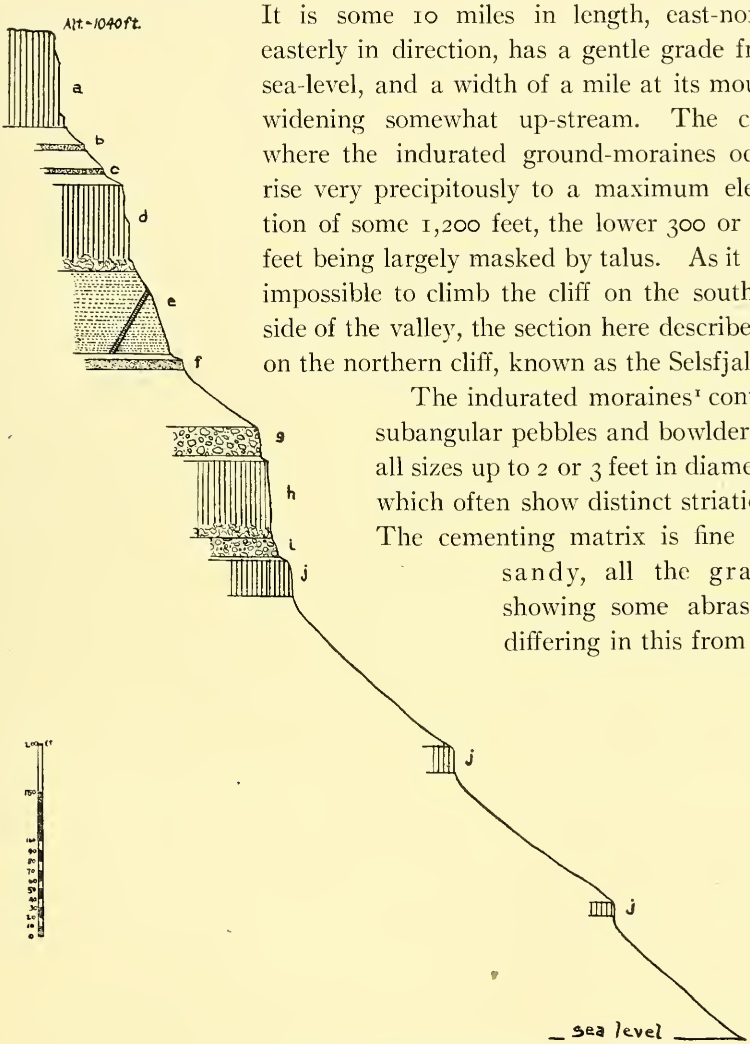

FIG. 3.—Main section on the Selsfjall.

a, basalt, several flows; *b*, flat-lying tuffaceous sandstone; *c*, third moraine; *d*, basalt, several flows; *e*, ripple-marked sandstone, cut by basalt dike; *f*, contorted tufaceous sandstone; *g*, second moraine; *h*, basalt, several flows; *i*, first moraine; *j*, basalt.

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[1] For a description of Quaternary indurated moraines in southern Iceland, see H. Pjetursson, "The Glacial Palagonite Formation of Iceland," *Scottish Geographical Magazine*, Vol. XVI (1900), No. 5.

volcanic agglomerates and breccias, which contain small angular bits of black glass or "palagonite." The material is absolutely unstratified, thus differing from the "jökullhlaup" sediments described below, which show more or less distinct bedding. Dr. von Knebel,[1] however, describes indurated "jökullhlaup" sediments of the southern part of Iceland in terms which would be equally applicable to the beds I here describe as moraines.

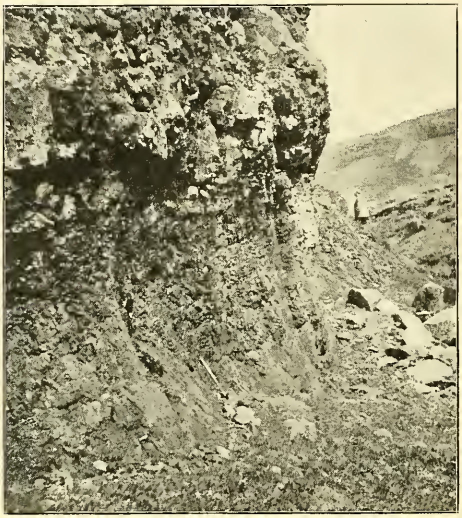

FIG. 4.—Lower moraine and overlying basalt.

The basalt flows, averaging about 25 feet in thickness, are almost invariably brecciated near the lower surface, strikingly columnar in the center, and vesicular near the top. Where immediately covered by another flow, the upper surface is ropy.

The section on the Selsfjall is best explained by the accompanying illustrations. In the main section (Fig. 3) it will be seen that there are three morainal beds, usually covered by sandstone, instead of being directly overlain by basalt.

The lower ground-moraine is about 20 feet thick, and has no overlying sandstone. In consequence of being directly overlain by the basalt, the upper 3 or 4 feet of the bed are so thoroughly baked that the pebbles break off even with the matrix.

The second moraine, at the point shown in the section, is almost hidden by the talus. A few feet above the moraine is a small outcrop of a much contorted tufaceous sandstone. This contortion

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[1] Dr. Walther von Knebel, "Vorläufige Mitteilung über die Lagerungsverhältnisse glazialer Bildungen auf Island etc.," *Centralblatt für Mineralogie Geologie und Paläontologie,* Jahrgang 1905, No. 17–18, p. 539. See also, H. Pjetursson, "Das Pleistocän Islands," *Centralblatt für Mineralogie, Geologie und Paläontologie,* Jahrgang 1905, No. 24.

seems inexplicable, except through the action of an advancing glacier, thus showing, with the earlier advance supplied by the ground moraine below it, a twofold advance and retreat of the ice during the period represented by this sedimentary series.

Above the contorted tufaceous sandstone is almost 100 feet of flat-lying ripple-marked sandstone, alternating between layers of fine clay and sandstone, the latter often spotted with pebbles of vesicular basalt. The clay layers were generally about an inch in thickness, while the sandy layers were often a foot thick and seemed to represent the annual flood of the stream. The ripple marks, by the steeper slope of the ripple ridges, showed a southwesterly direction of flow. In one place the sandstone was cut by a basalt dike which probably served as a feeder to some of the upper lava flows.

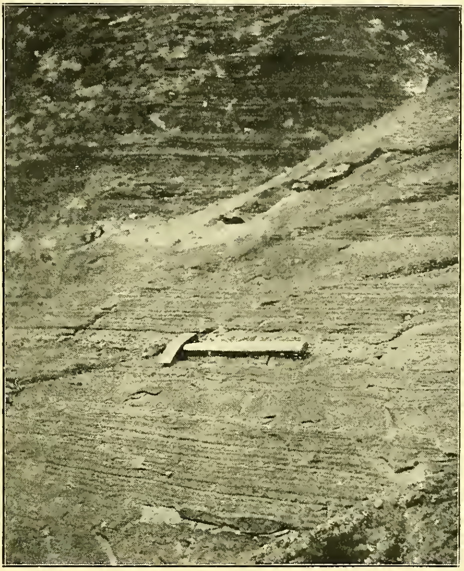

FIG. 5.—Ripple-marked sandstone above the second moraine.

The third moraine in this section did not exhibit any marked peculiarity. Like the second, it was overlain by tufaceous sandstone, in this case nearly flat-lying and not ripple-marked.

About 5 miles down the valley, to the westward from the main section, there is a good exposure of what is probably the second moraine of the first series. Here the overlying contorted sandstone is entirely lacking, and the sandstone above the moraine is more evenly bedded, shows no ripple marks, and is much more conglomeratic, containing several subangular bowlders, which at first sight gives it the appearance of morainal material.

Higher up on the cliff the third moraine is well exposed in a small gorge, and consists of about 10 feet of indurated moraine, containing some well-striated pebbles. It rests on basalt which has a polished surface, but is not distinctly striated. It is overlain by 20 feet of fine sandstone, which, in turn, is covered by extremely brecciated basalt.

Near this point at the top of the cliff, at an altitude of about 1,200 feet, remnants of a fourth indurated ground-moraine were found. A deep gorge prevented close examination of this bed, which differs slightly from the others. It rests directly on the truncated columns of a basalt flow, and seems to have sections of these same columns caught up in it, and but slightly rounded. The bowlders are larger than in any of the other ground-moraines, several being 3 feet in diameter. Where seen, it was not overlain by basalt; hence it is not necessarily Tertiary in age.

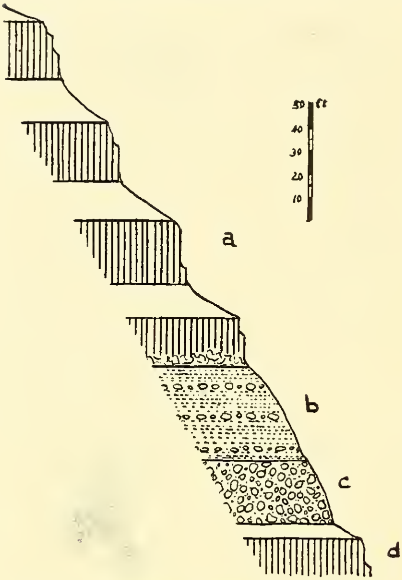

FIG. 6.—Second moraine, five miles to the west of main section

a, basalt, several flows; *b*, flat-lying sandstone and conglomerate; *c*, moraine; *d*, basalt.

Another, somewhat similar section appears on the face of the Botnselvens Klöft, a deep gorge entering the eastern end of the Botnsdalr on the northern side. The section is shown in Figure 8. It is impossible to attempt any definite correlation, but unless the beds have been disturbed by faulting, of which there is abundant evidence in the Skorradalr, a neighboring valley, the moraines here shown should correspond approximately to the third moraine of Fig. 3. The stratified material above the upper moraine appears to be overlain by basalt farther to the eastward. The two moraines have extremely uneven upper surfaces, as if there had been great irregularity in their upper surfaces as deposited, or as if they had undergone considerable erosion between the time of the retreat of the ice-sheet and the deposition of the sandstone and conglomerate above them. The upper surface of the basalt flow between the two moraines is distinctly striated adjacent to the moraine, the scratches often running under the moraine itself.

On the southern side of the valley one of the higher moraines is nearly horizontal, with the gently tilted basalt flows resting against it, as if the moraine had originally been deposited on a sloping surface and had been subsequently buried by overlapping lava flows. Later tilting has given the position shown in Fig. 9.

There are certain points of similarity in these different Tertiary morainal beds which are worth noting:

The indurated moraines are weaker members of the cliffs than are the basalts, and hence tend to form shelves and have their lower contacts, the critical points of such beds, covered by talus. Whenever the contact is visible, as in the two points mentioned above, and in several other localities in the vicinity of the Hvalfjord, it is smoothed or striated.

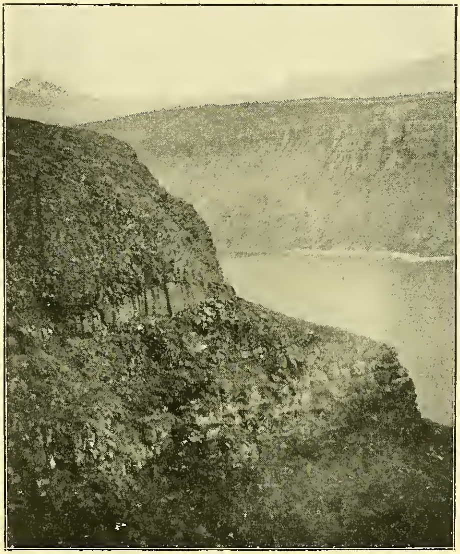

Fig. 7.—Sandstone above the second moraine.

In nearly every case the moraine is overlain by bedded material, as if from deposits laid down by glacial streams during a retreat of the ice-sheet. No delta beds, so common in our glacio-fluvatile deposits, were seen, but perhaps these might be found if the sedimentary beds of the basalt plateau were studied in greater detail.

The lower surfaces of the basalt flows lying above the sandstone seem much more brecciated than those which rest on other basalt flows. This brecciation may have been caused by explosions due to the presence of standing water when the lava was fluid.

The inconstant nature of the moraines and sandstones is very noticeable; the beds change greatly in size in a very short distance, and it is at present impossible to make any definite correlation between the sections.

The later glacial history of the Botnsdalr is illustrated by the following facts:

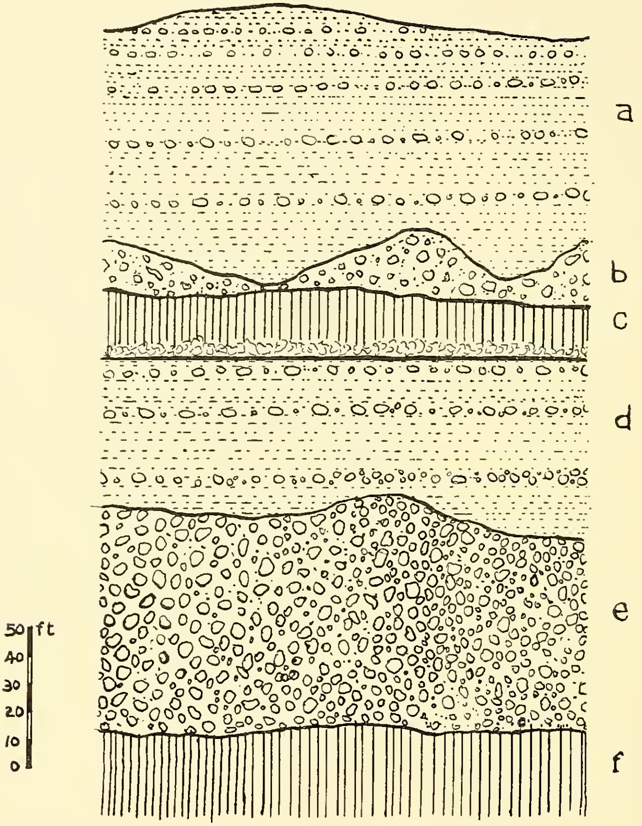

Fig. 8.—Section in Bothselvens Klöft.

a, sandstone and conglomerate; *b*, thin moraines; *c*, glaciated basalt, single flow; *d*, sandstone and conglomerate; *e*, large moraine; *f*, basalt.

In the eastern part of the valley, at a point where the cliffs are less prominent and the valley opens out considerably, is a glaciated hill, somewhat in the form of a *roche moutonnée,* composed chiefly of tuffs, breccias, and a little lava, indicating by their radial dips the ruins of a volcano, younger than the valley. These tuffs, bomb-breccias and lavas were capped by a few feet of indurated moraine, evidently inter-volcanic, as if it was even more thoroughly lithified than the indurated moraines in the Tertiary basalts. The pebbles were of vesicular basalt and, owing to their slaggy nature, did not show as good striations as the Tertiary moraines described above. The pebbles were all subangular, however, and a number showed striations.

A narrow gorge through this volcanic remnant showed an interesting section. The northern side was composed chiefly of tuff, volcanic breccias, and bomb-breccias, and thin lava flows, overlain by the indurated ground-moraine. These deposits rested on the older "regional" basalt, which showed distinct glacial striations, one rather faint set trending S. 15° W., the same direction as on the Botnsheidi, the plateau above the valley, showing the existence of an ice-sheet radiating outward from the center of the island; and the other more distinct trending S. 60° W., showing the action of a glacier following the present direction of the valley. The southern side of this hill has suffered most from recent glacial erosion, and here the indurated moraine seems to have been eroded off. Small pieces of a similar indurated moraine are found in the later terminal moraines at the mouth of the valley. The sedimentary beds, however, are different from those seen on the northern side of the hill. These are in part deposits, which Dr. Pjetursson believes to be due to a "jökullhlaup," literally "glacier-run," a flood caused by the sudden melting of vast quantities of ice, by a subglacial volcanic eruption. This material consists of very roughly stratified sandstone and conglomerate, of rapidly changing texture, varying from a hard clay, which, however, often contains subangular bowlders, to a coarse conglomerate. Often these beds show a faint and rather irregular cross-bedding. Large "scour and fill" unconformities are common, showing frequent changes in the stream-courses. At the point

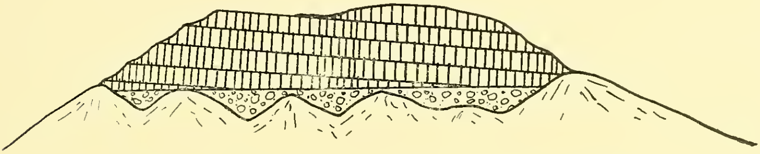

FIG. 9.—Contact of tilted basalts and upper moraine.

shown in Fig. 10 a stream-bed has been filled with an angular unstratified volcanic breccia. These sediments rest on glaciated "regional" basalt which shows the same double set of striations as before.

Later glaciation of the valley is shown by recent polishing of rock-ledges, the striations running parallel to the direction of the valley, and by three well-marked frontal moraines. The westermost of these, at an altitude of about 150 feet, forms a barrier across the valley, except where cut through by the present stream; the other two are merely remnants on the sides of the valley. At the northern end of the valley is a large delta, perhaps 150 feet above sea-level, somewhat over a mile in length, which marks the head of a body of water formed after the retreat of the last valley glacier. If this were a fresh-water lake, it is remarkable that its level remained constant long enough to allow such a large delta to be built, if the outlet stream was at a grade to enable it to do any effective down-cutting on the morainal barrier. The possible explanations seem to be either that, at the time of the formation of the delta, the sea stood at, or nearly at, the height of the top of the moraine, and that the gradual uplifting of the land allowed the stream to cut through the morainal dam and so drain the lake, or that the fiord itself formerly extended to the delta, and that the moraine was deposited in its shallow waters. These inferences are rendered more probable by the presence of old beaches and shell-beds at many places along the whole coast of Iceland, at elevations of from 50 to 300 feet above the present sea-level.

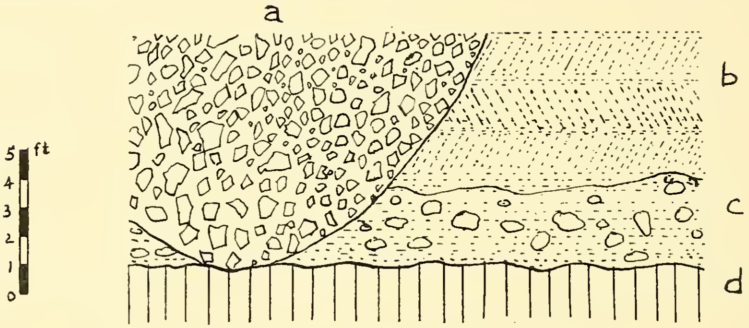

FIG. 10.—"Jökullhlaup" sediments and volcanic breccia.
a, volcanic breccia; *b*, roughly cross-bedded sandstone; *c*, conglomeratic sandstone; *d*, glaciated basalt.

To sum up the glacial history of the valley; it is evident that, during the formation of the Tertiary basaltic plateau, there were several advances of a glacier. This glaciation was probably local rather than continental, as the indurated ground-moraines are not a common feature of the plateau. After the break-up of the plateau—and the isolation of Iceland—by faulting—the evidence goes to show that the region was again glaciated by an ice-cap, moving radially outward from the center of the island. This is suggested by the directions of ice-movement, given by professor Thoroddsen in his geological map of Iceland,[1] and by the direction of striæ on the Botnsheidi and the faint striæ of S. 15° W. direction found on the basalt under the pleistocene volcano. The ice-cap gradually retreated and became broken up, the remnant, sending down glacier tongues which eroded out the valleys, as is the case today with the Vatna, Myrdals, Eyafjalla, Lang, Dranga, and other great ice-fields of the island. During the period of valley glaciation, and after the excavation of the valley, a small volcano, possibly contemporaneous with Mosfell, a pleistocene volcano, 20 miles to the southeast, broke out under the ice, causing sudden floods, which have left their characteristic deposits. The glacier, however, recovered what was lost by this melting, as is shown by the indurated moraine above the glacial volcano, and in one of its recent stages advanced to the shores of the Hvalfjord and there deposited its best-marked terminal moraine. On the last retreat of the ice, this moraine probably formed a dam holding back the waters of a glacial lake. The sea, being nearly at the top of the moraine, prevented the drainage of the lake, until the uplifting of the land allowed the stream to cut through the morainal barrier; or else the sea-water of the fiord itself followed the ice on its retreat and the delta was deposited at the head of a former extension of the Hvalfjord.

[1] See also Th. Thoroddsen "Explorations in Iceland during the Years 1891–98," *Geographical Journal*, Vol. XIII (1899), No. 5, p. 493.

A PECULIAR FORMATION OF SHORE ICE

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On January 27 of the current year the writer noticed that the ice along the Milwaukee shore of Lake Michigan from Lake Park to the city pumping-station, a distance of nearly a mile, was formed almost entirely of large snowballs such as are formed by children rolling the damp snow until it grows into a ball by accretion. The phenomenon was so peculiar that it led to a more careful study, and as the author has found no report of a similar condition, it seems worth while reporting.

The beach where the peculiar formation occurred is not wide, varying from only 3 or 4 feet to as much as 50 or 60; on the landward side it terminates at the bottom of an 80-foot bluff of glacial material, composed of the unstratified bowlder clay at the bottom and stratified sands and clays above, culminating in the "red lake clay" characteristic of the Wisconsin shore of Lake Michigan. Beyond the edge of the beach the water is very shallow for a considerable distance out, so that in time of even moderate waves bowlders of 3 and 4 feet in diameter appear in the trough of the waves 100 and more feet from shore. This bench has been formed by the waves cutting into the cliff and distributing the material on the adjacent bottom. During ordinary winters this shallow water freezes to the bottom very early, so that the ice-foot is far out beyond the usual water-line. The exceptionally mild winter of 1905–6 did not permit the water to freeze far out, so that at the end of January there was only a very narrow zone of shore ice, extending out not over 50–100 feet.

At the time of the author's visit the condition was somewhat as follows: There had been several very mild days with decided thawing, and the beach presented the appearance of a compact mass of balls of semi-solid ice, which upon investigation turned out to be masses of snow crystals which, by thawing and freezing and by additions from the water of the lake, had grown to the diameter of a millimeter or two. The mass of ice had been broken along several parallel lines and displaced, showing a thickness of 3–4 feet; and this showed that the beach ice was a mass of the snowballs cemented by snow and frozen spray. The beach at this point runs slightly west of south, and the snowballs on the surface had been forced into prominence by the melting away of the softer cementing snow between them; moreover, about one-third of each ball was melted away on the south side. The southern faces which had suffered by melting presented a most peculiar appearance, which led to the recognition of the true nature of the balls. As shown in the figures, the melting had caused the contained dirt to accumulate on the surface, and it appeared as concentric rings. Close examination showed that this dirt was true beach sand and gravel. All the balls, varying in size from 3 inches to 3 or 4 feet, showed the same concentric arrangement, but in some the layers were alternately snow and clearer ice rather than snow and sand.

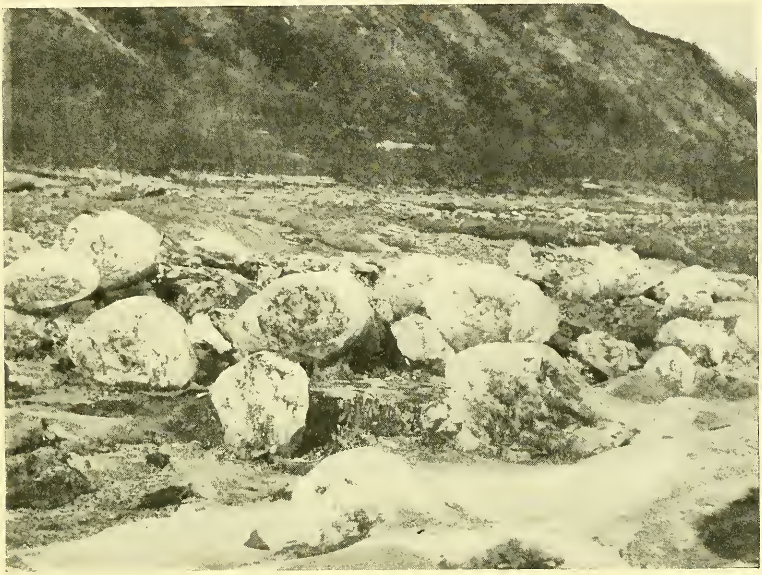

FIG. 1.—A group of large snowballs showing concentric arrangement of layers of dirt and snow.

There seems but one explanation of this very queer phenomenon: the balls were rolled by the waves. The beach is a flat, smooth sand beach, and the water is very shallow for a considerable distance out. It seems that in some snowstorm early in the winter, before any ice-foot had formed, the beach must have been covered with 2 or 3 inches of a snow (the layers of the snowballs are from an inch to an inch and a half in their present compacted condition), in a very damp and soggy state, perhaps filling the water adjacent to the shore with a heavy slush. The water must have been very close to the freezing-point, so that there was little or no melting of the snow as it came in contact with the water. Now, a rise of the wind would produce a surge which, moving up the beach and back, started the snow in motion, and as the snow was water-soaked, and too heavy to float with any buoyancy, it was pushed back and forth until it was compressed into a small mass which began to roll. There is no distinct nucleus to the balls either of harder snow or of small pieces of ice, as might be expected, but the center

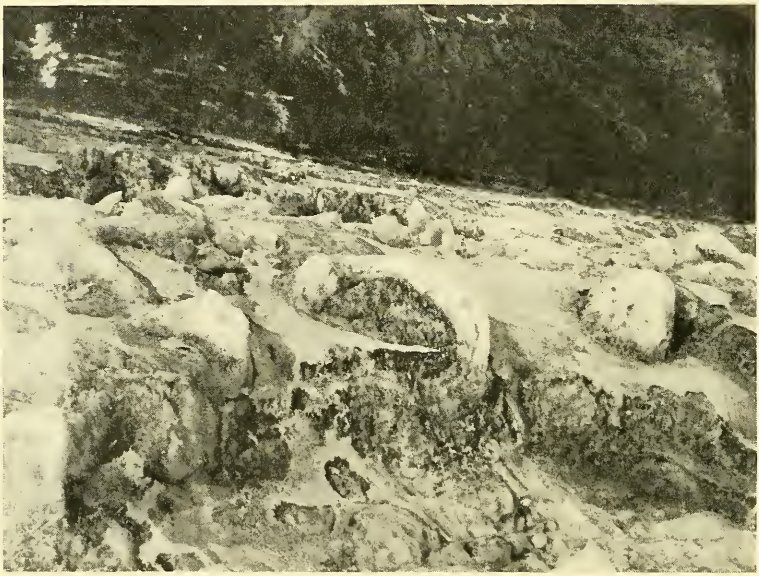

FIG. 2—A large snowball about 3 feet in diameter, half melted and showing concentric structure.

seems the same as the outer parts. As the balls grew in size, it is evident that they rolled on the solid beach, gathering up a layer equal to the thickness of the snow on the beach, and including a thin layer of the sand and small gravel in the bottom of the layer.

The scarcity of the phenomenon seems amply accounted for by the peculiar conditions necessary for its production. There must be wide, flat beach such that the surge of the waves can carry them forward and back for a considerable distance; the water must be reduced to the freezing-point without the formation of an ice-foot which would hold the waves off the beach; and there must be a mass of soft, damp snow ready for the action of the waves.

RED MOUNTAIN, ARIZONA: A DISSECTED VOLCANIC CONE

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University of Chicago

The location and form.—On the peripheral portion of the San Francisco Mountains, and about 30 miles northwest of the village of Flagstaff, Ariz., there is a small tuff cone, locally known by the somewhat appropriate name of Red Mountain. This cone bears the name of Mesa Butte on the San Francisco Mountain sheet of the topographic atlas. It rises between 700 and 800 feet above the general level of the plateau on which it stands, and at the summit is at least 7,750 feet above sea-level (Fig. 1).

When approached from the southeast or northwest, Red Mountain presents an even, dome-shaped form, such as is common to many of the cinder cones of the region, and if seen from either of these directions it would not attract special attention. On the southwest side a valley has developed, and the material taken from the mountain has been spread out at the base as an alluvial fan. On the northeast side there is a unique exposure, where the mountain has been so cut open that its internal structure is beautifully shown. From a distance (Fig. 2) few details of the exposure can be made out, but a number of layers appear which are roughly concentric and approximately parallel to the profile of the mountain. At closer range (Fig. 3) the concentric layers come out more strongly and they are seen to decline, not only to the right and left, but also toward the observer.

The material.—The material of Red Mountain consists of volcanic dust, cinders, lapilli, small crystals and fragments of crystals, a few bombs, many angular blocks, some agglomerate, and a bed of lava which is in part scoriaceous and in part compact. By far the greater amount of the material consists of the smaller products of volcanic eruption. About the base of the mountain, and high on the slopes, there are large quantities of black cinders and lapilli. They were a relatively late contribution to the cone, and are unconsolidated. Within the mountain the fragmental material is cemented into a typical volcanic tuff. When seen from a distance, the color of the tuff resembles that of the red beds, but at close range it is seen to be a combination of yellows and browns.

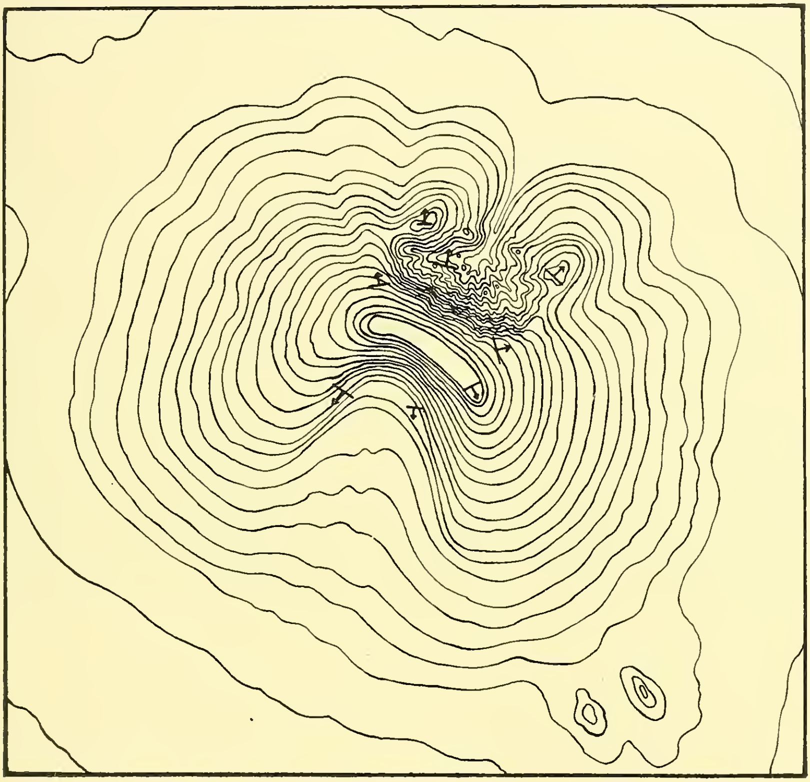

FIG. 1.—A topographic sketch of Red Mountain, Arizona, with the directions of dip and strike plotted at several points.

The angular blocks, which range up to 4 feet in diameter, are composed of a dark-red porphyritic andesite. The phenocrysts are labradorite feldspars, pyroxenes, hornblendes, and magnetites. The lava flow and agglomerate are exposed only on the southwest side of the mountain, about 100 feet below the summit. The largest out-crop shows a zone, 10 feet thick, of compact lava in which there is a distinct flow-structure, between scoriaceous zones. The scoriaceous zone at the base is at least 5 feet thick, and that at the top is about 10 feet thick. At another exposure, 6 feet of compact lava overlie a scoriaceous zone 10 feet thick. Imbedded in the scoriaceous zone, at the base, there are huge blocks of compact lava. Both the scoriaceous and compact portions are porphyritic. The exposures of agglomerate are near the layer of lava, and associated with the surface of the flow.

Small crystals and fragments of crystals are exceedingly common in the tuff. Probably there is not a square foot on the surface of the tuff, as now exposed, where crystals could not be found. The chief minerals represented are plagioclase feldspars, pyroxenes, and hornblendes. The plagioclases have characteristic striations, they are clear and glassy, and range up to an inch in diameter. The pyroxenes and hornblendes are commonly jet-black, and vary in size up to three-fourths of an inch. The crystals are a part of the fragmental material ejected by the volcano, and were therefore formed in the magma before eruption. The formation of these crystals, as well as those in the angular blocks and in the lava flow, caused an increase in the gaseous pressure in the magma, and according to the suggestion of Chamberlin and Salisbury, may have been an important factor in causing the explosions.[1]

The gases occluded in the andesite and in the pyroxene crystals have been determined by R. T. Chamberlin. One volume of the rock gave 6.37 volumes of gas of the following composition:

H_2S	0.01
CO_2	80.38
CO	9.02
CH_4	4.72
H_2	1.84
N_2	4.00
	99.97

One volume of the crystals gave 1.11 volumes of gas of the following composition:

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[1] Chamberlin and Salisbury, *Text-book on Geology,* Vol. I, p. 618.

H_2S	8.90
CO_2	62.62
CO	14.46
CH_4	1.30
H_2	7.01
N_2	5.71
	100.00

The structure.—The San Francisco Mountains and associated cones rest on the Colorado plateau, where Carboniferous limestones appear at the surface. According to Dutton, the plateau was not reduced to the Carboniferous horizon until late in Miocene times.[2] The writer has reported evidence of Pleistocene glaciation in the main crater of the San Francisco Mountain,[3] and it is fair to assume that volcanic activities had ceased in the entire region by that time. The geologic age of these mountains is therefore probably late Tertiary. The cone under consideration appears to rest, in part at least, upon a lava flow that issued from the main crater or from

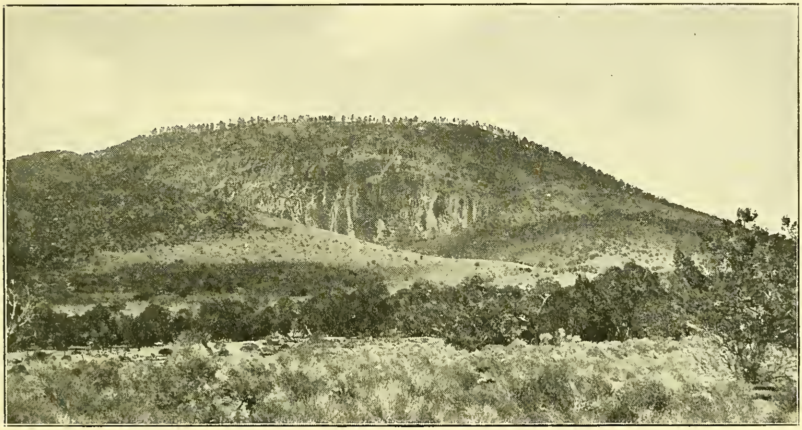

FIG. 2.—General view of Red Mountain from the northeast.

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[2] Dutton, *Tertiary History of the Grand Canyon District*, Monograph II, U. S. Geological Survey, p. 221.

[3] "Glaciation of San Francisco Mountain, Arizona," *Journal of Geology*, Vol. XIII (1905), p. 276.

some fissure associated with the center of activities. This relationship indicates that Red Mountain was developed during the later, rather than during the earlier, phases of vulcanism in the region.

The general position of the layers of tuff has been referred to, and the directions of the strike and dip have been plotted at several points on the topographic sketch (Fig 1). The layers near the base, and as near the center of the mountain as it is possible to get, decline 4°. They are, probably, some of the ealiest deposits made about this vent. As the fragmental material accumulated, it formed steeper and steeper slopes about the rim of the crater, and today the exposures show an increasing dip from the base to the summit, passing gradually through angles of 5°, 10°, 15°, up to 20°. The major divisions in the tuff appear, from a distance, to be from 15 to 20 feet thick. On closer examination subdivisions may be recognized down to an average thickness of from one to two inches. Within a layer or bed of tuff there is no noticeable assortment of material.

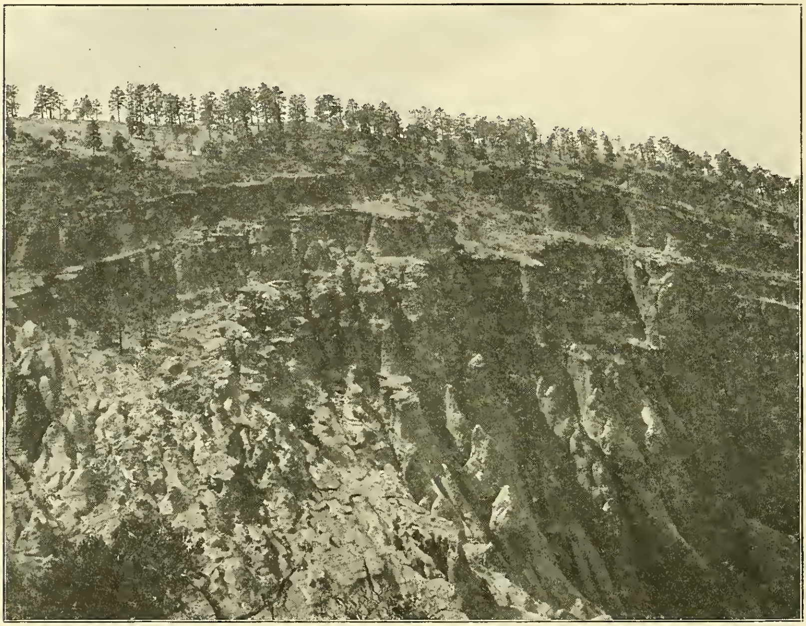

FIG. 3.—Northeast side of Red Mountain, showing structure.

Each explosion added a thin coating of fragments that were intimately intermingled in the air before falling to the mountain slopes.

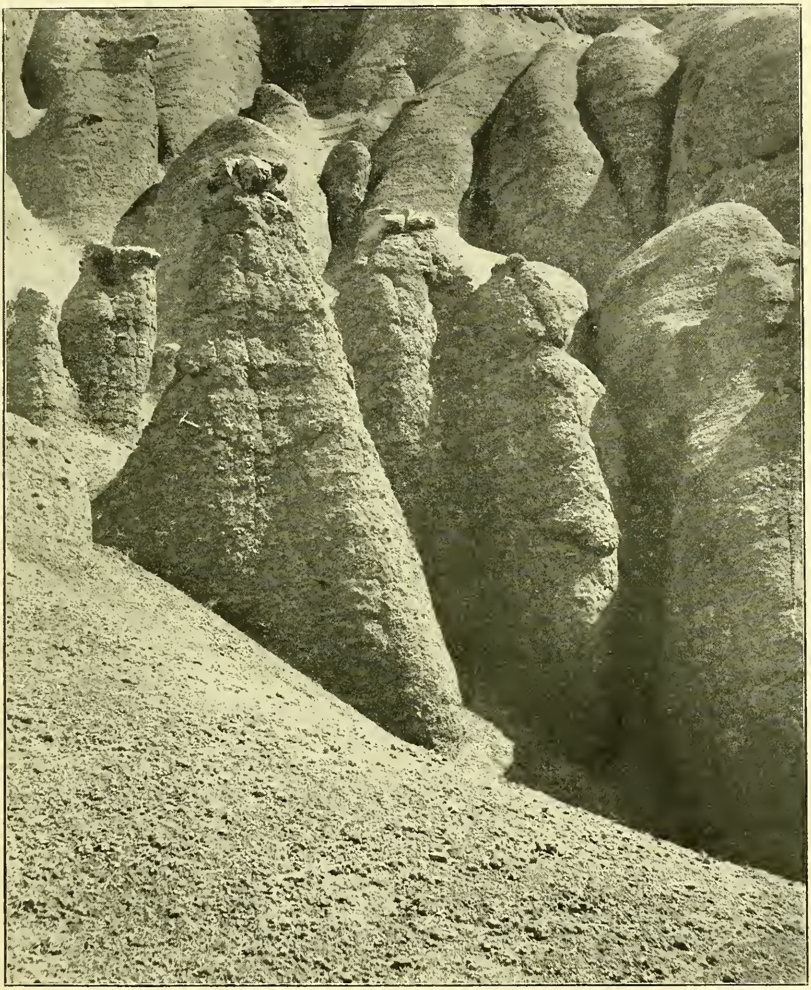

Fig. 4.—Close range view in Red Mountain, showing pillars of volcanic tuff capped by angular blocks of lava.

At very close range (Fig. 4) the surface of the tuff appears rough and the bedding is indistinct. Certain explosions contributed large quantities of angular blocks which now characterize different horizons. In general, the contributions of angular blocks were greater during the later than during the earlier eruptions. At times true volcanic bombs were thrown out, which indicate that molten lava must have risen well up into the crater.

The lava which issued near the close of the period of growth overflowed to the southwest and descended but part way down the slope.

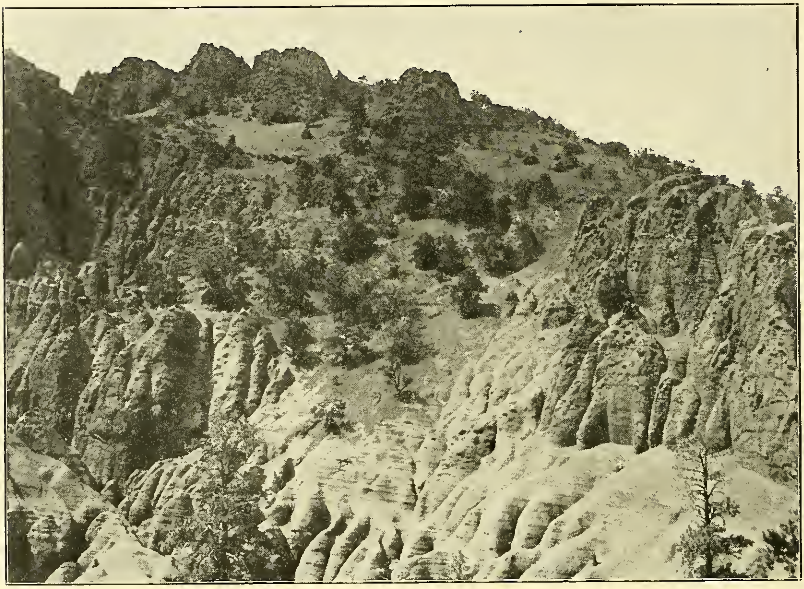

FIG. 5.—Looking west in Red Mountain. The layers of tuff come out clearly near the base, but are obscured on the upper portions of the slope by the general pitted condition of the surface. The pits are where great masses of lava have been weathered out.

The southwest portion of the crater rim was presumably lower most of the time, for the prevailing winds from that direction must have carried a large proportion of the ejected material to the northeast side.

The erosion.—Rain and running water have removed all traces of the crater, and the present summit is but a narrow crescentic ridge dividing the waters which operate on the southwest and northeast slopes. The erosion on the southwest side has been referred to with sufficient detail. On the northeast the mountain may be entered through a narrow gorge. This gorge is not commonly occupied by a stream, but its form is such as to indicate that it was made by running water. Within the gateway the excavation in the mountain broadens out into an open amphitheatral form, and serves as an immense funnel concentrating the waters which fall on that side of the mountain.

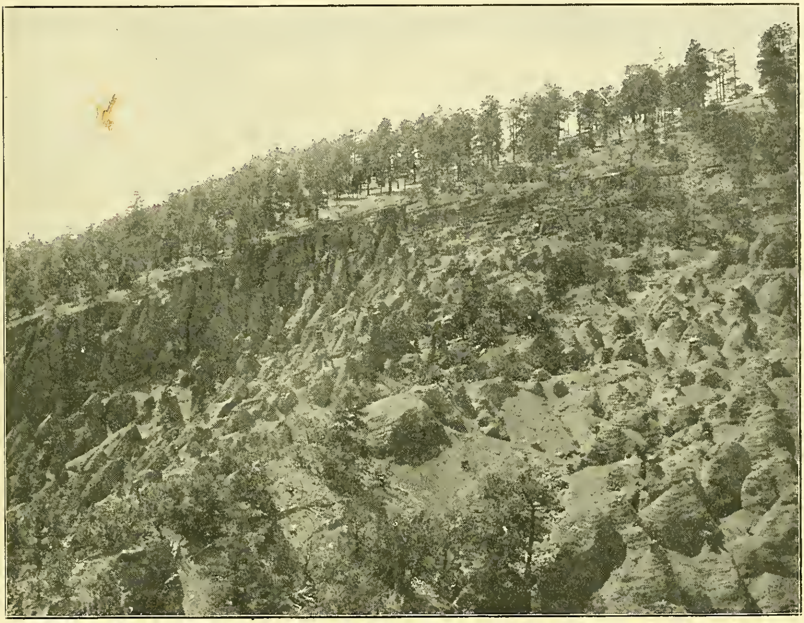

FIG. 6.—Looking east in Red Mountain, showing numerous pillars and mounds which have resulted chiefly from rain erosion.

The erosion-forms in the amphitheater resemble those common to bad lands. There are narrow winding passageways which end as box canyons; on projecting spurs there are sharp pinnacle-like forms capped with angular lava blocks; the walls are decorated with strangely irregular forms, and marked by great pits where large masses of lava have been weathered out. To the west (Fig. 5), the layers come out clearly near the base, but higher on the slopes they are indistinct. To the east there are numerous pillars and mounds in various stages of development (Figs. 4 and 6). Some of the pillars are just being separated from the main mass of the mountain. Others have become isolated and stand 5–15 feet above their surroundings. Some appear to have recently lost their capstones and stand as unprotected spires. Others have long since lost the protection offered by the blocks that caused their development, and are now reduced to mounds. In portions of this area these mounds resemble an irregular grouping of old-fashioned bee-hives. The work of erosion goes on very slowly now, but may be assumed to have been more rapid during the moist climate of Pleistocene times.

A summary.—Based on the above data the history of Red Mountain may be sketched as follows: Late in the Tertiary period a secondary volcanic vent opened on the outskirts of the San Francisco Mountain center. A series of explosions occurred, building up a cone of fragmental material to a height of several hundred feet. The first material ejected fell on a relatively flat surface. As the cone grew in size, the fragmental material rested at higher and higher angles. Lavas rose into the crater, and volcanic bombs were formed. The winds carried much of the loose material to the northeast, building that portion of the crater rim highest. Late in the growth of the mountain a small amount of lava issued from the crater and flowed part way down to the southwest slope. Eruptions continued until the mountain rose about 1,000 feet above the plateau level. Based on the number of layers in the tuff, a conservative estimate of the number of explosions necessary to have built the cone is between 4,000 and 5,000. This estimate does not allow for any height above the present summit, and is therefore probably far below the correct figure.

Waters that were presumably associated with each eruption and more recent rains assisted in cementing the fragmental material together. Rain and running water have now partially dissected the cone, exposing the successive layers of fragmental products and developing a large variety of peculiar forms. The remarkable exposure on the northeast side extends nearly to the core of the mountain.

CARBONIFEROUS FORMATIONS OF NEW MEXICO

CHARLES R. KEYES

Several features contribute to make the Carboniferous section of New Mexico the most noteworthy of the American continent. Its enormous thickness, the strictly marine nature of its sediments which constitute it the most imposing limestone plate among the known formations of the country, the feeble development of extensive shale beds so familiar elsewhere, the total absence of workable coal-beds which are the one feature of all others that is usually characteristic wherever the rocks of this age are found, the existence of a number of great planes of unconformity clearly indicating enormous erosion intervals, and the great abundance of organic remains, are some of the more salient points contrasting the Carboniferous of New Mexico with the sections of the same system elsewhere.

It has been unfortunate that the notes which have been made during the past half-century upon the Carboniferous rocks of the southwestern United States have been so meager, and so disconnected, and the publications in which they have appeared so widely scattered. From the literature alone, practically no correlation of separated sections has been possible. Confronted with these exceptional conditions, it soon became one of the main objects in the course of the geological survey of the New Mexican region to examine not only all of the Carboniferous exposures, as far as possible, and to correlate them in the field, but from the point of vantage thus gained to connect with these broader observations the fragmentary notes previously published.

The great thickness of the "Upper Carboniferous limestones" of the southern Rocky Mountain region has always been a matter of comment among all those who have traversed this part of the country. Few of these persons have ventured to put the measurement of these great limestones above about 2,000 feet. That the connected section of the Carboniferous strata as represented within the boundaries of New Mexico, indicated a thickness which was actually so enormous as it is, and as the recent measurements clearly show, was never thought of. This maximum thickness is now known to exceed 6,000 feet. Six great and important series have been differentiated. As now recognized, they are, with their respective thicknesses, as follows:

Unconformity	
Cimarronian sandstones and shales	1,000 feet
Unconformity	
Guadaloupan limestones	2,500 "
Maderan limestones	700 "
Manzanan limestones	1,300 "
Unconformity	
Ladronesian shales and sandstones	100 "
Unconformity	
Socorran limestones	500 "
Unconformity	

Of these, one series is Early Carboniferous, and is found only south of the central portion of the state; two are of Mid-Carboniferous age; and three belong to the Late Carboniferous.

With the schematic, or standard, section of the American Carboniferous series, as represented in the Continental Interior province, in Missouri and Kansas (II), may be paralleled the section of the Southwestern province represented by New Mexico (I), and also the eastern section of Pennsylvania (III), as usually given.

	TIME DIVISIONS	PROVINCIAL SERIES		
		I	II	III
CARBONIFEROUS	Late	Cimarronian Guadaloupan Maderan	Cimarronian Wanting Oklahoman	Wanting Wanting Permian
	Mid	Manzanan Wanting Ladronesian	Missourian DesMoines Arkansan	Pennsylvanian
	Early	Socorran	Mississippian	Pocono

Comparing in a general way the New Mexican succession of the Carboniferous formations with that of the Upper Mississippi valley, there is at once noticeable in the first-mentioned section a relatively much poorer representation of the Early Carboniferous sediments, an almost entire absence of the early Mid-Carboniferous shales, a very much greater development of middle and late Mid-Carboniferous marine beds, and a very great expansion of the middle Late Carboniferous marine deposits, while the sediments of the closing period are very much the same in both.

The thicknesses of the various formations are readily determined, usually in single unobscured vertical sections displayed in the fault scarps of the block-mountains which rise 3,000 to 5,000 feet above the plains at their bases, giving continuous outcrops that for unbroken extent are nowhere in the world surpassed.

The marine nature of practically the entire Carboniferous sequence, as represented in New Mexico, contrasts it strongly with the sections of the central and eastern United States. The main body of limestones composing the Manzanan and Maderan series were early recognized by government explorers as "Upper Carboniferous limestones." These two series and some other beds, taken together, have more recently, especially in the Grand Canyon district, eastern Arizona, and western New Mexico, generally gone under the title of the Aubrey limestone; and in western Texas, under the vaguely defined name of the Hueco limestone. Over the greater part of all of these regions the formation passing under a single title is easily separable into three or four distinct formations having serial rank, and each again is locally subdivisible.

The general absence of shales and coal-beds in the Carboniferous formations of the New Mexican region is one of its most striking features, particularly to one who has been accustomed to the great beds of shales, shaly sandstones, bituminous beds, and coals of the East. The horizons at which these deposits could be naturally expected are immediately beneath the great limestone plate having the Manzanan series for its base. There is, however, at this stratigraphic level a great plane of unconformity which is of very wide extent, and which represents a profound erosion interval.

If extensive shales ever existed here, and they evidently have, they have been almost entirely swept away. That there were once important coal-measures deposited on this old erosion surface is amply demonstrated by isolated deposits which still remain in protected localities, accidentally preserved through dropped fault-blocks. For example, near Socorro there have been recently discovered several such remnants of coal-bearing shales, both in the Sierra Ladrones and to the east of the town. The deposits of the latter rest in marked unconformity upon the rocks beneath, and appear to have unconformable relationships with the strata above. Although only about 100 feet of these shales now remain in the locality mentioned, the recognition of their presence, their character, and their location is very likely to lead soon to discoveries of very much greater developments. For this reason, and on account of the important period which the deposits manifestly represent, they have been called the Ladronesian series.

The principal or great planes of unconformity which have been made out are five in number. They all represent great erosion intervals. The only similar phenomenon in the Mississippi valley at all comparable to any one of them is the unconformity at the base of the DesMoines series, in Iowa, Illinois, and Missouri; and it is now known that during this interval the entire Arkansan series of shales, over 10,000 feet in thickness, was laid down. With two exceptions, all of the six series recognized are separated by great unconformities, and there are also unconformities at the base and at the top of the Carboniferous sequence. Besides these five unconformities of wide extent, there are a number of local phenomena of similar character, the exact magnitude of which is as yet not fully determined.

The character and location of some of these unconformity horizons in the New Mexican field suggest their presence in the Kansas, Oklahoma, and Texas sections where they have not before been suspected. And this accounts for some hitherto inexplicable observations that have been made in those states.

Organic remains of the entire Carboniferous section are, with few exceptions, strictly marine types. They are abundant throughout the whole sequence, except perhaps at the very top. In most localities where the rocks are well exposed fossils are as plentiful as they are in the more familiar sections of eastern Kansas. Some of the faunas are totally unlike anything described from other parts of the American continent. Their definition, range, distribution, and comparison with those of other provinces promise interesting and instructive results. In the New Mexican province a most inviting and unique field awaits students of Carboniferous life.

Enough is now known of the fossils to enable their general affinities to be made out with reasonable certainty. Much that is new is to be found among them. The careful determination of the range and distribution of the various faunas and faunules is necessary before exact comparisons can be made with those of other provinces, and correlation made according to biotic methods alone.

The serial subdivisions of the New Mexican Carboniferous succession is based partly upon biologic data, but largely upon direct stratigraphic grounds. Correlation with the Kansas section has been mainly by organic content, and secondarily by general formational relationships. The correspondence of the two perfectly independent records is close to a degree that is quite remarkable.

As already intimated, six distinct and easily recognizable subdivisions of the great succession of strata have been defined. Taxonomically they hold the rank of series. Special mention of the numerous minor formations which go to make up these series need not be made at this time. However, the several series may be briefly characterized.

The basal series to which the title Socorran has been given comprises all of the Early Carboniferous sediments in the Southwestern province. It corresponds to the original Mississippian series of the Continental Interior province, though it manifestly does not include so much. According to present faunal and stratigraphical evidence, its equivalent in the Upper Mississippi valley is the Chouteau and Burlington limestones. A prolific Lower Burlington fauna, including most of the most typical crinoids, is found at Lake Valley. Nothing higher than the strata containing the Lower Burlington fauna has yet been found in this region. Whether this later part is present and concealed, or actually absent altogether, cannot be at present stated. A profound erosion plane bevels off all known Early Carboniferous strata; hence it is quite probable that considerable more of the basal portion of the general section will sooner or later be brought to light in this region.

Ladronesian is a title applied to the only coal-bearing formation of the entire section under consideration. This series now exists only in remnants of a formation that was once evidently quite extensive. It consists chiefly of shales and sandstones with thin coal-seams. The formation rests unconformably upon the rocks beneath. Profound Carboniferous erosion has all but completely obliterated all evidences of its existence. The shales carry interesting coal plants, chiefly of lepidodendrid types. There is but small doubt that the formation is the representative of the Arkansan series of the Ozark region.

Resting unconformably upon all rocks beneath is the great blue and gray limestone plate which is that portion of the Carboniferous section with which most travelers have come into contact, and which is most familiar. Farther west the lower portions have been called the Aubrey limestones. To the south the major portion is known as the Hueco limestone. The upper part of this unbroken limestone sequence is absent over all of Arizona and New Mexico, except in the extreme southern part of the latter. Faunally, as well as stratigraphically and lithologically, the great plate is separable into three distinct sections. These three formations, which have serial rank, are the Manzanan, the Maderan, and the Guadaloupan series.

The Manzanan series is composed chiefly of massive blue and gray limestones with some thin gray shale layers. The fossils are essentially those which characterize the Missourian series of eastern Kansas. In the northern half of New Mexico this formation reclines directly upon the eroded surface of the Acrhæzoic and Proterozoic crystallines.

Above the Manzanan series, and apparently continuous with it, is a lithologically similar formation, though it is more of a gray color, and often having dark layers intercalated. It is termed the Maderan series; and it carries the so-called Lower Permian fauna of Kansas. It is paralleled approximately with the Oklahoman part of that succession. This hard limestone formation is the rock-floor over a considerable portion of northern Arizona and west-central New Mexican region. It is this formation that manifestly constitutes the chief part of the Hueco formation of Trans-Pecos Texas.

The Guadaloupan series is unique. In all the American continent there is no formation with which it may be compared, or with which it may be geologically correlated. At the typical locality it consists of a thick sandstone at the base, surmounted by over 1,000 feet of white massive limestone. So far as known, the formation is exposed only on the southern border of New Mexico. It has suffered enormous erosion, and has been entirely removed from the central New Mexican area, over which it no doubt at one time extended. The extensive faunas which it carries have no known counterparts in the Kansan section. They are all younger than any of the described faunas of Carboniferous age in that district, yet older than the earliest Mesozoic faunas. The greatest development of the formation is found in the Guadaloupe Mountains, in southeastern New Mexico, which form the western border of the broad Pecos valley. Fossils were described from this locality by Shumard more than half a century ago. Nothing more was known of them until quite recently, when Girty identified a large number of Shumard's species from this place and many others. The relationships of the formation with the other parts of the Carboniferous section of New Mexico have never been known until quite lately.

Along the east slope of the Guadaloupe range the Carboniferous Red Beds, or Cimarronian series, appear to overlie the white limestone series in marked unconformity. Its position in the Kansas section probably is marked by a hiatus at the bottom of the Cimarronian beds of that region.

The great fault-scarp at Guadaloupe Point presents a sheer precipice of more than 3,000 feet in height. The lower 200 feet appear to be the uppermost dark limestone of the Maderan series (Hueco limestone of Richardson). Then follow 1,500 feet of light-colored, coarse-grained massive sandstone—the Eddy formation,[1] which extends northward through Eddy County, New Mexico. The white Capitan limestone forms the upper 1,000 feet.

The Carboniferous Red Beds of New Mexico appear to be the western extension of the Cimarronian series of central Kansas.

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[1] Richardson's name of Delaware formation for this bed is preoccupied for a well-known Ohio formation.

They rest unconformably upon the older rocks and have the triassic Red Beds reposing in a very marked unconformable relations upon them.[1] The formation has a very wide geographic distribution, and is, for the most part, unfossiliferous.

The complete sequence of formations composing the New Mexican Carboniferous section may be tabulated as follows:[2]

		SERIES	FORMATIONS	ROCKS
CARBONIFEROUS SYSTEM	PERMIAN	Cimarronian	Moencopie	Shales
			————?	Sandstones
			————?	Shales
		Guadaloupan	Capitan	Limestones
			Eddy	Sandstones
		Maderan	————?	Limestones
			————?	Limestones
			————?	Limestones
	PENNSYLVANIAN	Manzanan	Mosca	Limestones
			Coyote	Sandstones
			Montosa	Limestones
			Sandia	Shales
		Ladronesian	Alamito	Shales
	MISSISSIPPIAN	Socorran	Lake Valley	Limestones
			Berenda	Limestones

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[1] *American Journal of Science* (4), Vol. XX (1905), pp. 423–29.

[2] The wavy lines represent unconformities.

EDITORIAL

The suggestive article by Professor Schwarz relative to a former land connection between Africa and South America (p. 81) furnishes an excellent illustration of the vital dependence of our studies of most large problems on fundamental conceptions of the early states of the earth. An essential part of his argument from the nature of the rocks of the oceanic islands hangs upon theoretical views as to what the specific gravities and the structures of the oceanic and continental portions of the crust, respectively, should be, under alternative assumptions relative to the configuration of the ocean surface. If the average specific gravities of the sub-oceanic and of the sub-continental sectors were the same, the waters of the hydrosphere would be drawn up about the continental masses, and would add their gravity to that of the continents, and thereby increase the differential stresses within the lithosphere and tend to depress the continents. To sustain stresses of such magnitude, the rigidity of the lithosphere must be assumed to be very effective, and the agencies of elevation must have worked against these stresses ever since the continents were formed.

If, on the other hand, the sub-oceanic rocks are sufficiently higher in specific gravity to counterbalance (with the aid of the overlying oceanic waters) the weight of the continental protuberances, the surface of the ocean must be more nearly spheroidal and the lithosphere much less affected by differential stresses.

To test these alternative hypotheses in the most direct and positive way, there is need that geodetic measurements of the ocean surface be extended outward from the continents on chains of islands as far as possible, and that pendulum observations be made on the oceanic islands and on the open ocean itself, so far as practicable.

But even if such determinations were at command, there would still be need, whatever their results, to take careful note of the different inferences that legitimately arise from alternative views of the earth's genesis, if we are to proceed on safe grounds of interpretation. The criteria deduced by sound reasoning from a molten earth do not altogether hold if the earth was built up by gradual accretions and was solid at all stages.

If the earth was once molten, it is a fairly sure inference that all the deeper portions were affected by essentially the same specific gravities at the same distances from the center. Only at and near the surface is it probable that there was much differentiation of specific gravity in the original liquid spheroid, if indeed much even there. If, therefore, the geodetic determinations were to show that the oceanic surface is nearly spheroidal, and the pendulum observations were to show that the crust is in approximate isostatic equilibrium in a general way, neglecting local inequalities, it is a firm inference that there must be a rather marked difference in the specific gravities of the sub-oceanic and of the continental portions of the crust respectively, as Professor Schwarz has indicated, for the sub-oceanic crust, plus the water that is on it, must counterbalance the continental protrusions. The amount of this difference in specific gravity *must depend on the depth to which the differentiation of rock extends.* For example, if the continental protrusions be taken to average three miles in height above the oceanic bottoms, and the lower limit of differentiation of specific gravities be assumed to be reached at a depth of six miles below the average surface, the specific gravity of the differentiated portion of the sub-oceanic crust, three miles thick, must be enough, with the aid of the overlying water, to counterbalance the six miles of the differentiated continental shell, from which it is obvious that a very high specific gravity for the sub-oceanic rock is required. If the differentiated portion of the crust were no thicker under the continental surfaces than under the oceanic, the differences of specific gravity would be still greater. If the limit of differentiation be taken at the greater depth of nine miles below the average surface, six miles of rock and three miles of water on the oceanic side must counterbalance nine miles of rock on the continental side, in which case a less, but still a pronounced, difference in specific gravity is required to meet the conditions of the case. For any such moderate depth of differentiation as would probably arise in the development of a crust upon a molten sphere, a marked difference between the specific gravities of the sub-oceanic and of the continental rocks seems to be implied, and this furnishes a working basis for such inferences as are discussed in Professor Schwarz's article. These are representative of the lines of interpretation that have most prevailed under the dominance of the doctrine of a primitive molten condition.

If, however, the earth be supposed to have been built up by the accretion of planetesimals, with a concurrent differentiation into continental and oceanic segments through the agency of weathering and transportation, as recently suggested,[1] the differentiation of specific gravities between the sub-oceanic and the sub-continental segments may extend to a possible depth of 1,500 to 1,800 miles. With such a depth of differentiation, a difference of surface protrusion of three miles only requires an average differentiation of specific gravity of about one-fifth of one per cent., a difference quite beyond detection lithologically. If the depth of effective differentiation were much less, as is not improbable, the average specific gravity of the sub-oceanic rocks would still need to be only slightly greater than that of the sub-continental ones to meet the requirements of the case.

When we consider the wide range of variation that was likely to be introduced by selective fusion and by the magmatic differentiation of the extruded rocks of both the sub-oceanic and the sub-continental segments, it does not seem safe to infer that any specific class of rocks would be excluded from either area. The probable differences between the rocks of the two areas would be detectable merely by a greater preponderance of heavy rocks in the sub-oceanic areas and of lighter ones in the continental. If a compilation of available data, made some years ago at the suggestion of the writer, is to be trusted, the preponderance of basic rocks in the extrusions of the oceanic volcanoes, present and past, is quite as high as the planetesimal hypothesis requires, and the discovery of a notable percentage of granitic and other acidic rocks is quite consistent with this hypothesis.

Under the planetesimal hypothesis the segments now beneath the ocean were, at an early stage, parts of the land surface alike with the continental segments. They are presumed to have been gradually converted into ocean bottoms by surface differentiation, leading

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[1] Chamberlain and Salisbury, *Geology*, Vol. II, pp. 106–11.

on to greater depression, the volume of the hydrosphere meanwhile increasing and assisting in the submersion. The portions now submerged were presumably affected by reliefs not unlike those of the continental portions at like stages of evolution. In the course of their gradual submersion, the more protuberant swells and ridges are presumed to have stood forth from the growing seas as variously shaped lands which doubtless had a dominant tendency to elongated swells of ridge-like aspect, such as now affect the ocean bottoms and are being brought out more and more as soundings multiply. Not that all are necessarily of this class, however. In the slow process of their submergence, these swells and ridges were doubtless subject to denudation and circum-decomposition, as are other lands, and hence are similarly attended by sedimentary rocks. Some of these may have been submerged only in the later deformations of the earth's body, those of the Tertiary period perhaps, and previous to this they may have constituted bridges between the continents, and thus have satisfied the requirements of biological data, if these are indeed requirements. The loss, through deformation, of such bridge-connections of comparatively limited area and of moderate depression makes a relatively small demand on dynamic agencies and involves the withdrawal of a relatively small volume of water from the continental platforms. On the other hand, if vast continents be supposed to have arisen from the depths of the Atlantic, Pacific, and Indian Oceans, and to have again subsided, not only is a heavy tax laid on dynamic resources, but great volumes of displaced water must be accounted for in a complete hypothesis. We can no longer leave these considerations out of account as in the past, for the days of legitimate appeal to *terrae incognitae* are over.

If the hypothesis of a relatively thin shell shearing over a solid substratum, which seems to be forced upon us by a study of the folds of the corrugated mountains, be entertained,[1] the occurrence of foliated rocks at shallow depths beneath the oceans, as well as the continents, is to be assumed, though perhaps their extent and degree of development may be inferior. These foliated rocks may have as wide a range of lithological characters as the igneous rocks of the sub-oceanic crust which, as we have seen before, under the

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[1] Chamberlin and Salisbury, *loc. cit.*, pp. 125–32.

planetesimal hypothesis may have a range little short of that of the continents. The existence of various gneisses and schists is not, therefore, in itself discriminative.

It is not improbable that, in time, the notable chain of islands that now skirt the eastern border of the Asiatic continent from Sumatra to Kamtchatka, standing along the outer border of the true continental platform, will be degraded and a portion of their material carried toward the mainland and re-deposited, and that this, conjoined with continental detritus, will at length fill up the intervening seas with stratified rocks, and thus extend the mainland eastward to the vicinity of these islands. In the meantime, sea encroachment, downward flexure, and the other agencies that affect the borders of continents[1] may have brought about the submersion of the sites of the islands themselves, in which event the border formations of the continent will present the same evidences of oceanward derivation of material that some of the coast formations of the continents do today. It is obvious, however, that, in this case, the phenomena will not imply a lost continent or any radical change in the configuration of the lithosphere, or even of the continent; much less will it afford evidence adverse to the essential permanence of the continents.

The intent of these suggestions is not to enforce any particular interpretation of the extremely valuable and suggestive data afforded by the oceanic islands, nor indeed to imply the limitation of alternative hypotheses to those here mentioned, but rather to emphasize the fact that the hypotheses employed in these inquiries, as in most others of a far-reaching nature, need to be traced back scrupulously to their sources, and to be put into comparison with other hypotheses, so that the true values and the limitations of the criteria employed may be made apparent, and their dependence upon fundamental hypotheses may be brought forth into sharp definiton and working application.

T. C. C.

The article in this number of the *Journal* on the Tertiary glaciation of Iceland possesses much interest for students of glacial geology

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[1] *Op. cit.*, Vol. III, pp. 518–30.

in this country; but it should perhaps be pointed out that the Tertiary age of these morainic formations is not to be accepted, except on the basis of the most irrefutable evidence, and evidence of this sort is not cited in the article. The glacial deposits are interbedded with lava, and since the lava has been thought to be of Tertiary age, the moraines are inferred to be of Tertiary age. If the first of these conclusions is correct, the second is; but, so far as the evidence cited in this paper is concerned, the argument would seem quite as plausible if stated the other way, namely: Since the sediments interbedded with the lavas are glacial, they are Pleistocene; the lavas interbedded with them are therefore Pleistocene. Indeed, the presumption is strongly in favor of this statement, since abundant lavas of Pleistocene age are known, and no glacial formations of Tertiary age in any part of the earth are known, unless these constitute the exception. If they are really of Tertiary age, the fact is most significant, since it will call for a revision of present opinion concerning the climate of some part of the Tertiary period.

On the other hand, great deformations, great erosion-unconformities, and great physiographic features due to erosion have been developed since the close of the Tertiary, and igneous eruptions of consequence are known to have taken place, in America at least, since the Tertiary period. Accumulating evidence makes it clear that the rather common conception that the Pleistocene period was a very short one, must be abandoned. The evidence is now altogether adequate to show that the period was long enough for changes and events far greater than those which have taken place in Iceland since the inter-lava drift of that island was deposited.

R. D. S.

REVIEWS

Les tremblements de terre et les systèmes de déformation tétraédrique de l'écorce terrestre. ("Earthquakes and the tetrahedral deformations of the globe.") Par M. MONTESSUS DE BALLORE. *Annales de Géographie*, No. 79, XV, 1–8, Paris, 1906.

Six months ago we called attention in this *Journal* (Vol. XIII, p. 462) to a notable paper by M. Montessus de Ballore upon the distribution of earthquakes. The author of that article has another in the *Annales de Géographie* for January, 1906, upon "Earthquakes and the Tetrahedral Deformation of the Globe," which is well worthy of especial attention in connection with the general subject of earthquakes and their distribution. Evidently the theory of the tetrahedral form of the earth — a theory so much favored by M. de Lapparent and by Michel-Lévy— is regarded by the author as worthy of serious consideration in connection with the study of the distribution of earthquakes. The following are the general conclusions formulated in the course of the article:

1. Considering the matter from a purely geographic point of view, earthquakes occur about equally and almost exclusively along two narrow zones that follow two great circles of the earth: the Mediterranean (or Alpino-Caucasian-Himalayan) circle, with 53 per cent. of the recorded shocks, and the circum-Pacific (or Ando-Japan-Malay) circle, with 41 per cent. of the shocks.

2. These seismic zones coincide exactly with the geosynclinal zones of the secondary epoch which during the Tertiary were thrown into mountain chains or geosynclines by the foldings and displacements.

3. The folded structure of the geosynclines is seismically unstable, while that of the tabular continental areas, on the contrary, is stable.

4. Finally, it is concluded that the existence, well established by observations, of two great circles of maximum seismic unstability affords no argument in favor of the theory of the tetrahedral deformation of the globe. On the contrary, it would be surprising if there were no relations between the earthquake regions of the earth and the elements of the tetrahedron, if such a solid really determined the most general movements of the surface of this planet.

It may be added by way of postscript, and for the benefit of students of seismologic phenomena, that a new volume of five hundred pages by M. Montessus de Ballore, entitled *Les tremblements de terre*, has been recently published at Paris. In the preface M. de Lapparent directs attention to the great statistical value of the author's catalogue of earthquakes, and to the fact that he has brought seismology into its relations with geologic structure.

J. C. BRANNER.

The Linear Force of Growing Crystals, and an Interesting Pseudo-Solid. By G. F. BECKER AND A. L. DAY. Proceedings of the Washington Academy of Sciences, Vol. VII (1905), pp. 251–300.

About six months ago a modest paper, filling only five octavo pages, was published by George F. Becker and Arthur L. Day upon the "The Linear Force of Growing Crystals."[1] The writer has looked in vain for expressions of appreciation of this important piece of work.

Evidences of the linear force of growing crystals have long been familiar to geologists, but while the process of growth seemed clear enough from field observations, the demonstration of it and its quantitative determination have hitherto been altogether lacking, while the writer's efforts to interest chemists and physicists competent to deal with the problem have failed of success for twenty years. Discussions of the origin of secondary veins usually proceed on the theory of cavities, or of the replacement of one mineral by another. So far as we now recall, not one of the many writers on this much-discussed subject has ventured the suggestion that the growing force of crystals may have thrust apart the rock walls, and thus made room for the veins in the very process of formation. A few geologists have suggested that some such force operated in the formation of veins, but these are so few, and their suggestions have been made with such apparent hesitation, that little or no attention has been paid to them by the more voluminous writers upon ore deposits.

In 1882 Chamberlin recognized the displacing force of growing crystals of sphalerite, galenite, and pyrite in the ore deposits of southwestern Wisconsin, as indicated by the following quotations from Vol. IV of *Geology of Wisconsin:*

> In most instances it is perfectly clear, from the nature of the ore filling, that the separation of the beds took place before the implanting of the ores,

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[1] *Proceedings of the Washington Academy of Sciences*, Vol. VII (July, 1905), pp. 283–88.

> and was not due to any intrusive or crystalline force inherent in the deposit itself. Some, however, instead of being simple sheets between well-defined layers of rock, split and reunite, forming between and about cracked and riven layers of rock, leaving it less clear that all the mechanical action preceded the deposition of the ores. In other cases "dice mineral" and blende impregnate soft beds of rock in sheetlike belts, in which instances it is quite evident that the metaliferous substances displaced the yielding rock in the process of their growth. (P. 468.)
>
> Upon close inspection the soft clayey rock will be found to be thickly inset with scattered crystals of black blende, giving to the fractured rock a beautiful speckled appearance. Looking still closer, it will be seen that the laminæ of the rock curve around the particles of blende, showing that they were displaced by the growth of the blende crystals. (See Fig. 39.) We have in this and the next instance just as clear cases of the forming mineral making room for itself by its own concretionary force, as in some preceding cases it is evident that the receptacle was first formed and the ore subsequently implanted. (P. 474.)

Two other cases are cited, pp. 474, 475, and p. 464.

The first edition of Branner and Newsom's syllabus of economic geology, published in 1895, referred (p. 28; p. 36 of the second edition, 1900) to the enlargement of veins by accretion, under the following heads: "Illustration of needle-ice and crystallization in the soil. The size, form, and structural relations of some geodes shown to be due to enlargement. Evidences of mechanical force of the process. Possible relations to vein enlargement; to brecciation."

That same year, 1895, the fourth edition of Dana's *Manual of Geology* appeared, in which Professor Dana briefly mentions (p. 138) "displacement by intrusion of crystalline material," and cites Worthen upon the splitting and enlargement of crinoids. The paper of Worthen has not been located by the writer. In 1899 Professor Shaler published a paper upon the formation of dikes and veins,[1] in which he uses geodes as illustrations of vein-forming, and remarks (p. 262) that "the pressure of the growing vein . . . . is likely to be even more effective in the group of tabulate deposits in forcing the walls asunder." This is the only instance, with which the writer is acquainted, in which the relation of geode formation to veins has been formally discussed.

In the twentieth annual report of the United States Geological Survey, Part II, published in 1900, Professor I. C. Russell says in regard to the filling of certain brecciated veins (p. 207): "I venture the suggestion that these minerals (quartz and calcite), in crystallizing, have exerted a

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[1] *Bulletin of the Geological Society of America*, Vol. X, pp. 253–62.

force analogous to the expansion of water on freezing, which has crowded the rock fragments asunder."

In 1900 also an article by R. A. Daly appeared in the *Journal of Geology* (Vol. VIII, pp. 135-50), in which the author shows the evidence of mechanical force exerted in the formation of calcareous concretions.

Messrs. Becker and Day have now not only demonstrated the mechanical force of growing crystals, but they have been able to measure that force in some instances. The bearing of this work upon the formation of veins is recognized by the authors, for they conclude that

> it thus becomes possible that . . . . great veins have actually been widened to an important extent, perhaps as much as 100 per cent., or even more, by pressure due to this cause. . . . . Again, in a vein where auriferous quartz is being deposited, the growth of crystals may readily extend the space in which successive crops of crystals might grow, so that in certain cases . . . . the deposition of ore might continue almost indefinitely.

The investigation is to be continued, and we shall be greatly disappointed if it does not prove to be one of the most important modern contributions to the theory of vein deposits.

J. C. Branner.

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PROWERSOSE (SYENITIC LAMPROPHYRE) FROM TWO BUTTES, COLORADO[1]

WHITMAN CROSS

In 1896 G. K. Gilbert[2] described in this *Journal* the laccoliths occurring at Two Buttes, in the Arkansas valley, near the eastern border of Colorado and about 150 miles from the mountain front at Canyon City. The igneous rocks of this locality, embracing specimens from two laccoliths and many associated dikes, were submitted to me for determination, but no detailed descriptions have as yet been published. The interest attaching to the principal rock type and some of its associates made a renewed examination of their field-relationships desirable, and such a study is contemplated for the field season of the current year.

The rock of the larger laccolith at Two Buttes possesses an unusual mineral composition, and it was subjected to chemical analysis by W. F. Hillebrand. The analysis, which was published, with a brief description by myself, in the well-known compilation of rock analyses made in the U. S. Geological Survey laboratory,[3] has led to the classification of the rock by the quantitative system in a subrang without other known representatives until the one described by Mr. Bastin in the accompanying paper was discovered. The rarity of such rocks, and the fact that the one from Colorado

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[1] Published with the permission of the Director of the U. S. Geological Survey.

[2] "Laccolites in Southeastern Colorado," *Journal of Geology*, Vol. IV, pp. 816–25.

[3] "Analyses of Rocks," tabulated by F. W. Clarke, *Bulletin No. 228* (1904), U. S. Geological Survey, p. 186.

has received practically no petrographic discussion, make its description at this time appropriate, although nothing can as yet be added to the general statement of occurrence given by Gilbert, which is summarized below.

Features of occurrence.—The rock forms the lower of two laccoliths, of an extent not clearly determinable, owing to surficial gravels. The horizons of intrusion of the known masses are in Triassic Red Beds, but a few hundred feet below Cretaceous strata. The lower Cretaceous beds are upturned about the laccolith, and Gilbert considers it probable that the intrusions occurred either in "the closing epochs of the Cretaceous or the earlier half of the Eocene." The outcrop of the rock to be described "is nearly continuous for three-fourths of a mile from north to south and more than half a mile from east to west." While it is not desired to present details of occurrence here, it may be noted that Gilbert observed some fifty dikes traversing the sediments of horizons above that of the laccoliths, and that many of these dikes belong to the type under discussion. The upper and probably smaller laccolith, separated from the lower one by a few feet of limestone, is composed of very similar material.

General description.—The rock of Two Buttes submitted to analysis is fine-grained, greenish-gray, with a habit sometimes exhibited by minette. Its most prominent megascopic constituent is biotite, occurring in glistening brown, hexagonal plates 2^{mm} or less in diameter, with a few blades 1^{cm} long. There are a few reddish-brown phenocrysts, 2 or 3^{mm} in length, representing original olivine, now wholly replaced by serpentine and chlorite, and colored by iron oxide.

A hand lens reveals many prisms of pale-green augite, and an abundance of feldspar is evidently present as interstitial material. A few aggregates of feldspar grains are scattered irregularly through the mass, but there are no normal phenocrysts. The lens also shows many minute pores, but the rock is so fresh that these seldom contain secondary minerals. The fractured surface is rough or hackly.

Microscopic characters.—Under the microscope this rock is found to consist essentially of a feldspathic base holding, besides the megascopic phenocrysts, many small biotite leaves, augite grains and prismoids, and a multitude of minute magnetite grains. There is a gradual transition from the minute biotite and augite individuals to those 2 or 3^{mm} in diameter—a feature which causes the porphyritic texture to be subordinate and crude.

Feldspar is the most abundant constituent, and it seems to be wholly orthoclase, occurring in ill-defined scales or tablets which are characteristically arranged, and possibly intergrown, in sheaf-like, imperfectly radial groups. There are no sharply defined crystals, and the maximum dimension of the particles is perhaps $\frac{1}{5}^{mm}$. Because of the great number of other mineral grains which are held by this orthoclase mass, and through the presence of many minute dustlike interpositions, the feldspathic constituent can be satisfactorily studied only in certain small areas scattered through the rock, where the femic minerals are quite subordinate.

All feldspar on the borders of the sections has a lower index of refraction than the Canada balsam, no multiple twinning has been observed, and the analysis of the rock shows that a soda feldspar is not likely to be present. Probably the orthoclase contains a small amount of the albite molecule.

Biotite is quantitatively the next constituent of importance. It occurs in scales which are seldom crystallographically bounded, the large phenocrysts and some of the smallest flakes being the prominent exceptions. The pleochroism ranges from pale yellow to a reddish brown. It is clear that the mineral is poor in iron. It is quite fresh throughout the rock.

The pyroxene occurs in prismoids, colorless or faint green as a rule, but some of the stouter prisms contain a core of bright grass-green color. The clino-pinacoidal extinction in such cases is about 36° for the green core and 45° for the outer zone. The pyroxene, being fresh and very nearly free from inclusions, was isolated and analyzed by Dr. W. F. Hillebrand, with the result given in Column II of the table, p. 168. Its specific gravity is 3.45 at 25° C.

This pyroxene is a strongly diopsidic augite, and by assuming the Fe_2O_3 to be about one-half too high, the mineral may be calculated to have the composition: 6 $Na_2\ Fe_2\ Si_4\ O_{12}$ (aegirite) + 34 $(Na_2R)\ (Al\ Fe)_2\ SiO_6$ + 403 $Ca\ (Mg\ Fe)\ Si_2O_6$ (diopside). It is unusually high in alumina for the augite of a rock with potash strongly predominant over soda.

TABLE OF CHEMICAL ANALYSES

	I	II	III	IV	V	VI	VII
SiO_2	50.41 0.840	51.27 0.855	1.58	52.26	56.39	57.31	51.75
Al_2O_3	12.27 0.121	3.05 0.029	1.00	10.63	12.88	14.71	14.52
Fe_2O_3	5.71 0.036	3.08 0.019	None	2.47	2.36	1.21	5.08
FeO	3.06 0.045	4.34 0.061	0.87	5.45	3.54	4.37	3.58
MgO	8.69 0.217	14.21 0.355	1.22	9.32	7.83	7.80	4.55
CaO	7.08 0.128	22.58 0.403	0.68	5.62	4.06	6.90	7.04
Na_2O	0.97 0.016	0.67 0.011	Undet.	1.60	1.30	1.35	2.93
K_2O	7.53 0.080	0.06	Undet.	5.99	7.84	6.38	7.61
$H_2O-110°$	0.46	None	None	0.98	1.33	0.18	2.25
$H_2O+110°$	1.80	Undet.	Undet.	1.97	....	....	....
TiO_2	1.47	0.70	....	1.92	2.07	0.40	0.25
ZrO_2	0.019	0.009	....	0.08	....	....	....
CO_2	....	....	....	0.75	....	....	....
Cl	....	....	....	....	....	....	0.05
P_2O_5	0.46 0.003	....	0.46	0.98	....	....	0.18
V_2O_3	0.03	....	....	....	....	....	....
NiO	0.04	0.03	....	....	....	....	....
MnO	0.15 0.002	0.28 0.004	Trace	0.12	....	....	Trace
BaO	0.23 0.002	None	None	....	...	....	0.30
SrO	0.06	None	?	....	....	....	0.07
	100.42	100.27	5.81	100.14	99.60	100.61	100.14

I. Prowersose (syenitic lamprophyre), Two Buttes, Colo.; W. F. Hillebrand, analyst.

II. Augite from I; W. F. Hillebrand, analyst.

III. Portion of I soluble in dilute nitric acid (1:40).

IV. Prowersose (syenite porphyry), Knox county, Maine. George Steiger, analyst.

V. Ciminose (selagite); Monte Catini, Tuscany; H. S. Washington, analyst; *American Journal of Science*, Vol. IX (1900), p. 47.

VI. Ciminose (ciminite), La Colonetta, near Viterbo, Italy; H. S. Washington, analyst; *ibid.*, p. 44.

VII. Fergusose (fergusite), Highwood Mountains, Montana; E. B. Hurlburt, analyst; *Bulletin No.* 237, U. S. Geological Survey, p. 86.

The microscope shows the presence of serpentine and chlorite occupying areas which probably represent original crystals of olivine. Some are large, corresponding to those seen in the hand specimen, while others are very small. The alteration is so extreme, however, that neither by outline nor by indications of the course of alteration can one positively determine this matter.

Magnetite occurs in very numerous particles only 0.01^{mm} to 0.02^{mm} in diameter, and apatite is chiefly developed in minute needles, with here and there a large stout phenocryst, comparable to the augite in size.

The obscure character of the salic constituents led to a careful search for leucite and nephelite, without evidence of either being found. The 5.81 per cent. of the rock soluble in dilute nitric acid contains no appreciable soda, and hence nephelite and zeolites derived from it are excluded.

On the basis of the above description, this rock may be called, in the prevailing nomenclature, a syenitic lamprophyre allied to minette.

The rock contains some small angular and sharply defined inclusions of white color and fine granular texture, which are seen in thin section to consist mainly of orthoclase and very obscure microperthite, with possibly a small amount of some highly sodic plagioclase. These minerals are developed in anhedral grains, and resemble the orthoclase of the rock only in their dustlike interpositions. A few flakes of biotite, prisms of augite, and grains of magnetite larger than those of the rock are scattered through this feldspathic mass. It seems to represent material genetically related to the host, but derived from some deep-seated source. There is no suggestion of fusion or assimilation of the included particles.

Classification by the quantitative system.—The norm of the Two Buttes lamprophyre is given in Column I of the accompanying table. For comparison the norms of the other rocks of which analyses have been given are appended. The figures for IV are taken from Bastin's paper; for V and VI, from Washington's tables; and for VII, from Pirsson's bulletin on the Highwood Mountains.

The position of the Two Buttes rock in the quantitative system

TABLE OF NORMS

	I	IV	V	VI	VII
Salic molecules—					
Quartz			1.0		
Orthoclase	44.5	35.6	46.1	37.8	45.0
Albite	3.9	13.6	11.0	11.5	3.7
Anorthite	6.9	3.9	6.0	15.0	3.9
Nephelite	2.4	....	....	....	11.4
Femic molecules—					
Diopside	20.1	13.9	11.1	15.3	23.8
Hypersthene	....	15.0	15.6	16.2	....
Olivine	8.7	4.9	....	1.8	1.5
Magnetite	6.0	3.4	3.5	2.2	7.2
Ilmenite	2.9	3.6	....	....	0.5
Hematite	1.6	....	....	....	....
Apatite	1.0	2.3	....	....	0.3

I. Prowersose, Two Buttes, Colo.
IV. Prowersose, Knox County, Maine.
V. Ciminose, Monte Catini.
VI. Ciminose, La Colonetta.
VII. Fergusose, Highwood Mountains.

is shown, by the subjoined analysis of its norm, to be in the subrang *prowersose* (III, 5, 2, 2).

$$\frac{\text{Sal}}{\text{Fem}}=\frac{57.8}{40.3}=1.43<\frac{5}{3}>\frac{3}{5}=\text{Class III, } \textit{Salfemane.}$$

$$\frac{\text{L }(ne)}{\text{F }(or+ab+an)}=\frac{2.4}{55.3}<\frac{1}{7}=\text{perfelic order (5), } \textit{gallare.}$$

$$\frac{K_2O'+Na_2O'}{CaO'}=\frac{80+16}{25}=3.8<\frac{7}{1}>\frac{5}{3}=\text{domalkalic rang (2), } \textit{kilauase.}$$

$$\frac{K_2O'}{Na_2O'}=\frac{80}{16}=5<\frac{7}{1}>\frac{5}{3}=\text{dopotassic subrang (2), } \textit{prowersose.}$$

The *prowersose* from Maine, while lower in salic molecules than that from Colorado, is so much richer in normative orthoclase and albite as compared with anorthite $\left(\frac{K_2O'+Na_2O'}{CaO'}=\frac{90}{14}\right)$ that it approaches the peralkalic rang *orendase*. But its ratio of potash to soda is lower than for the Colorado rock; hence it does not come so near to the perpotassic *orendase* as does the latter. There is no known member of the dopotassic subrang of *orendase* with which the *prowersose* may be compared.

By consulting Washington's tables it will be seen that the only other salfemanes possessing high potash greatly in excess of soda are the peculiar leucite rocks of the Leucite Hills, Wyoming, orendite and wyomingite. These are, however, so extremely rich in potash that they fall within the peralkalic rang of the gallares and in its perpotassic subrang, *orendase.* Hence they are farther removed from *prowersose* than are other rocks of which analyses are given in the table.

The rock of Washington's tables within the rang *kilauase* which comes nearest to *prowersose,* belongs to the sodipotassic subrang *lamarose.* It is a leucite-absarokite of Yellowstone Park, but in the low total of alkalis (K_2O 3.79 per cent. Na_2O 1.88 per cent.) and in the high magnesia contents (15.96 per cent.) this rock differs so markedly from the *prowersose* that further comparison seems unnecessary.

On the whole, the nearest relatives of the *prowersose* described are two rocks of the Italian province, belonging to the corresponding subrang of the Dosalane class—namely, *ciminose* (II, 5, 2, 2). These rocks, while notably richer in the albite molecule, maintain a strong preponderance of orthoclase.

Another rock with which comparison is particularly interesting is the unique *fergusose* (II, 6, 2. 2), described by Pirsson from the Highwood Mountains. This rock is very near the *prowersose* of Two Buttes in normative orthoclase, albite, and anorthite, but it is so rich in normative nephelite as to be brought within the lendofelic order (6) of the Dosalane class. The close chemical relationship evident in the analyses is made plain systematically by observing that, if somewhat less than 4 per cent. of normative nephelite of this *fergusose* were replaced by any femic molecule, it would be changed to *prowersose.* It may be noted that there is as yet no known rock of the Salfemane class corresponding to *fergusose* in its chemical relations.

Modal characteristics of the rocks compared.—The *prowersose* of Two Buttes clearly belongs to one of the rock groups illustrating the fact, not yet sufficiently recognized among petrographers, that there may be important variations in the mode or actual mineral composition of igneous rocks possessing very similar chemical composition. The most notable variation in this particular group is in the development of biotite on the one side, and leucite (or orthoclase) and olivine on the other. That this variation is in large degree dependent on geological occurrence as influencing conditions of consolidation has been pointed out, notably by Iddings[1] and Washington,[2] the latter while discussing the rocks of Monte Catini and La Colonetta of which analyses have been given.

The rocks of the above tables are all intrusive, except the ciminite of La Colonetta, which is a surface flow. The latter is the only one in which biotite is not an important constituent. It contains numerous phenocrysts of augite and olivine, with a few of orthoclase and labradorite in a very dense groundmass, which is "a felt of minute orthoclase and some labradorite laths lying in a glassy base" (Washington).

On the other hand, the selagite or mica-trachyte of Monte Catini has very closely the habit of the Colorado *prowersose*, as I am able to state through examination of a type specimen donated by Dr. Washington to the Petrographic Reference Collection of the Geological Survey. The development of biotite and the megascopic appearance of the groundmass is very nearly the same in the two rocks. Microscopically, the difference in texture is more pronounced, as in the selagite augite occurs in small crystals forming a part of the groundmass, and the orthoclase tables are much more sharply defined than in the Two Buttes rock.

In marked contrast with the syenitic lamprophyre of Two Buttes stands the fergusite or pseudoleucite-syenite of the Highwood Mountains. That rock contains numerous pseudoleucite grains 5^{mm} or less in diameter, held in a matrix consisting chiefly of augite, with small amounts of biotite, olivine, and other accessory minerals.

The great textural difference between the two known types of *prowersose* is most striking. The rock of Knox County, Maine, is a most pronounced porphyry, as a reference to the description by Mr. Bastin, and a glance at the photographic illustration, will show. There are many large alkali feldspar phenocrysts lying in a groundmass of biotite and green hornblende.

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[1] J. P. Iddings, "The Origin of Igneous Rocks," *Bulletin of the Philosophical Society of Washington*, Vol. XII (1892), pp. 176, 177.

[2] H. S. Washington, "Some Analyses of Italian Volcanic Rocks," *American Journal of Science*, Vol. IX (1900), p. 49.

SOME UNUSUAL ROCKS FROM MAINE[1]

EDSON S. BASTIN

I. PROWERSOSE FROM KNOX COUNTY

This unusual rock was collected by the writer in the summer of 1905 near Burkettville post-office in Knox County, Maine. It outcrops over a nearly circular area about 3½ to 4 miles across, which lies mainly in the town of Appleton, but extends a short distance west into the town of Washington, and north into the town of Liberty (Waldo County). It intrudes pelite schists and gneisses, and is itself cut by numerous dikes of pink aplitic granite. Bowlders of this rock had previously been observed 20 to 25 miles to the southeast, near the villages of Sprucehead and St. George.

In the field the rock was called a syenite-porphyry. The commonest phase is massive and shows numerous purplish-gray phenocrysts of feldspar in a rather fine, dark-green, even-grained matrix made up almost entirely of biotite and green hornblende (Fig. 1). The feldspar phenocrysts vary in length from ¼ to 1½ inches, 1 inch being about the normal length. A series of measurements on three hand-specimens showed that they constituted about 42 per cent. of the rock. Many are twinned according to the Carlsbad law, and some show zonal structure very perfectly brought out through concentric alternation of yellowish-gray with purplish-gray layers.

Microscopic study shows most of the feldspar to be a perthitic intergrowth or a somewhat irregular interpenetration of orthoclase or microcline, and albite. Microcline and orthoclase may or may not be present in the same crystal. In general, the potassic feldspar dominates greatly over the sodic, so that megascopically no albite twinning is visible in any of the phenocrysts. Some of the smaller phenocrysts are pure microcline, and a very few are pure orthoclase. Albite, not intergrown with the potash feldspars,

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[1] Published with the permission of the Director of the U. S. Geological Survey.

occurs in a few places in aggregates of small grains associated with similar grains of orthoclase, and both grading into the perthitic intergrowths. It also occurs occasionally in small subangular grains inclosed in the large feldspar crystals. Most of the feldspar phenocrysts are full of inclusions. Some are dotted with subangular or rounded inclusions of quartz, and sometimes of orthoclase and albite, in grains averaging about $\frac{1}{10}$ of a millimeter in diameter; quartz thus included makes up perhaps 2 per cent. of the phenocrysts. Minute prisms of zircon are also of common occurrence. The most abundant inclusions appear hairlike under the low-power, but under the high-power are seen to consist of large numbers of minute, brownish, globular bodies arranged close together in perfectly straight lines. Some of these lines of globules are a millimeter in length. In a few cases the globules are seen to increase in length, so that they form a row of short prisms arranged end to end; these

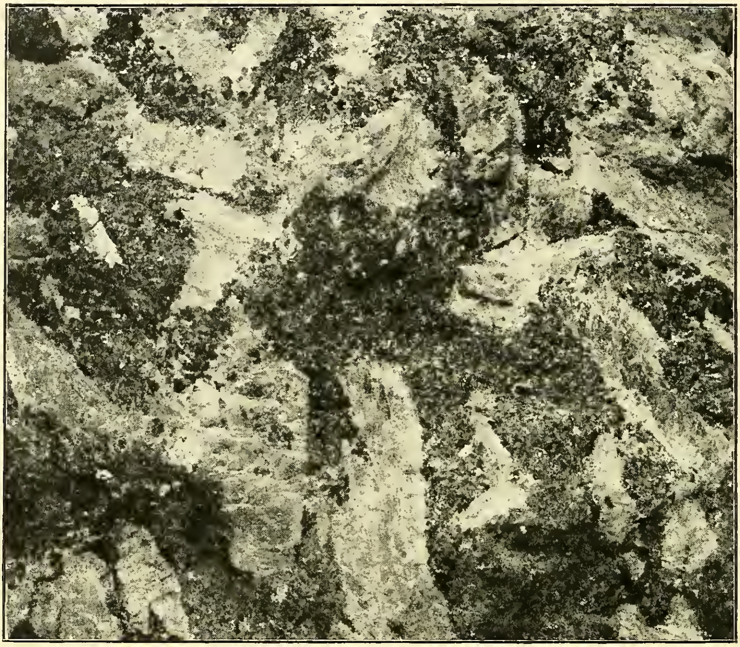

FIG. 1.—Prowersose from Knox County, Maine. Natural size.

become more and more elongate until we have a single long, needle-like crystal which resembles the rutile needles common in many quartzes. In certain of the feldspars these inclusions are arranged in two or three intersecting sets which, in some cases at least, parallel the cleavage planes, though in other parts of the feldspar they seem to have every conceivable orientation. Besides those mentioned above, there occur, scattered irregularly through the feldspar, a large number of minute, globular, or prismatic inclusions of indeterminate character.

The zonal structure observed in many of the feldspars is the result of the alternation of bands of only slightly different composition, rather than any considerable and progressive change in composition in passing from the center outward. The index of refraction in this case never rises above that of Canada balsam. Some bands are orthoclase, while others are microcline, and slight variations in composition are also indicated by slight differences in the double refraction and in the extinction angles. Inclusions are very much more abundant in some of the bands than in others, and it is those bands which contain the abundant inclusions that are dark-colored megascopically. This suggests that the peculiar purplish-gray color of certain parts of the feldspar may be due largely, if not wholly, to the inclusions.

The groundmass, when examined microscopically, shows the minerals indicated in the following table:

	Proportions in Groundmass	Proportions in Whole Rock
Biotite	55.5%	29.0%
Hornblende	32.6	19.0
Titanite	6.3	3.5
Apatite	5.0	3.0
Quartz	3.2	3.0
Titaniferous Magnetite	1.6	1.0
Feldspar	0.7	41.5*
Total	99.9	100.0

*An estimated amount of 1 per cent. of quartz occurs as inclusions in the feldspars.

Brown biotite, the most abundant of the ferromagnesian constituents, occurs in plates of various sizes up to 2^{mm} across. All are perfectly fresh. Within the larger plates inclusions of titanite, often forming a border about ilmenite or titaniferous magnetite, are abundant. Some zircon and numerous apatite prisms are also inclosed.

The hornblende individuals seldom exceed $\frac{1}{2}^{\text{mm}}$ in diameter, but are usually grouped in aggregates which may be 2 to 3^{mm} across. The color is light green, and the pleochroism is not marked. The aggregates inclose some biotite, some titanite, and abundant prisms of apatite.

Titanite occurs abundantly in small grains, but larger aggregates are usually associated with a mineral showing the optical properties of magnetite. This mineral is probably ilmenite or titaniferous magnetite. If forms a core surrounded by rather an even border of titanite, or else occurs in small irregular grains scattered through the central portion of the titanite aggregate. Some of these titanite and titaniferous magnetite masses are over $1\frac{1}{2}^{\text{mm}}$ in diameter. This association suggests that the titanite is a decomposition product from the titaniferous magnetite. This decomposition is somewhat remarkable in view of the exceedingly fresh state of the hornblende and the biotite; but it seems improbable that the titanite and titaniferous magnetite are in parallel growth, or that the hornblende and biotite owe their fresh appearance to recrystallization.

Apatite is very abundant in short prisms averaging about $\frac{1}{10}^{\text{mm}}$ in diameter. These are inclosed by all the other constituents of the rock, even by the titaniferous magnetite.

Quartz occurs, mainly about the borders of the feldspar phenocrysts, in small grains which are usually aggregated.

Feldspar is present only rarely in the groundmass, and is then usually close to the phenocrysts. It is microcline or orthoclase.

In some of the feldspar phenocrysts we find inclosures which have the same mineral composition as the groundmass. Upon careful examination, these are seen to occur along lines of healed fracture. When several such inclosures occur in the same phenocryst, they seem to be connected by an irregular band of feldspar differing slightly in appearance from the rest of the phenocryst. This difference may consist (1) in a lesser abundance of minute inclusions,

(2) in a slight difference in the proportions of the two feldspars in the microperthite, or (3) in a slight difference in the form of the bands, where the feldspar is microperthite. Along this zone we may also find small, scattered crystals of hornblende or of biotite. This phenomenon indicates a fracturing of the phenocrysts before the groundmass was completely crystallized, the introduction of portions of the groundmass into the fracture, and the healing of the fracture, probably by crystallization out of the mother-liquor.

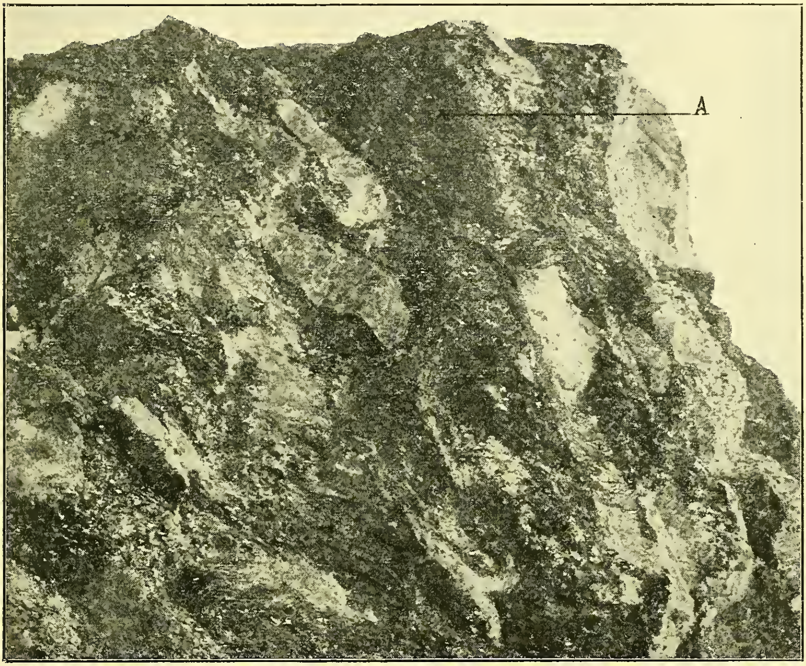

Fig. 2.—Sheared specimens of Prowersose from Knox County, Maine. Nearly natural size. Face slightly inclined to the schistosity. A = one of the mica-coated phenocrysts.

The feldspar phenocrysts seem to have been developed early in the crystallization of the rock, though antedated by the small quartzes and feldspars which they inclose. It is possible that they were fully grown before crystallization of the groundmass commenced. None of the slides show clearly that the feldspars inclosed portions of the groundmass in any other way than that described above. Of the minerals of the groundmass, apatite seems to have been the first to crystallize, followed by titaniferous magnetite, biotite, quartz, and hornblende. In only a few instances is the hornblende inclosed in biotite, but the reverse relation is very common.

Near the border of the area the porphyry has, in many places, been considerably sheared. The feldspars for the most part remain intact, though showing some fracturing and bending under the microscope. They have become coated, however, with a "skin" of secondary biotite which adheres even after they have weathered out from their matrix (Fig. 2). Except for this development of mica, the sheared rock differs but little in microscopic appearance from the unsheared.

The chemical analysis, and the classification of this rock according to the quantitative system, are given in the tables on the opposite page.

According to Washington's[1] table of rock analyses, the only other known rock falling in this subrang is one collected by G. K. Gilbert from Two Buttes, Prowers County, Colo., and briefly described by Whitman Cross.[2] This is a laccolitic rock, and has as its chief constituents diopside, alkali feldspar, considerable biotite magnetite, and olivine. The ferromagnesian minerals predominate.

These rocks are peculiar in their high alkali content and in the preponderance of potash over soda. The only other highly alkaline rocks (perkalkalic or domalkalic) of this class which show a corresponding preponderance of potash (perpotassic or dōpotassic) are wyomingose, madupose, and orendose from the Leucite Hills of Wyoming, chotose from the Bearpaw Mountains of Montana, and albanose from the Alban Hills of Italy. All of these rocks show leucite in the mode, and in all except orendose it is present also in the norm. In orendose the high potash content is indicated by the presence of potassium metasilicate in the norm. In prower-

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[1] H. S. Washington, "Chemical Analyses of Igneous Rocks," *Professional Paper No. 14*, U. S. Geological Survey, p. 313.

[2] See *Bulletin No.* 228, *U. S.* Geological Survey, p. 186.

	Prowersose from* Knox Co., Maine	Prowersose from† Two Buttes, Prowers County, Colo.
SiO_2	52.26 0.871	50.41 0.840
Al_2O_3	10.63 0.104	12.27 0.120
Fe_2O_3	2.47 0.015	5.71 0.035
FeO	5.45 0.076	3.06 0.043
MgO	9.32 0.223	8.69 0.217
CaO	5.62 0.100	7.08 0.127
Na_2O	1.60 0.026	0.97 0.016
K_2O	5.99 0.064	7.53 0.080
H_2O+	1.97	1.80
H_2O-	0.98	0.46
TiO_2	1.92 0.024	1.47 0.018
P_2O_5	0.98 0.007	0.46 0.003
MnO	0.12 0.002	0.15 0.002
ZrO	0.08 0.001	....
CO_2	0.75	....
BaO & SrO	....	0.29
V_2O_3 & NiO	....	0.07
Total	100.14	100.42

* Analysis by George Steiger, Laboratory of U. S. Geological Survey

† Analysis by W. F. Hillebrand, Laboratory of U. S. Geological Survey.

NORM OF PROWERSOSE FROM KNOX COUNTY, MAINE, CALCULATED FROM THE ANALYSIS

Orthoclase	35.58%
Albite	13.62
Anorthite	3.89
Diopside	13.90
Olivine	4.91
Hypersthene	15.04
Magnetite	3.48
Ilmenite	3.65
Apatite	2.35
Zircon	0.18
Water	2.95
Carbon dioxide	0.75
Total	100.27

Class, $\frac{\text{Sal.}}{\text{Fem.}} = \frac{53.09}{43.51} = < \frac{5}{3} > \frac{3}{5} = \text{III}$, Salfemane.

Order, $\frac{Q}{F} = \frac{O}{53.09} = < \frac{1}{7} = 5$, Gallare.

Rang, $\frac{K_2O + Na_2O}{CaO} = \frac{90}{14} < \frac{7}{1} > \frac{5}{3} = 2$, domalkalic, Kilauase.

Subrang, $\frac{K_2O}{Na_2O} = \frac{64}{26} < \frac{7}{1} > \frac{5}{3} = 2$, dopotassic, *Prowersose.*

sose the only potash minerals in the mode are biotite, microcline, and orthoclase, while in the norm only orthoclase is present.

II. ALBITE-PYROXENE-SYENITE

These rocks form part of a series of greenstones which have a more or less scattered distribution over an area of about 250 square miles among the islands of Penobscot Bay. The largest continuous area is on North Haven, where they occupy all but the extreme southern parts of the island. From North Haven they extend northwestward to Islesboro and the islands south of it; eastward they extend to the western part of Deer Isle; to the north they reach the mainland in the vicinity of South Brooksville.

The greenstone series consists of diabases, basic trachytes, and albite-pyroxene-syenites, which in very many places show the characters of surface volcanics in the occurrence of tuffs, breccias, and amygdaloidal phases, and in the development of columnar parting and "bolster" or "pillow" structure. Most of these rocks show considerable alteration, but enough moderately fresh specimens occur to place their original character beyond doubt.

It is difficult to estimate the exact proportion which the albite-pyroxene-syenite bears to the trachytes and diabases, but it probably constitutes nearly, if not quite, one-half of the greenstone series. Its normal phase is massive, and it is usually associated with the other greenstones and with the neighboring acid volcanics in the form of dikes and sills. In a few cases, as will be described later, it shows the characteristics of a surface volcanic. With most of the other rocks of this region, it has been affected by regional metamorphism, and in numerous localities a slight schistosity has been developed.

Intrusive phases.—The commonest type of albite-pyroxene syenite is a massive to feebly schistose rock, usually dark green in color, or showing a mottling of light and dark green, the light-green portions representing somewhat altered feldspar areas, and the dark-green the ferromagnesian constituents; in some of the more feldspathic phases the feldspars are almost pure white.

Upon microscopic examination, the texture is usually found to be poikilitic. In some specimens this texture is rendered irregular by the great variations in the size of the feldspar individuals, while in others it has been obscured or destroyed in the development of a schistose structure or in the weathering. The feldspars are striated and usually form rather short prisms, most of which range from ½ to 1½^{mm} in length; in many of the slides they are remarkably fresh. They are shown to be albite by their low extinction angles, and by the index of refraction, which is uniformly equal to, or less than, Canada balsam. The pyroxene, which normally forms a poikilitic matrix for the feldspar laths, is pale pinkish-yellow in color, with a hardly noticeable pleochroism, and shows extinction angles ranging up to 45, but usually under 40°. These angles are found in both augite and diopside, but the fact that the angles never exceeded 45° in the half-dozen or so slides studied, as well as certain considerations as to chemical composition to be brought out later, points to the non-aluminous diopside rather than to an aluminous pyroxene. Magnetite is the only other original constituent which plays an important rôle; it occurs in irregular grains, which sometimes assume skeleton forms, and may then partially inclose feldspar crystals.

Near the head of Southern Harbor, on the island of North Haven, the syenite is peculiar in the possession of scattered feldspar phenocrysts which are occasionally ½ inch in length. Relatively fresh representatives of the common massive type are found on Hardhead Island and at the southern end of Spruce Head Island.

Exrustive phases.—Amygdaloidal phases of the syenite were found on the southern end of Bare Island. A part of Mark Island and the greater portion of Beach Island are occupied by a phase of the greenstones characterized by the development of very ragged surfaces on weathering, and by the possession often of a purplish tint which is not characteristic of the greenstones elsewhere. In certain places the weathering reveals a distinctly tuffaceous character. In the field these were looked upon as flows and tuffs, and this is borne out by the microscopic examination, which shows them to be a very fine-grained phase of the albite-pyroxene-syenite series. The rock shows a diabasic texture with laths of albite, varying considerably in size, but mainly minute; between them is chlorite, epidote in small grains, and somewhat altered magnetite.

Weathering and shearing effects.—Even those occurrences of the syenite which, in the hand-specimen, appear massive and very fresh, show under the microscope traces of dynamic action and of very considerable weathering. Distinctly, though not highly, schistose phases are even commoner than the massive phases, and are usually much more altered mineralogically. In a few of the less schistose phases considerable pyroxene still remains, but even here some of this mineral has decomposed with the development of hornblende. In the more schistose phases the femic constituents are green hornblende, fibrous actinolite, and chlorite; in some only chlorite remains. Albite has resisted decomposition much longer than a calcic feldspar would have done under the same conditions. The laths often show fracturing, a pulling apart of the fragments, and their rotation, partial or complete, so that their longer axes lie in the plane of the schistosity. The rotation of the feldspars contributes to the development of the schistose structure, which, however, is due primarily to the distribution of the chlorite in long irregular bands, to some parallelism among the shreds of fibrous hornblende, and to the distribution of secondary epidote grains in irregular aggregates which are elongate palallel to the bands of chlorite. Occasionally some muscovite is developed and aids in defining the schistosity. Magnetite is usually largely altered to titanite or leucoxene. Zoisite, calcite, apatite, biotite, and chloritoid minerals are minor secondary constituents which are sometimes present. Very rarely serpentine has been abundantly developed, as in the intrusive mass which forms the 80-foot hill just east of the steamboat landing at Eggemoggin on Little Deer Isle.

So far as the writer's knowledge goes, all of the pyroxene-syenites thus far described which have contained albite have also contained nephelite or some calcic feldspar, and in most cases the albite has been a very subordinate constituent. The rock here described is unusual in the abundant association of the non-calcic feldspar, albite, with the calcic mineral, pyroxene. In the absence of sufficient material from localities where the rock was freshest, no chemical analyses could be made, and without such it would be unsafe to attempt an explanation of this association. It may be suggested, however, that the explanation may lie in a deficiency of alumina.

The soda, having a stronger affinity for alumina than the calcium, would appropriate it all in the production of albite, while the calcium would be forced to combine with the iron and magnesia in the formation of diopside.

III. A NEW OCCURRENCE OF CORTLANDITE

In 1886 G. H. Williams[1] described certain peridotites from the Cortland series near Stony Point, N. Y., which were peculiar mainly in the development of large hornblende crystals which served as a poikilitic matrix for olivine grains. It was in the description of these rocks that the term "poikilitic" was first applied. The hornblende crystals occasionally reach a diameter of 4 inches, and frequently show "schillerization." The olivine is usually very fresh. Besides these two constituents, some hypersthene, augite, biotite, and magnetite are usually present; feldspar is sometimes an accessory, but is never important. For this rock Williams[2] proposed the name "Cortlandite."

Professor B. K. Emerson[3] has described a peridotite from Belchertown, Hampshire County, Mass., which exhibits most of the characters of William's rock and to which he has applied the same name, and Williams[1] has published an analysis of a somewhat altered occurrence from Howard County, Md. The analyses of these rocks place them in Class IV Dofemane, Order 1 Perpolic, and Rang 1 Permirlic, of the quantitative system.

The rock to be described below occurs near the village of Penobscot in Hancock County, Maine, in the Bluehill Quadrangle. It forms a single outcrop, hardly 30 feet in length and breadth, located about ½ mile east of Pierce Pond. The ledge rises above its surroundings in such a manner as to resemble a huge half-buried bowlder, but the rock is undoubtedly in place and owes its prominence merely to a superior resistance to glacial erosion. Post-glacial weathering has been very considerable, and a red soil containing scattered

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[1] G. H. Williams, "The Peridotites of the 'Cortland Series' on the Hudson River near Peekskill, N. Y.," *American Journal of Science*, Third Series, Vol. XXXI (1886), pp. 26–41.

[2] *Ibid.*, p. 30.

[3] B. K. Emerson, *Monograph XXIX*, U. S. Geological Survey, 1898, pp. 346, 347.

hornblende crystals is the result; on the weathered faces the large hornblendes, some of them $2\frac{1}{2}$ inches across, stand out so as to give a knotty or warty appearance. The rock is exceedingly tough and resistant under the hammer.

The megascopic appearance is very similar to that described by Williams for the type locality. The hand-specimen shows a dark-green to almost black rock, with hornblendes ranging from $\frac{1}{2}$ to $2\frac{1}{2}$ inches in diameter; when held at the proper angle, these reflect the light as units, but show numerous dull, irregular inclusions from $\frac{1}{32}$ to $\frac{1}{8}$ of an inch in diameter, which under the microscope prove to be olivine or its alteration product, serpentine, with an occasional crystal of pyroxene. Light-brown biotite is the only other mineral recognizable megascopically; it occurs between the hornblendes and is quite abundant.

Under the microscope the rock is seen to be only slightly altered. The hornblende is mainly massive, but is occasionally fibrous about the edges of the grains, where some alteration has taken place. The color ranges from light green to light brown; the pleochroism is noticeable, but not very strong, $\mathfrak{a}$ = light yellow, $\mathfrak{b}$ = light green, $\mathfrak{c}$ = light green to light brown. Inclusions of magnetite are abundant in the hornblende and vary greatly in size. The majority are quite irregular in outline, but show a tendency toward elongation in the direction of the hornblende cleavage and toward the possession of straight boundaries in this direction. In some of the hornblende crystals inclusions of magnetite and also of pyrite assume minute needlelike or platelike forms, usually elongate parallel to the cleavage planes, but in some cases occurring in as many as three sets, inclined at widely divergent angles. This latter type of inclusions gives to the mineral, when viewed in reflected light, the peculiar metallic sheen which has been described by Judd and others, and has been termed "schillerization."

Olivine ranks next to hornblende in abundance and occurs in grains of more or less rounded outline, usually inclosed by the hornblende; they vary considerably in size. The characteristic irregular fracturing is present, and a few grains show slight serpentinization along the cracks. The serpentine is usually light-colored and appears gray between crossed nicols; occasionally the yellowish-green variety is developed. The olivine contains numerous magnetite inclusions, usually very irregular in form, and distributed principally along the cracks; some of the smaller ones show dendritic forms. All are probably of secondary origin.

Hypersthene occurs in irregularly bounded grains. Pleochroism strong, $\mathfrak{a}$ = pale salmon-pink, $\mathfrak{b}$ = pale yellow, $\mathfrak{c}$ = pale green. It occasionally incloses both olivine and biotite. In a few places it shows slight alteration to hornblende.

Biotite is abundant and quite strongly pleochroic, colorless to pale yellow parallel to $\mathfrak{a}$, yellowish to light brown parallel to $\mathfrak{b}$ or $\mathfrak{c}$; it seems to be in small part a product of hornblende alteration.

A micaceous mineral showing only feeble pleochroism and interference colors never above yellow of the first order is probably intermediate in character between chlinochlore and pennine. It appears to be uniaxial and optically positive, with the slow direction parallel to the micaceous cleavage (i. e., perpendicular to $\mathfrak{c}$). The pleochroism is light green for rays vibrating parallel to the base, and colorless for rays at right angles to this.

Magnetite and olivine were the first minerals to crystallize, followed by hornblende, hypersthene, and biotite, the last three being about contemporaneous. The elongation of many of the magnetite inclusions parallel to the cleavage planes of the inclosing hornblende, shows either some secondary magnetite crystallization, or else a partially contemporaneous crystallization of hornblende and magnetite.

Megascopically, the Maine rock differs from the type rock of Stony Point, mainly in showing a much larger amount of biotite. Microscopically, the same difference is apparent, and it is also seen that the colors of the hornblende are much paler in the Maine specimen; in the Stony Point rock this mineral is a dark reddish brown. Some of the Stony Point specimens show feldspar as a subordinate constituent, but here it is wholly absent. The relative proportions between hornblende and olivine seem to be about the same in the two rocks. No chemical analysis was made of the Maine rock, but it is probable that it will fall within the same order as those already analyzed.

The geologic age of the rock here described is uncertain, because the actual contacts are not exposed. It is associated with a border zone of diorite and gabbro surrounding, and practically contemporaneous with, a large granite mass of probable Devonian age. This association, however, may be accidental, and the Cortlandite may be a considerably later intrusion.

IV. PORPHYRITIC GRANITE FROM SOMERSET COUNTY

The specimen here described was collected by Dr. George Otis Smith in the course of a reconnaissance trip in the summer of 1905, and is worthy of brief notice because of its unusually coarse porphyritic character. Bowlders of this rock are common in Somerset County, and in going up the Carrabassett valley they become more and more plentiful, the rock being found in place in Highland Plantation. Here it forms the divide between Dead River and Carrabassett River, both tributaries of the Kennebec. Where crossed by the county road it shows tabular feldspars 3 to 5 inches in length, and is exposed for several miles. The porphyritic granite does not extend into the adjacent townships to the east and west, and that seen both to the north and south of this locality is more of the normal type. The coarsely porphyritic rock seems to be characteristic of an area a few miles square, which does not, however, represent a peripheral zone, but is more probably a separate intrusive mass in a region quite thoroughly intruded with granite.

The specimen examined by the writer came from well within this area. It shows a number of phenocrysts of feldspar, tabular parallel to the *b* pinnacoid, and lying in approximately parallel positions. The largest of these is 7 inches long, 3 inches wide, and ½ to ¾ of an inch thick. In most of the crystals a very pronounced zonal structure is shown on these side pinnacoid faces, and is seen to be due partly to the greater abundance of muscovite along certain layers, and partly to slight differences in tint which probably correspond to slight variations in composition. A microscopic examination of material from the center and from various points on the periphery of the crystal, using Wright's[1] adaptation of Schroeder's method, showed that there was no considerable or progressive change in composition from the center outward. The

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[1] F. E. Wright, *American Journal of Science*, Vol. XVII (1904), pp. 385–87.

feldspar throughout is microcline and orthoclase, occasionally perthitically intergrown with small amounts of albite. The groundmass is a medium-grained association of quartz and potash feldspar, in nearly equal amounts. With these are associated abundant brown biotite and small amounts of muscovite. The texture is granitic.

NOTES ON THE RANGE AND DISTRIBUTION OF *RETICULARIA LAEVIS*[1]

E. M. KINDLE

Progress in stratigraphic paleontology in recent years has been largely along the line of increasing our knowledge of the range and distribution of faunas and of the individual species composing them. The important bearing of this class of knowledge upon questions concerning the evolution and dispersal of faunas is evident. Its interest to the general geologist lies chiefly in the fact that the accuracy with which fossils can be used in correlation is in direct proportion to the completeness of our knowledge of their range.

The rapid growth of stratigraphic paleontology during the last two decades, as compared with preceding decades, is illustrated in the history of the development of our knowledge concerning the distribution and range of *Reticularia laevis*, a well-known Devonian brachiopod. For nearly forty years after it had been described practically nothing was added to the information concerning its distribution and range given by Hall at the time of its description. In 1881 Williams wrote: "Only a few localities are known in which this large fossil is found, and, so far as I can learn, none outside of the state" (New York).[2] Its vertical range was then supposed to be limited to about 3 feet[3] of strata. During the twenty years which have elapsed since this was written the distribution of the species has been extended from a small area in central New York across two other states, and the known vertical range has grown from 3 feet to more than a thousand.

Reticularia laevis first appears in the New York section in the lower part of the Nunda or Portage formation. It belongs normally to the brachiopod fauna of the Ithaca facies of the Nunda or Portage. It has never been found associated with the Naples facies which

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[1] Published by permission of the director of the U. S. Geological Survey.

[2] *Annals of the New York Academy of Science*, Vol. II (1881), p. 140.

[3] *Ibid.*, p. 141.

flourished alongside and to the westward of the Ithaca fauna. At the best-known locality of its occurrence *R. laevis* is found abundantly through 3 feet of strata, above and below which it is unknown for a considerable interval. At this locality, which is at the foot of Ithaca Falls, at Ithaca, N. Y., the associated fauna, as determined by the writer,[1] is as follows:

Lingula ligea? r.
Crania sp. r.
Chonetes lepida a.
Chonetes scitula r.
Leiorhynchus mesacostalis
Cyrtina hamiltonensis r.
Spirifer laevis a.
Lunulicardium fragile a.
Paleoneilo filosa a.
Ariculopecten rugaestriatus?
Aviculopecten lautus var. ithacensis r.
Modiomorpha subalata
Grammysia subarcuata r.
Glyptocardia speciosa r.
Nucula diffidens r.
Mytilarca chemungensis? r.
Leda diversa
Pleurotomaria capillaria r.
Orthoceras pecator r.
Tornoceras discoideum c.
Taxacrinus ithacensis

This zone of *Sp. laevis* is about 250 feet above the Genesee shale and near the top of the Sherburne sandstone. It lies below the typical Ithaca fauna at a horizon where more or less intermingling of the Naples and Ithaca faunas occurred. The Ithaca element of the fauna is seen in the brachiopod species, while the western fauna is represented by such forms as *Lunulicardium fragile* and *Glyptocardia speciosa.*

This horizon, from which the species was described by James Hall in 1843,[2] remained the only one known for it till forty years later, when Williams found it near the top of the Ithaca fauna,[3] at a single locality in the Fall Creek section about 400 feet higher.

While studying the Ithaca fauna in 1896 the writer found a third zone of *Reticularia laevis* at Ithaca in the McKinneys Station section, which is 120 feet below the zone at the foot of Ithaca Falls.[4]

The discovery of this third zone extended the known vertical range to about 520 feet. The upper zone of the species at or near the top of the Ithaca group had not been relocated since its discovery

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[1] *Bulletins of American Paleontology,* No. 6 (1896), p. 17.

[2] Geology of New York, *Report of Fourth District* (1843), p. 245, fig.

[3] *Bulletin No. 3,* U. S. Geological Survey, 1884, p. 20.

[4] *Bulletins of American Paleontology,* No. 6 (1896), p. 28.

by Williams in the early eighties, until the areal survey of the Watkin's Glen quadrangle was undertaken. During this survey the writer found it at several localities near the top of the Ithaca group. In this zone *Reticularia laevis* is associated with typical Ithaca species, such as *Leptostrophia mucronatus*, *Spirifer mucronatus* var. *posterus*, and *Pugnax pugnus*. This zone near the top of the Ithaca member lies about 650 feet above the Genesee shale. No higher occurrence of the species within the Nunda formation is known. The few fossils which occur in the upper half of the Nunda sections near Ithaca belong to the Naples or western facies, a facies with which *Reticularia laevis* has nowhere been found associated. In the Brookton section, near Ithaca, the writer found a fourth zone of this species entirely above the Nunda, and very near the base of the Chemung formation. Here *R. laevis* occurs in abundance in the same bed with *Spirifer disjunctus*, which is also abundant. This, the highest known horizon of *R. laevis*, is not more than 50 feet above the base of the Chemung, and lies about 1,300 feet above the Genesee shale.

We are indebted to J. M. Clarke and D. D. Luther for the recorded observations on the range of the species to the east and west of Ithaca. Hall, in his orignal descriptions, reported the species to occur[1] on the "shore of Seneca Lake," but gave no definite locality, and the species was not found by subsequent workers in the Seneca basin until a comparatively recent date. In 1885 Clarke wrote: "I do not know of its occurrence[2] west of Tompkins County." In Clarke's first report on the Portage faunas of the Seneca basin *R. laevis* does not appear. In the recent paper by Clarke and Luther it is recorded from a single locality near Montour Falls. In this region Mr. V. H. Barnett and the writer found this species at the locality cited by Clarke and Luther, and also in the Watkins and Havana Glen sections. It occurs in the Watkins Glen section about 185 feet above the level of Seneca Lake. These occurrences in the Seneca basin are within the horizon occupied by the Ithaca fauna in the section. The Naples facies has largely supplanted the Ithaca facies in the Seneca section, greatly reducing the thickness of the portion of the column occupied by it.

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[1] Geology of New York, *Report of Fourth District* (1843), p. 245.

[2] *Bulletin No. 16*, U. S. Geological Survey, 1885, p. 66.

Eastward of Ithaca, *R. laevis* has not been found beyond the valley of the Chenango River. The easternmost localities known in the New York area are the McGrawville section 4 miles east of Courtland, East Homer,[1] and the Cowles Hill section at Greene.[2] In the region intervening between the Cayuga section and the Chenango valley, *R. laevis* has been found at a number of localities during the survey of the quadrangles in this district. Its occurrence in this area has also been recorded by Clarke and Luther.[3] East of Ithaca the Ithaca brachiopod fauna extends upwards, filling the upper part of the Nunda column, which was occupied by the Naples facies to the westward before the Tiognioga River is reached. All of the occurrences of *R. laevis* in this region are associated with the Ithaca fauna.

The occurrence at Greene represents the highest horizon attained by the species in this eastern region. It occurs here above the Oneonta sandstone in what Clarke calls a "proemial Chemung fauna,"[4] and "not less than 1,200 feet above its first appearance"[5] at Ithaca, according to this author. In this section *R. laevis* occurs with *Leptostrophia mucronata*, an Ithaca species, and no Chemung fossils are reported as occurring with it, so that Clarke's conclusion as to its post-Nunda age is based presumably upon stratigraphic grounds. The discovery of *R. laevis* and *Sp. disjunctus* in association, by the writer, as already noted, however, leaves no question as to the fact that *R. laevis* appears in the New York section as late as the lower part of the Chemung.

In Pennsylvania *R. laevis* has been found at only two localities. These are on the Susquehanna River, in sections studied by the writer at Hollowing Run and Catawissa. In both of these sections the species is found associated with the fauna of the Ithaca facies. In the Catawissa section *R. laevis* occurs at two horizons. The lower faunule in which it occurs contains:

Cystodictya meeki (a)
Cyrtina hamiltonensis (r)
Spirifer mucronatus var. posterus (r)
Sanguinolites (?) sp. (r)
Nucula sp. (r)
Palaeoneilo plana (c)
Leda diversa (r)
Actinopteria perstrialis (a)

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[1] *Fifteenth Annual Report*, New York State Geologist, 1895, p. 72.

[2] *Ibid.*, pp. 37–39.

[3] *Bulletin No. 82*, New York State Museum, p. 64.

[4] *Sixteenth Annual Report*, New York State Geologist, 1896, p. 36.

[5] *Fifteenth Annual Report*, New York State Geologist, 1895, p. 39.

This lower zone lies 480 feet, and the second zone 1,380 feet, above the Genesee shale, so that the species in this section has a known range of 900 feet.

In the Hollowing Run section, which lies about 25 miles southwest of the Catawissa section, *R. laevis* was found at only one horizon. Its occurrence in this section is not far from the horizon of the lower *R. laevis* zone in the Catawissa section.

In Pennsylvania the Naples and Ithaca facies of the Nunda hold the same geographic relation to each other that they do in New York, the first occupying the westerly, and the second the easterly, sections of the Nunda. The Altoona section, which has been studied by Mr. Charles Butts and the writer, lies well to the west of the Susquehanna sections, and within the area of the dominance of the Naples facies. Neither *R. laevis* nor any other faunal element of the Ithaca facies was found in it. The limitation of the known occurrence of *R. laevis* to two sections is doubtless due to the fact that these are the only sections which have been carefully studied within the area where this species may be expected to occur. It is safe to predict that *R. laevis* will be found in many of the more easterly sections of the Nunda from the New York to the Maryland line, and that it will not generally be found in the westerly sections.

A collection of fossils from West Virginia recently submitted to the writer by Mr. George Stose for determination contains two specimens of *R. laevis*.[1] They occur in association with a brachiopod fauna representing the Ithaca facies of the Nunda. They were collected on Yellow Spring Run, 3 miles southeast of Berkley Springs, W. Va. Mr. Stose's collection represents the most southerly occurrence of the species which has been discovered. The determination of these West Virginia specimens gives the species a known distribution in a northerly and southerly direction of about 225 miles. In New York its distribution in an easterly and westerly direction appears to be limited to about 60 miles. In the southern part of its range we have as yet no data for determining its distribution in this

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[1] The Hancock quadrangle in which this species was found is being surveyed co-operatively by the Maryland and United States Geological Surveys, and the writer is able to publish these data through the courtesy of Professor W. B. Clarke, director of the Maryland Geological Survey.

direction, but it may be stated that it will probably be found to coincide with the distribution of the Ithaca facies of the Nunda.

The maximum range of the species, as shown by the New York sections, extends from near the base of the Nunda into the lower Chemung. It has, however, been found at a post-Nunda horizon in only two of the many sections in which it is known.

THE HOT SPRINGS AT THERMOPOLIS, WYOMING[1]

N. H. DARTON

At the southern end of the Bighorn Basin there is a great hot spring which presents some notable geologic features and an interesting question as to the source of the hot water. The spring is at the town of Thermopolis, a village and health resort which owes its existence largely to the reputed therapeutic value of the water. The locality is on the bank of Bighorn River, a few miles north of a high range which may be regarded as the southwestern continuation of the Bighorn Mountains. There are several springs, but one of them has by far the greatest volume. They issue from the red beds, here brought to the surface by a prominent local anticline. The present springs and their predecessors—for the region has been one of thermal activity for many centuries—have built extensive terraces of travertine or hot spring deposits similar to some of those in the Yellowstone National Park.

The geologic structure at Thermopolis is relatively simple and, owing to the extensive exposures of the formations, it is perfectly plain. The cross-section (Fig. 1) shows the relations from the crest of the Bighorn uplift in the mountain summit 10 miles south to a point a few miles north of the springs.

South of the springs there is the long monocline constituting the north slope of the anticline of Bighorn Mountains, and in the vicinity of Thermopolis this monocline is crenulated by a sharp anticline. The axis of this flexure crosses Bighorn River a short distance north of Thermopolis, and along it there are exposed the Chugwater red beds, while on either side is a succession consisting of Sundance (Jurassic), Morrison, Cloverly ("Dakota"), and Benton formations. The dips on the south limb of the anticline are steep, 50° to 65°, while those on the north side are gentle. The Cloverly sandstone on either side gives rise to a prominent "hogback ridge,"

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[1] Published with permission of the Director of the U. S. Geological Survey.

as shown in the distance in the upper view in Fig. 2, facing a region of red bed hills about a mile wide and with outer slopes descending into valleys of Benton basal shales. Thermopolis is on the eastern limb of the anticline, the village extending across the outcrop zones of the Sundance, Morrison, and Cloverly formations, locally covered by an alluvial plain which extends back a few hundred rods from the river. There is no evidence of igneous rocks in the region.

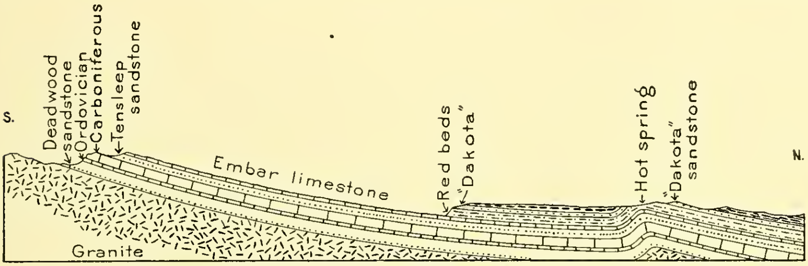

FIG. 1.—Section through the hot springs at Thermopolis, Wyo. Looking west. Length of section about fourteen miles.

The springs rise from the middle beds of the Chugwater formation, apparently through a number of deep cracks. The largest one issues from the foot of a high bank of 80 feet of red sandstones, as shown in Figs. 2 and *2a*, with a volume stated to be over a thousand gallons a second. The water is clear and hot, having a temperature of 135°. It flows over a wide terrace built of hot-spring deposits, over the edge of which it falls into the river. A part, however, is diverted into conduits of various kinds which lead to the various bathhouses, and to the reservoirs in which a portion of the water is cooled so that it may be used for diluting the hot water to the required temperature for bathing. The spring flows with great force, and evidently comes from considerable depth under high pressure. Numerous algæ of various colors grow in the hot and cooling water, as in the Yellowstone Park and other places. Besides the main spring, there are on the east side of the river a deep, hot pool which does not overflow and, some distance farther north, a hot sulphur spring which gushes out of the travertine bank a few feet above the river. On the west side are several small springs, one of which is utilized for a bathhouse and swimmingpool. An analysis of the water from the great spring, by Professor E. E. Slosson is as follows:

ANALYSIS OF WATER FROM HOT SPRINGS AT THERMOPOLIS, WYO.

	Grains per Gallon
SiO_2	4.986
Fe_2O_3 and Al_2O_3	0.227
K Cl	10.249
Na_2SO_4	15.110
Mg_2SO_4	19.443
Ca SO_4	13.156
Ca CO_3	40.454
Na Cl	26.195
Total	129.820

Hot Spring deposits.—The hot-spring deposits in the vicinity of Thermopolis indicate a long period of accumulation, for they occur on several distinct terraces, some of which date back probably to Tertiary time. The most recent deposits are being laid down on a broad terrace about 30 feet above the river, which is being built up very gradually. No precise estimate has been made of the rate of increase, but objects placed in the water are rapidly coated with the deposit, and a thickness of an eighth of an inch is accumulated in a short time. There are wide areas of the deposit on both sides of the river below the present springs, which were formed at no distant date, while, on the buttes which rise above this terrace level, there are caps of hot-spring deposits at various elevations. Some of the relations of these are shown in Figs. 3 and 4. The highest deposit caps a prominent butte near the cemetery, at an altitude of about 700 feet above the river. A larger terrace remnant remains on a butte which rises immediately west of the river to a height of about 350 feet above the water. It is probable that these terraces represent three distinct stages of deposition, and, although possibly hot-spring action has been continuous since the formation of the first or highest terrace, most of the deposits at intermediate levels have been removed. As travertine is often deposited on slopes, it is possible that the hot-spring waters issuing at the level of the higher buttes flowed to somewhat lower levels, with a continuous deposit from one to the other. It is evident, however, from the relations that there has been extensive erosion since the earliest period marked by the higher terraces on which the travertine caps are now found. The high butte near the cemetery—the one shown to the left in Figs. 3 and 4—is probably the remnant of a much more extended sheet of the travertine which was largely removed prior to or during the development of the lower terraces.

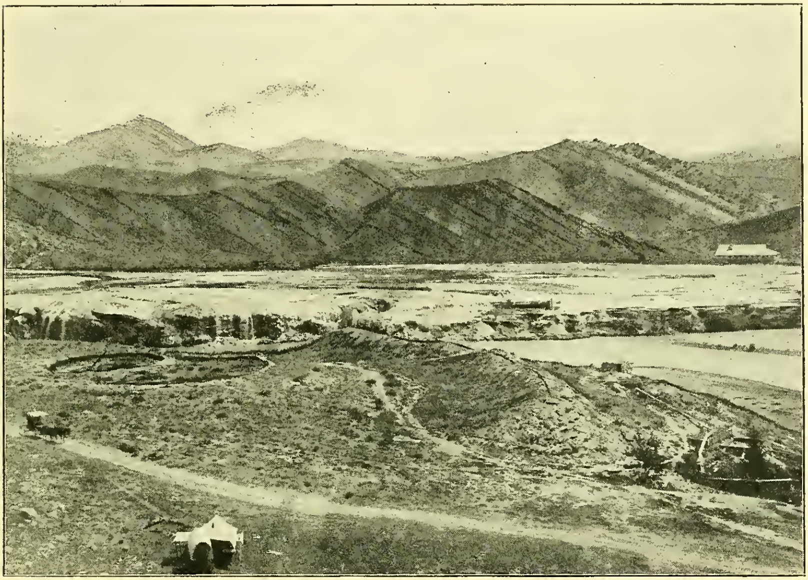

Fig. 2.—Travertine terrace of the Great Hot Spring on the east bank of Bighorn River near Thermopolis, Wyo. The spring is under the *S*. In the foreground are extinct hot-spring craters and a low ridge with long fissure in its summit. Shows upturned red beds and overlying formations.

It is evident, from the disposition of the material, that the springs have shifted their position, but in general the outflow has been in the immediate vicinity of the crest of the anticline. The hot-spring deposits show remnants of numerous hot-spring craters and cracks, some of the most marked of which are on the terraces near the river. On the west bank, a short distance north of the bathhouse, there is an empty crater 30 feet in diameter, shown in Fig. 2, indicating the former existence of a large hot pool, and there is another similar crater of still larger size, a short distance northeast of the sulphur spring on the east bank. One of the same character, but much less distinct, is found on the high terrace west of the cemetery 500 feet above the river. It is probable, from the present appearances of the deposits, that formerly the hot-spring activity was much greater than at present. Whether or not there were geysers is difficult to state, but some of the features of the deposits strongly suggest

FIG. 2*a*.—Terrace of hot-spring deposit on the bank of Bighorn River. Looking south to Thermopolis, with Owl Creek Mountains in the distance. Shows overflow of hot spring.

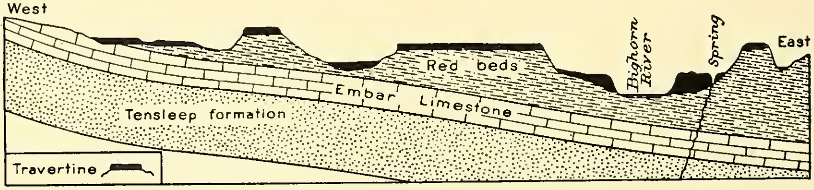

FIG. 3.—Cross-section of travertine terraces a short distance north of Thermopolis, Wyo. Looking north. Length of section about one mile.

that if the water was not thrown out by geyser action, it at least flowed in large volume.

Source of the water.—The source of the water in the Thermopolis springs is difficult to ascertain, but undoubtedly the flow is not derived from the adjacent Red beds, nor from the underlying Embar limestone. Probably the strata are somewhat fractured in the crest of the arch and permit the escape of the water from deep-seated sources. One of the most likely of these might be thought to be the porous Tensleep sandstone which outcrops high on the mountain slopes southward. It undoubtedly carries a water supply which passes beneath the syncline south of Thermopolis, and retains sufficient head to rise to and above the surface in any vent to the northward. If the water is from no greater depth than this horizon, there is difficulty in accounting for the high temperature, for the top of the sandstone does not lie at a greater depth than 500 feet at the spring and 2,000 feet in the bottom of the syncline a short distance south. Assuming that the mean annual temperature at Thermopolis is 50°, and that the temperature of water increases one degree for every 50 feet underground below

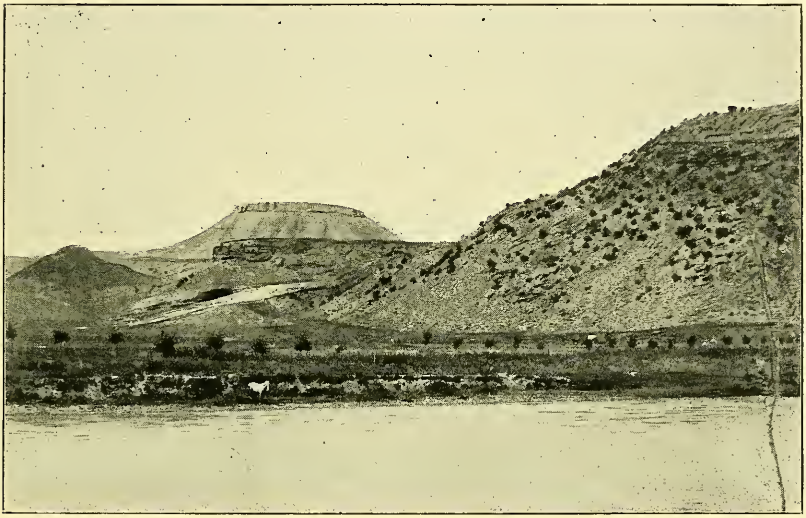

FIG. 4.—Hot Spring deposits on old terraces at various heights in western part of Thermopolis, Wyoming. Looking south across Bighorn River.

the first 50 feet—where the mean annual temperature is the underground temperature—a depth of 4,300 feet would be required for the spring water to become heated to 135° under ordinary conditions. As the granite probably lies only 2,500 feet below the spring, or 4,000 feet below the surface in the syncline south, this rate of increase would indicate a source at least as low as the base of the Deadwood formation. If the water is derived from the basal sandstone of that formation, it passes underground in the outcrop area in the high mountain slopes to the southeast, and becomes heated in the bottom of the syncline a short distance south of Thermopolis. In order to preserve this heat in its course to the outlets, there must exist cavernous channels affording rapid flow, as heat would be lost in slow percolation through the interstices of the rock. It is possible also that the source of the water is much less deep, and the heat may be due to deep-seated igneous rocks in this vicinity, which have not yet cooled. As the nearest outcrops of igneous rocks are in the Shoshone Mountains 40 miles west, it appears improbable that there are any intrusions under the Thermopolis region.

THE SEDIMENTARY ROCKS OF SOUTH MOUNTAIN, PENNSYLVANIA[1]

GEORGE W. STOSE

The area described in this paper is the western portion of South Mountain, Pa., and the adjacent part of the Cumberland Valley from near the Maryland state line to the vicinty of Shippensburg, Pa. It is about 15 miles in length. The accompanying topographic map of this area (Fig. 1) is taken from the Chambersburg sheet of the United States Geological Survey and the South Mountain atlas of the Pennsylvania Geological Survey. South Mountain is the local name for the Blue Ridge which parallels the Great Valley of the Appalachian Province on the east, and Cumberland Valley, a section of the Great Valley.

TOPOGRAPHY

The Cumberland Valley is a broad, rolling lowland extending from the Potomac River to the Susquehanna River. Its general elevation is from 400 to 800 feet, and scattered, low eminences rise to 1,100 feet. These hills are usually of the rounded form characteristic of limestone country, but in part they are shale tablelands with steep escarpments. The valley has a width of approximately 13 miles in the vicinity of Harrisburg, but expands to 20 miles in the area under discussion. The southern half of the valley is drained by Conococheague Creek and its tributaries into the Potomac, the northern half by Yellow Breeches Creek into the Susquehanna.

South Mountain is a more or less irregular aggregate of ridges with a general northeast-southwest trend. Although cut across by numerous gaps, and deflected in places by sharp bends, the ridges maintain a marked continuity. The mountain front rises abruptly from the plain to elevations of 1,700 or 1,900 feet. The interior ridges are generally higher, reaching 2,100 feet in places, whence they decline again eastward into lower hills.

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[1] Published by permission of the Director of the U. S. Geological Survey.

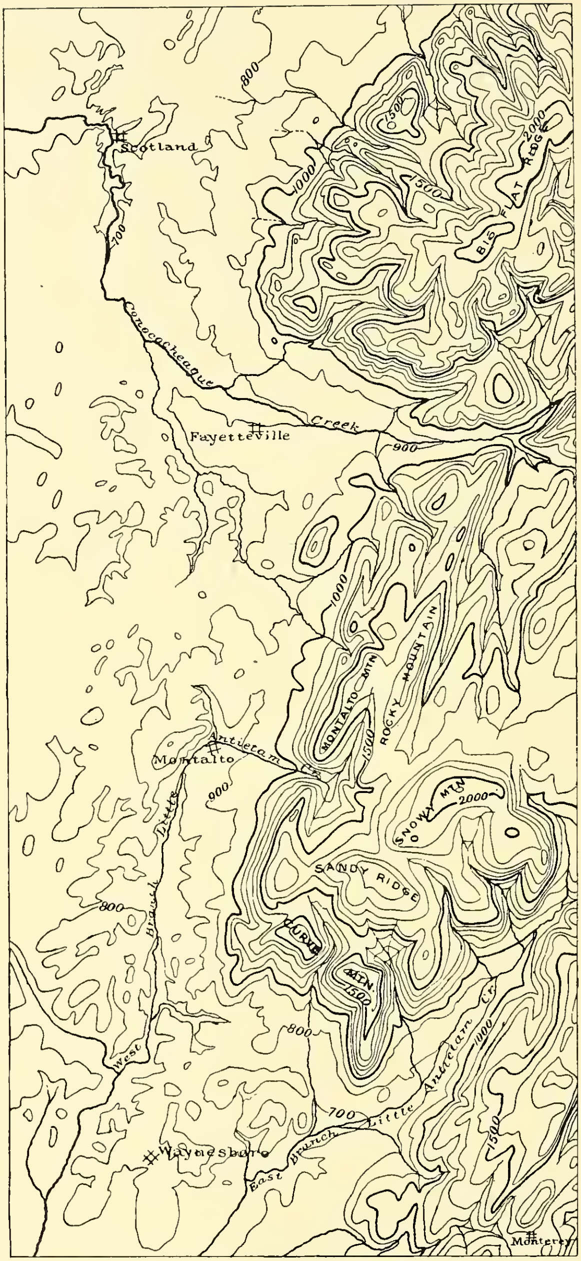

Fig. 1.—Topographic map of South Mountain in southern Pennsylvania, and adjacent portion of Cumberland Valley.

From the Potomac to the Maryland-Pennsylvania state line the mountain has approximately a straight, unbroken course nearly due north. At the East Branch of Little Antietam Creek, in the southeast corner of the area shown on the accompanying map, there is an offset of the mountain front of about one mile westward, the ridges on the north side lying farther into the valley. A short distance to the north another offset into the valley, of about 2½ miles, is produced by the sharp bend of the ridges to the westward, beyond which they again assume their northeasterly course, as may be seen on the map. North of Conococheague Creek another offset of 3½ miles is produced by the development to the westward of another ridge, broad and flat-topped, and dissected by numerous deep lateral valleys. This Big Flat Ridge has an altitude of over 2,100 feet, the highest point of South Mountain in Pennsylvania.

The drainage of the mountain area is accomplished by the East Branch of Little Antietam Creek and Conococheague Creek and their tributaries. The former rises some distance east of the area represented on the map, and flows southwestward directly across the ends of the ridges on the north side of its valley, but nearly parallel to the ridges on the south side. Its tributaries are all short, and form longitudinal valleys between the ridges on the north. The West Branch of Little Antietam Creek drains a portion of the Cumberland Valley adjacent to the mountains, and has its headwaters in the short longitudinal valley which outlets at the gap east of Montalto.

Conococheague Creek heads far beyond the border of the mapped area, and, after flowing southwestward in a longitudinal valley, turns abruptly westward through a gap in the ridges. It has several large tributaries which drain the interior of the mountain area in this vicinity, chief of which are Newmans Branch, a transverse stream from the east, and Rocky Mountain Creek, a longitudinal stream from the south. Numerous short tributaries head in the deep ravines on the east flank of Big Flat Ridge. Others on the west side of the ridge find underground courses beneath the covering of wash on the surface, or sink into limestone caverns before they reach the main stream. The waters of both Conococheague and Little Antietam creeks ultimately reach the Potomac River to the south.

GEOLOGY

The rocks in this area are largely concealed by the sandstone débris which covers the mountain tops as well as the valleys and slopes. Their character, thickness, and relation are therefore not readily determined. The structure is also complicated by schistosity and jointing which exist in all these rocks. The mountains are composed of Georgian (Lower Cambrian) quartzites, sandstones, and shales, and older igneous rocks; the adjacent portions of the Valley of Cambrian and Ordovician limestones and shales.

STRATIGRAPHY

Old volcanics.—The basement rocks exposed in the area are ancient volcanic rocks, greenstone and altered rhyolite, which underlie the basal Cambrian uncomformably. They occupy the plateau-like tract overlooked by higher peaks in the center of the mountain area shown on the map and in the extreme southeast corner, and are extensively developed to the eastward. The volcanic origin of these ancient rocks is clearly shown by flow banding, amygdaloidal structure, and spherulites, as described by Williams[1] and Bascom.[2] The greenstones are sheared dense rock, veined with asbestos and chlorite. The original structure is seldom preserved, but the rock is apparently an altered basalt. The rhyolitic rocks are of purple and red tints, often porphyritic and frequently banded by flow structure or spherulitic streaks. The rhyolitic rocks predominate in this area, and apparently overlie the greenstone, for the basal Cambrian sediments are composed largely of rhyolitic fragments and not of basaltic detritus, as would be the case if the greenstone were younger and had been eroded from most of the area.

Basal sandstones.—Overlying these softer rocks are about 4,500 feet of sandstone, quartzite, and shale of Georgian (Lower Cambrian) age. The basal beds, forming the higher and more rugged portions of the mountains, are composed of coarse, purple and yellowish banded sandstones, fine conglomerate, and arkose, with white

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[1] *American Journal of Science*, Third Series, Vol. XLIV, pp. 482–96.

[2] *Journal of Geology*, Vol. I, pp. 813–32, and *Bulletin of the U. S. Geological Survey*, No. 136.

feldspathic and vitreous sandstones above. The purplish conglomerate bed is composed of small pebbles and grains of quartz, feldspar, and purplish slate or tuff, the flat slaty fragments often having a diameter of 2 inches. This grades almost imperceptibly through soft purplish arkose into the reddish rhyolitic eruptives below, demonstrating their derivation largely from similar volcanic rocks exposed along the nearby shore of the Georgian sea. In Maryland, and also at Mount Holly at the north end of South Mountain, basal conglomerates contain numerous large quartz pebbles, probably in part derived from the granitic basement complex of the Piedmont.

This basal sandstone, on account of its hardness, forms high, rugged ridges in the heart of the range, such as Rocky Mountain and Snowy Mountain. It is continuous with the Weverton sandstone of the Catoctin and South mountains, Maryland, as mapped by Keith[1] and the name is therefore used here. The underlying Loudoun formation, which is described by Keith as variable in composition and thickness in Maryland, was not recognized as a distinct formation in this area, but may be represented in the soft arkose at the very base of the sedimentary series.

Upper shales and sandstones.—Above the Weverton sandstone there are about 3,200 feet of shale and soft sandstone in which are two horizons of hard, ridge-making sandstone. The softer beds are poorly exposed, being everywhere covered by the débris from the adjacent sandstones. Their presence is inferred from the fact that their outcrop is always occupied by valleys and depressions. Their character is indicated in part by occasional fragments of thin shaly sandstone and black banded slate or red ferruginous shale. The hard sandstone beds form the ridges along the mountain front and cap the high, flat-topped Sandy Ridge, as well as Big Flat Ridge north of Fayetteville. The lower of the two sandstones is the more massive, and is composed of a hard quartzitic stratum, usually of dark-gray color and veined with quartz, and a softer, granular, white layer containing long, slender *Scolithus* tubes. The upper hard bed at the top of the shale, is a milk-white or slightly pinkish, granular, calcareous sandstone, frequently disintegrating by the removal

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[1] "Geology of the Catoctin Belt," *Fourteenth Annual Report of the U. S. Geological Survey*, pp. 285–395.

of the soluble cement to yellowish quartz sand, which is quarried for building purposes. This bed also contains numerous *Scolithus linearis* borings, and in places *Camarella minor* and fragments of *Olenellus*[1] have been found, by which its age has been determined to be Georgian (Lower Cambrian).

In the Catoctin and South Mountains of Maryland Keith has mapped above the Weverton sandstone 800 to 1,200 feet of shale (Harpers), and 500 to 700 feet of sandstone (Antietam). The Harpers shale is typically exposed at Harpers Ferry, on the Potomac River, and, as described by Keith,[2] consists of a bluish-gray shale with a few thin sandstone beds. Northward these sandstones beds are said to thicken, some attaining 50 feet, but do not have an appreciable effect on the topography. On the road from Monterey to Waynesboro, in the southeast corner of the area shown on the map, this series is fairly well exposed, but, according to Keith, the structure is complicated by folding and faulting. Above the Weverton sandstone in this section, as seen by the writer, are shales or slates, in part dark-banded, containing a conspicuous white, *Scolithus*-bearing sandstone 20 to 30 feet thick, all of which is mapped by Keith as Harpers shale. Above the shale is the *Scolithus* sandstone in which Walcott found *Olenellus* and *Camarella minor*, as noted above, and which is mapped by Keith as Antietam sandstone.

North of Little Antietam Creek there are two ridge-making sandstones above the Weverton sandstone, one composing Sandy Ridge and the other Curve Mountain, and between them is black-banded slate with thin ferruginous sandstones. The upper bed forming Curve Mountain is undoubtedly the Antietam sandstone, and it is apparent that one of the sandstone beds in the Harpers shale of Maryland increases in prominence northward, so that in Pennsylvania it reaches such dimensions that it forms a distinct ridge. The Harpers formation in this area therefore consists of shales and soft sandstones, with a quartzitic member near the middle which is here named the Montalto quartzite, from Montalto Mountain. Northward the shale gradually thins, and the sandstone continues to expand until at the northern border of the area it occupies

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[1] Walcott, *Bulletin of the U. S. Geological Survey*, No. 134, p. 25.

[2] *Loc. cit.*, p. 308.

Table of Geologic Formations for South Mountain, Pa., and Adjoining Portions of the Cumberland Valley

Age		Name	Thickness (feet)	Character
Ordovician	Martinsburg group	Eden sandstone	500	Soft, buff to green sandstone
		Utica shale	1,000	Gray fissile shale, with black, carbonaceous and calcareous shale, probably of Trenton age, at the base
	Shenandoah group	Chambersburg limestone	1,000 +	Fossiliferous, crystalline and thin shaly limestones of Chazy-Black River age
		Stones River limestone	400 +	Homogeneous, dove-colored, pure limestones of Stones River age
Saratogan (Upper Cambrian)		Knox limestone	2,000 ±	Drab magnesian and siliceous limestones, in part cherty, with limestone conglomerate at the base
Acadian (Middle Cambrian) ?		Elbrook limestone	2,000 ±	Massive, bluish-gray, magnesian and cherty limestone with some red and green shales
		Waynesboro formation	600 ±	Purple shale and flaggy sandstones
Georgian (Lower Cambrian)		Tomstown limestone	800 ±	Drab to white magnesian and pure limestones
		Antietam sandstone	500 ±	White, calcareous, *Scolithus* sandstone, containing Georgian fossils
		Harpers formation and Montalto quartzite member	2,750 ±	Dark-banded shale or slate and ferruginous sandstone, with gray to white quartzitic sandstone, containing *Scolithus* tubes in the softer layers
		Weverton sandstone	1,250 ±	Purple to white feldspathic sandstone, conglomerate, and arkose
Algonkian ?		Old volcanics		Altered rhyolite and greenstone

almost the whole interval of the formation, indicating a gradual change from a fine mud deposit in the south to coarser siliceous sediments in the north. Similar conditions may have continued into Antietam time, and have affected the deposition of the Antietam sandstone. The patchy occurrence of the Antietam in the Maryland area, as mapped and described by Keith, may be due to its irregular deposition in that area, instead of to infolding in the Harpers shale and to faulting, as previously supposed. Irregularity of Antietam sedimentation in the Pennsylvania area also is indicated by the absence of ridge-making character east and southeast of Montalto, where the bed is thin, disintegrated, and inconspicuous.

Shenandoah limestone.—The rocks of the Valley are chiefly light- and dark-gray, massively bedded, magnesian limestones, described and mapped in the northern Appalachian folios of the United States Geological Survey atlas as the Shenandoah limestone. They are so intricately folded, and have so few easily recognized horizons, that the details of the stratigraphy cannot be determined nor the thicknesses accurately measured. The series is estimated to be about 6,800 feet thick, and is here divided into six formations. The lowest, composed largely of drab to white, impure limestones, has near its base beds of purer, mottled, dark- and light-gray limestone, which is frequently quarried and burned for lime, and near its top a massive bed of cherty limestone. The formation is limited above by ferruginous sandstone and purple shale. It is approximately 800 feet thick. The name "Tomstown limestone," here applied to it, is from a village at the foot of South Mountain, where the formation outcrops.

The next succeeding formation is composed largely of hard, siliceous, ripple-marked, purple shale and flaggy, calcareous sandstones, about 600 feet thick. At the base is a siliceous rock weathering into large slabs and masses, stained yellow by iron, and usually banded and contorted. These masses, together with fragments of vein quartz and white porous chert, strew the surface and in places produce a low ridge. Scattered deposits of limonite occur on the slopes of these ridges, produced by the leaching of iron from the ferruginous shale and its precipitation in the soil and wash at the surface. Flaggy sandstone and sandy shale, forming the top of the formation, make a rather continuous low ridge in the limestone lowland, thus affording a marker in the otherwise monotonous series of beds. Shattered portions of this sandstone are veined with barite, and in the soils at the base of the hillslopes the weathered product has in places been concentrated and mined on a small scale. At Waynesboro, in the upper sandy shales and in the immediately overlying limestones, fragments of trilobites and other fossils suggesting Acadian (Middle Cambrian) age, were found by the writer. The sandstone and the purple shale also outcrop conspicuously in the ridge just north of Waynesboro, so the name "Waynesboro formation" is suggested for this division of the Shenandoah. In central Virginia H. D. Campbell[1] recently subdivided the Shenandoah limestone into several formations, separating at the base a limestone and an overlying series of variegated shale, which he named respectively the Sherwood limestone and the Buena Vista shale. Presumably these are the same subdivisions mapped in this area, but from the data at hand this can not be determined for certain, and since it is known that a large fault and corresponding gap in the stratigraphy occur in the intervening Harpers Ferry area, new names are here proposed for the formations.

Massive, bluish-gray, magnesian limestones, with numerous thin layers and nodules of chert and beds of shale, possibly 2,000 feet in all, compose the next formation. Red and green shales are present in the middle of the formation, and beds of sandy limestone, which in places form low ridges, occur higher in the section; but none of the beds have been traced for any considerable distance. The only fossils which have been found in this portion of the section are those mentioned as occurring in the basal layers and indicating Acadian age. The name "Elbrook limestone," from a town at which the formation is quarried, is proposed.

A change to siliceous sediments with conglomerate, oölite, and red clay, marks the base of the next succeeding formation. The siliceous layers weather to granular porous sandstone, which produces a low ridge and offers another marker in the otherwise uniform limestone section. Conglomerates of rounded pebbles of dense magnesian limestone, imbedded in a matrix largely of quartz grains, indicate an elevation of a portion of the nearby sea bottom into a land area and the erosion of the limestone, the quartz sand coming from a more distant source on the land. Other conglomerates or breccias of flat fragments of thin slabby limestone variously arranged in a matrix of calcareous mud are intraformational conglomerates derived from recently deposited silt broken up by wave,

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[1] *American Journal of Science*, Fourth Series, Vol. XX, No. 120, pp. 445–47.

tide, or current action. The thin fragments are often tilted on end, and resemble the "edgewise beds" of Missouri described and figured by Nason.[1] Red clay in crevices and holes of the limestone suggests surface weathering and residual clay filling solution pockets. Oölite is evidence that the water was sufficiently shallow for the waves to oscillate the particles on the sea bottom. For these reasons it is concluded that this horizon represents a break of some consequence in the sedimentation, due to uplift and erosion in this or in some immediately adjacent territory. Since this change is accompanied by the introduction of a different fauna, specimens of which, chiefly trilobites, collected at Scotland, were determined by Walcott as Saratogan (Upper Cambrian), it is regarded as representing the base of the Saratogan. Associated with the conglomerates is a minutely laminated pure limestone with parallel, wavy, dome-shaped, and contorted structures. Horizontal sections of the dome-shaped structure show regular concentric rings, whereas the vertical sections show waves with round tops and angular bottoms, as shown in Fig. 3. No internal structures were observed by which organic origin could be determined, but in a general way they resemble *Stromatopora* and may represent some low form of life which spread out on the sea bottom and secreted minute layers of lime. They are undoubtedly similar to *Cryptozoan proliferum* described and figured by Hall,[2] which occur in oölitic limestone near the base of the Saratogan in New York.[3]

The conglomerate zone, 10 to 15 feet thick, is followed by drab magnesian limestone with the same Saratogan fauna, grading upward into siliceous limestones containing occasional poorly preserved gastropods of Beckmantown age. The formation is estimated to be 2,000 feet thick. Ulrich, who has recently made a careful study of the rocks throughout the Great Valley, regards this formation as stratigraphically and faunally the same as the Knox dolomite of Tennessee, and the name "Knox limestone" is therefore adopted.

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[1] *American Journal of Science*, Fourth Series, Vol. XII, pp. 358–61.

[2] New York State Museum of Natural History *Thirty-Sixth Annual Report* 1883, Plate 6 and description.

[3] Walcott, *Journal of Geology*, Vol. XI, No. 3, pp. 318–19.

The Knox is limited above by homogeneous, fine-grained, dove-colored, pure limestone, extensively quarried throughout the Valley. It contains a few leperditia, gasteropods, and brachiopods of Stones River age, and since the rock is lithologically the same as the Stones River of Tennessee, and apparently occupies the same interval, the name "Stones River limestone" is applied here.

Overlying the Stones River are darker and more crystalline limestones, somewhat cherty at the base and interbedded in the upper portion with argillaceous limestone. Fossils are not numerous in the lower cherty beds, but the upper portion contains a large and interesting fauna, referred by Ulrich to the Chazy and Black River. The formation is well exhibited along the edge of the shale belt west of Chambersburg, and is therefore named the "Chambersburg limestone." The thickness of this and the Stones River formation was not determined by the writer. Sections recently made by Ulrich near Greencastle, 8 miles west of Waynesboro, show 400+ feet of Stones River limestone and 1,000+ feet of Chambersburg limestone.

The Martinsburg group.—The calcareous strata are followed by a series of shales and soft sandstones previously called the "Martinsburg shale." At the base are a few feet of dark calcareous shale and thin beds of carbonaceous limestone, transition beds, containing a fauna regarded as Trenton in age. These are followed by dark to gray platy shale, with *Leptobulus insignia*, *Triarthus becki*, and other Utica forms, including numerous graptolites, and it is therefore named the "Utica shale." It is generally intricately folded and crinkled, but the thickness is estimated to be 1,000 feet. Above it are greenish to buff, soft sandstone which is named Eden because it contains a fauna referred by Ulrich to the Eden, and is regarded by him as stratigraphically its equivalent. It has a thickness of about 500 feet. These shales and sandstones form the tablelands rising out of the limestone lowland west of Chambersburg.

STRUCTURE

All the rocks of the region have been folded and highly compressed, and nearly all have acquired a secondary structure. In the mountains the rocks have a marked schistosity, most completely developed in the soft shales and feldspathic rocks, but even the hardest quartzites have parallel jointing and to some extent are schistose. The strike of the schistosity is parallel to the ridges, and the average dip is 35° southeast. In most cases this is the dominant structure, often producing a banding which closely resembles bedding and entirely obliterates the true stratification. It is not surprising, therefore, that many of the early geologists, mistaking the schistosity for bedding, failed to understand the relations. The stratification can be determined in the *Scolithus*-bearing rocks because it is perpendicular to the worm-tubes, and in the coarser sandstones and conglomerates it is sometimes shown by alternations of coarse and fine material or by color-banding. The dips are thus observed to be usually either vertical or steep to the west. The sandstone series is found to dip away from, and therefore to overlie, the volcanics, and to pass steeply beneath the limestone of the valley along the west front of the mountain. A similar highly inclined sandstone series on the east side of the volcanic rock belt is mentioned by Walcott in his paper on the Cambrian rocks of Pennsylvania.[1] The structure of the mountain belt as a whole is therefore a broad anticlinorium.

East of Montalto.—The general structure of the mountains east of Montalto is a flat-topped, steep-sided anticline, with the east limb not exposed in the area. The ancient volcanic rocks exposed in the low plateau at the eastern edge of the area are overlain by the flat-lying, purple, feldspathic sandstones of Snowy Mountain. These sandstones may also be seen in the mountain north of the volcanic area, beyond Conococheague Creek. Westward the strata bend down sharply, and their upturned edges form Rocky Mountain, one of the few really rugged heights in this area. The shale valley in which the West Branch of Little Antietam Creek has its source is followed by the *Scolithus* sandstone of Montalto Mountain, which dips steeply to the west. At the foot of the mountain soft, calcareous, *Scolithus*-bearing (Antietam) sandstone is followed by gray and mottled limestones, with vertical and steeply overturned dips. Farther out in the valley the limestones are found to be closely folded.

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[1] *Loc. cit.*, p. 24.

Northward a minor sandstone ridge forks at an acute angle from Montalto Mountain in strike with the soft calcareous sandstones at the foot of the ridge opposite Montalto. This seems to indicate that the Antietam sandstone is variable in thickness and hardness, as previously stated; but its failure to make a separate ridge at this point may in part be due to shearing along this highly compressed zone. The increased width of the shale valley to the north is due largely to flatter dips. The occurrence of brown iron ore in the residual clays along the mountain front, once so extensively mined in the vicinity of Montalto, has been considered by some as evidence of the existence of a great fault here. Similar ore deposits occur all along the mountain front, however, even around the ends of folds where faulting cannot have occurred, as will be demonstrated below, and are evidently produced by the leaching of iron from the ferruginous shales and sandstone of the mountain rocks and its precipitation, either by humic acid in bogs along the foot of the mountain, or by chemical action with the limestone with which the deposits are usually associated.

The Waynesboro fold.—Northeast of Waynesboro, where the mountain bends sharply to the east, the low hills of the valley are seen to curve first to the east and then to the south, roughly parallel to the offset in the mountain. The rocks of both the mountain and the valley ridges are found to trend and curve in the same direction as the ridges; i. e., the southwest strikes change abruptly to east, and even northeast, and then to the south again. The dips in this curved portion change from 60° W. to 20° S. Beyond, the ridges and the rocks resume their straight southward course for a short distance. It is thus seen that the offset in the mountains at this point is due to a sharp anticline and flat syncline plunging steeply to the southwest, the axis of the syncline passing through Sandy Ridge and Snowy Mountain. The parallelism and low accordant dip of the limestones of the valley and the mountain rocks throughout this fold, and the absence of any stratigraphic break, are conclusive evidence that no fault exists along the front of the mountain at this point.

The East Branch fault.—The East Branch of Little Antietam Creek flows in a limestone valley extending into the mountains several miles. The limestones strike northeast, approximately parallel with the ridges on the south side, but diagonally across the trend of the sandstone ridges on the north, which terminate abruptly. This condition is the result of a fault cutting off the quartzite beds along the north side of the re-entrant valley and offsetting them several miles to the east. The fault apparently marks the axis of a fold, similar to that just described east of Waynesboro, in which a sharp anticline, followed to the southeast by a deep syncline, was compressed so closely that the anticline was entirely sheared out, and the limestone in the syncline now rests against the edges of the broken quartzite beds.

Big Flat anticline.—Big Flat Ridge, north of the Conococheague, is a broad, flat-topped anticline which to the north, beyond the quadrangle, forms the major part of the mountain range. A line of small knolls, composed of the *Scolithus*-bearing Antietam sandstone and dipping from 50° to 70° to the northwest, skirts the western foot of the mountain. An inner row of higher knobs is composed largely of vitreous non-*Scolithus* rock, the Montalto quartzite member. The upper shale of the Harpers formation is thin in this ridge, and the sandstone member more prominent. Apparently the shale is gradually replaced to the north by sandstone, which becomes the major part of the formation. The counterpart of the line of knobs is found on the eastern side of the ridge, composed of similar rocks and with dips of 45° to the southeast. At the south end of the mountain the same rocks bend around parallel to the southern face and dip 20° to the southwest, abruptly ending the anticline. On the crest of the ridge the beds, where exposed, indicate gentle folds, and over the level surface of the mountain top the rock fragments are chiefly *Scolithus* sandstone, apparently of the Montalto horizon. The deep ravines intersecting the anticline may cut through the Montalto quartzite member into the lower shale of the Harpers, but in no place was the underlying Weverton sandstone observed.

Beyond the end of this plunging anticline the valley rocks for several miles are hidden by wash, but from exposures farther to the southwest they are seen to be intricately folded. Whereas the hard massive sandstone beds of the mountain form one bold broad

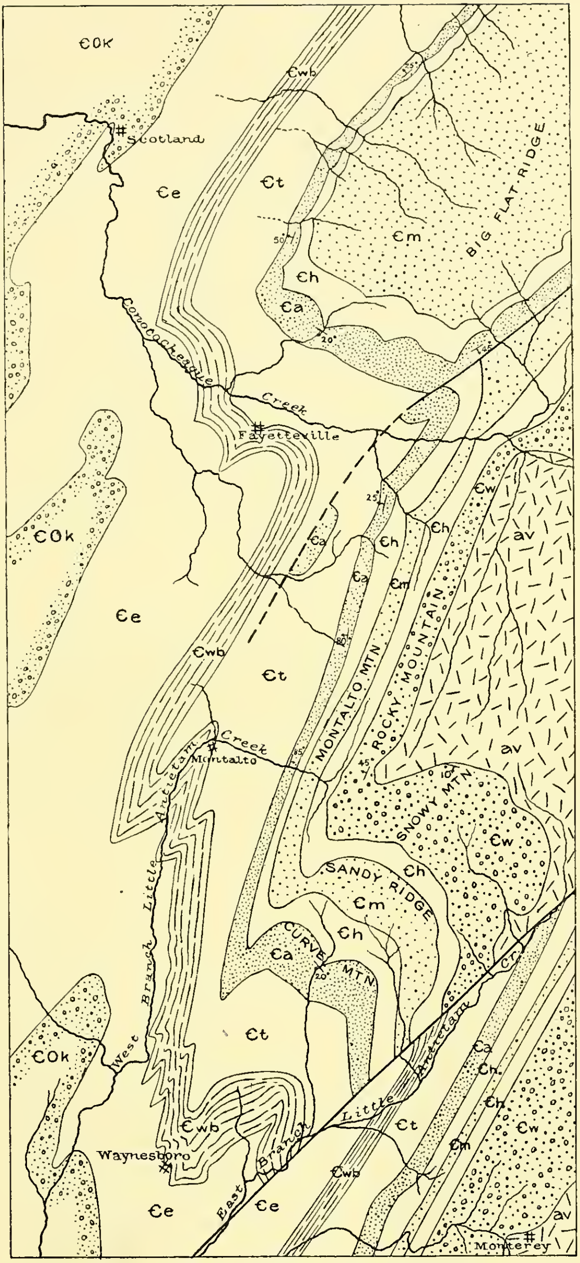


FIG. 2.—Geologic map of South Mountain in southern Pennsylvania, and adjacent portion of Cumberland Valley. *COk*, Knox limestone; *Ce*, Elbrook limestone; *Cwb*, Waynesboro formation; *Ct*, Tomstown limestone; *Ca*, Antietam sandstone; *Ch*, Harpers formation; *Cm*, Montalto quartzite member of Harpers formation; *Cw*, Weverton sandstone; *av*, ancient volcanics.

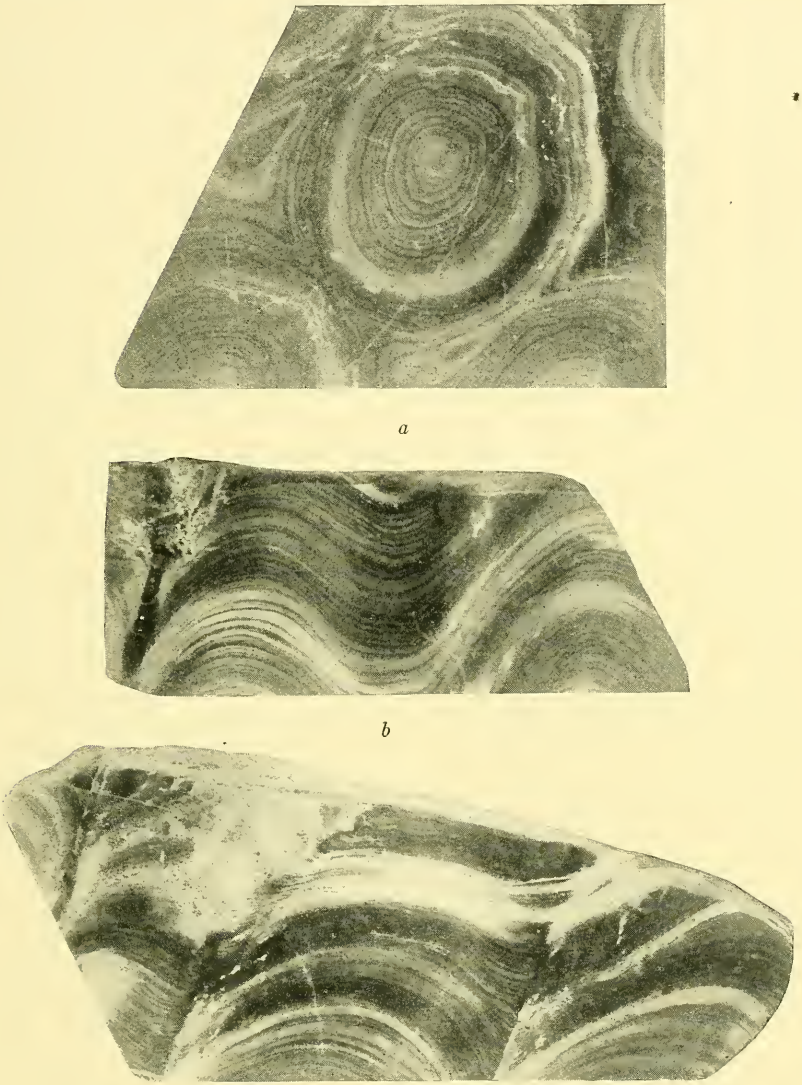
arch, the limestones around the pitching end are crumpled into numerous close folds, as may be seen on the geologic map, Fig. 2.

Just east of this Big Flat arch the Antietam sandstone, containing *Scolithus* and fragments of *Olenellus*, is crushed to a coarse breccia and cemented by iron. This crushed zone is the closely compressed, faulted syncline between the Big Flat and Montalto arches, and apparently the quartzite of Little Mountain is brought to the surface along this line of fracture by a minor anticline.

Origin of the structures.—It has been shown that the general structure of this part of South Mountain is a flat-topped arch, with the sedimentary beds on the western flank disposed as a steep monocline, dipping away from the older volcanics in the heart of the range, and beneath the limestones of the valley. This simple structure is complicated at several points along its strike by secondary folds, giving rise at their pitching ends to offsets in the mountain front.

The steep, often overturned, dips of the western limbs of the anticlines both in the mountain and valley rocks indicate that the crustal movement was to the west, and that the compressive force at the surface came from the east. This conclusion is also borne out by the schistosity dipping 35° to the southeast. The ultimate force, however, may have acted as a deeper-seated stress from the northwest. According to the theory of isostatic adjustment, the loading of the sea bottom during all of Paleozoic time would produce a deep-seated flowage toward the land. Isostasy need not, however, be depended on to account for such movement, for the thousands of feet of sediments in themselves represent an equivalent sinking of the sea bottom, whether the result of loading or of some independent cause. This landward motion would be transmitted in a certain degree to the overlying sediments, and they would be moved, by a force acting from below and from the northwest, against the consolidated land mass as a buttress, which would produce a resistant force in the opposite direction acting at the surface. The buttress in this case would be the Archean rocks of the Piedmont to the southeast, now partially covered by Triassic sediments. Thus we should have exhibited at the surface structures produced by the resistant stresses from the southeast, i. e. folds overturned to the northwest and schistosity dipping to the southeast.

At the north, opposite Fayetteville, a massive anticline rose to the west of the main axis and barred the way to further movement


a

b

c

FIG. 3.—Cryptozoan proliferum, from base of Knox limestone west of Fayetteville. Natural size. *a*, horizontal section, under side; *b*, cross-section of specimen *a; c*, cross-section of another specimen.

along the main axis in that direction. South of this point, however, by the yielding of the limestones of the valley in close folds, the rocks of the mountains moved bodily to the west, past the end of the anticline, thus causing a deflection of the trend of the axis of the main uplift behind this barrier, as may be observed by the change in direction of ridges on opposite sides of Conococheague Creek.

Earlier views.—The views of earlier writers on the geology of South Mountain are concisely summarized by Keith in his paper on the Catoctin belt.[1] These opinions were somewhat diverse. The two classes of rock composing the mountain were clearly distinguished by them all, and the igneous origin of the schists was generally recognized. The prevailing conclusion of the earlier writers, however, was that the sandstones of the mountain front dip eastward beneath the schists, and are therefore older, and probably Archean, and that a great fault exists along the west foot of the mountain. These views were held as late as 1892 by Lesley, who constantly refers in his final report[2] to the "lower or quartzite conglomerate slate series" and "the overlying feldspathic, micaceous, chloritic series,' thus reaffirming the interpretation of the stratigraphy and structure published in earlier volumes.

In this same year Walcott[3] found fossils in the uppermost layers of the sandstone series in the southeast corner of the area under discussion and in other parts of South Mountain, which, together with stratigraphic observations cleared up the stratigraphy and structure. The sandstone series was observed to overlie the orthofelsites and was proven to be of Georgian age. This view was confirmed, on structural evidence, by Keith in his paper on the Catoctin belt,[4] although he found the structures in the area to the south much more complicated by faulting than they are in this area.

Lesley, in discussing the offsets in the mountain front, says:[5]

> This geographical eschelon arrangement of the South Mountains is a good indication of their geological structure It renders it probable that the strata, whatever may be their age, have been thrown into a series of anticlinal and synclinal waves entirely analogous to those with which the Paleozoic country of middle Pennsylvania have made us so well acquainted.

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[1] *Loc. cit.*, pp. 318–20.

[2] Pennsylvania Geological Survey, *Final Report*, Vol. I, pp. 144–46.

[3] *Loc. cit.* p. 24.

[4] *Loc. cit.*, pp. 321–23.

[5] *Loc. cit.*, pp. 143–45.

Thus far his conclusion is good, but inasmuch as the sandstone series along the mountain front is, according to his interpretation, older than the orthofelsite series, and dips away from the limestone of the valley, he concludes further that

> *A master fault* must therefore run along the northwest foot of the mountains, along the low drift-filled valley of Yellow Breeches Creek [Mount Holly area], in which nowhere can any rock be seen in place, but only a series of brown hematite iron ore deposits, some of them of great size and once extensively mined in open quarry work. The northwest face of the mountain mass is therefore in fact the eroded basset edge of the quartzite series dipping away from the fault. The thickness of the quartzite and conglomerate series may be imagined from cross-section No. 10, laid 2½ miles north of Greenwood [east of Chambersburg], along which for five miles quartzite beds on a prevailing southeast dip are either seen or indicated suggesting a total thickness of 14,000 feet [a partial measure of the throw of the "master fault"].

Walcott accounts for the mountain offsets chiefly by thrust-faulting, as expressed in the following extract:[1]

> My impression is that these offsets [in the mountain front], and also the complicated structure of the mountain, arise partly from folding, but more largely from the westward thrusts of masses of strata along the lines of fault of a low hade. This westward thrusting on the fault plane, complicated by previous folding of the strata, leaves masses of the subjacent, pre-Paleozoic rocks resting, in various places, on different members of the Lower Cambrian series, and also appears to interbed the quartzites and schists of the Cambrian in the schists, eruptive, etc., of the Algonkian.

Keith also holds the view that strike faults have a prominent part in the structure of the mountains, especially along the western border. He shows their presence in the Catoctin belt,[2] and carries them into the area southeast of East Branch of Little Antietam Creek.

CONCLUSION

It has been demonstrated in this paper that the conclusions of the writers quoted above are not applicable to the area here discussed; that thrust-faulting cannot account for the offsets in the mountain front near Fayetteville and opposite Waynesboro, but that they are due to folds plunging steeply to the south, with the strata in unbroken sequence; that along the straight portions of the mountain front the youngest beds of the sandstone series are next to the

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[1] *Loc. cit.*, p. 27.

[2] *Loc. cit.*, pp. 358–62.

limestone of the valley; that they appear to be in comformable sequence with dips varying from low west to steeply overturned; and that, if faulting occurs along these lines, it is of minor importance. The fault producing the deep re-entrant valley of East Branch of Little Antietam Creek and the corresponding offset of the ridges, a thrust of considerable magnitude, does not follow the front of the mountain, but strikes at an acute angle into the valley. The same is true of the crushed and faulted zone north of Conococheague Creek.

THE CHEMICAL EVOLUTION OF THE OCEAN[1]

ALFRED C. LANE

The paper was suggested by the chemical character of the deeper mineral waters of Keweenaw Point. The fundamental ideas were stated years ago, by T. Sterry Hunt, who called attention to the fact that in the Canadian Paleozoics there is less sodium in proportion to the chlorine than in the present ocean. The same fact is true of the deeper waters, both in upper and lower Michigan. Not only so, but taking the lowest sodium chlorine ratio, which generally comes from the deepest, or one of the deepest, wells found in any water of a given geological horizon, it appears that the older this formation, the lower the ratio. The ratio of sodium to chlorine varies from 0.468 at Big Rapids, to 0.084 near the bottom of the Tamarack Mine.

TABLE I

SODIUM: CHLORINE RATIO IN MICHIGAN DEEP WATERS

Location of Water	Geological Horizon	Reference	$Na:Cl=R$	$\frac{1-1.81R}{1-0.531R}$	$\frac{1-1.81R}{0.648}$
Portsmouth	Base of Pennsylvanian	W.S. 31, No. 251	0.586	.....	.....
Big Rapids	Marshal, mio-Miss.	W.S. 31. No. 278	0.468	0.200	0.234
Midland	Marshal, mio-Miss.	W.S. 31, No. 281	0.284	0.570	0.750
Bay City	Berea, base of Miss.	An. 1901, p. 225	0.350	0.450	0.564
Alma	Traverse, mio-Devonian	W.S. 31, No. 329	0.306	0.490	0.632
Assyria	Dundee, mio-Devonian	An. 1903, p. 108	0.321	0.525	0.673
Mount Clemens	Salina, neo-Ontarian	W.S.31, No. 319	0.304	0.480	0.625
Manistee	Niagara, mio-Ontarian	W.S.31, No. 323	0.236	0.650	0.883
Britton	Niagara, mio-Ontarian	New Kedzie	0.358	0.440	0.544
Whitby, Canada	Trenton, Ordovician	18 An. U.S.G.S. p. 652	0.25	0.630	0.865
Osceola, Wis.	Potsdam, neo-Cambrian	W.S. 114, p. 240	0.214	0.700	.....
Freda, Mich.	Upper Keweenawan	An. 1903, p. 165	0.189	0.720	1.01
Tamarack Mine	Lower Keweenawan	New Wilson	0.084	0.890	1.31
Vulcan Mine	Huronian	Am. 1903, p. 155	0.000	1.000	1.515

The last two columns give the age in fractions of a hundred million years, supposing that none or all of the sodium chloride in the rivers is cyclical.

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[1] Abstract of paper read at the Ottawa meeting of the Geological Society of America, December, 1905.

One of the explanatory factors must certainly be that suggested by T. Sterry Hunt, that in river water there is always more sodium in proportion to the chlorine than in the ocean, and that hence the carbonate of sodium, as it may be supposed to be combined, is always reacting with the calcium-magnesium chloride of the ocean water, throwing out calcium carbonate, probably by organic agencies, and leaving sodium chloride in excess instead. Professor Joly, of Dublin, has based an estimate of the age of the earth upon this accumulation of sodium in the ocean, which has been criticised, because of some minor assumptions which do not affect the reason-

TABLE II

ANALYSES OF RIVER WATER

	1. Mississippi River[1]	2. Lake Superior[2]	3. Murray's Average[3]	4. Thousand Tons per in Mile
Si	0.00350	0.00317	0.008370	34.90
Al	0.00009	0.00048	0.001820	7.60
Mn	0.00012	Sr 0.00134	0.001960	4.00
Fe	0.00008	0.00069	0.002180	9.10
Mg	0.00680	0.00278	0.007850	32.80
Ca	0.02950	0.01280	0.034100	142.17
K	0.00230	bare trace	0.002180	9.13
Na	0.01000	0.00318	0.005790	24.10
Cl	0.01610	0.00243	0.003100	12.91
(SO_4) S	0.00960	0.00124	0.004540	18.94
(PO_4) P	0.00013	B tr	0.000140	0.58
(CO_3) C	....	22.2300	....	.....
(HCO_3) C	.02160	....	0.013230	55.28
N (free am.)	0.00016	....	0.000065	basic N. 0.27
N (alb. am.)	0.000014	....	....	basic H. 0.08
Nitrites	....	....	....	......
Nitrates	0.00023	0.00077	0.00106	(AcidN.) 443
Total solids filtered	0.16750	0.05896	0.10000	762.587
Unfiltered	1.06900			
Loss in ignition				
Organic matter				
Filtered	0.02750			79
Unfiltered	0.07160			

1. C. H. Stone, Analysis of Mississippi River Water, *Science*, 1905, p. 472, with oxygen consumed: filtered, 0.0142; unfiltered, 0.0033; hardness, 10.92; turbidity, heavy (twice averaged); sediment, large; odor, none.

2. Analysis of Lake Superior water, *Annual Report*, Geological Survey of Michigan, 1903, p. 113.

3. Average river water computed from Murray in grams per kilogram or liter.

4. Average river water according to Murray, compiled from figures given by Joly and Chamberlin's *Geology*, in thousands of tons per cubic mile. Multiply by 6.524 to get total yielded in millions of tons per annum.

TABLE III

COMPOSITION OF OCEAN[1]

	1	2	3	4
Na	306.37	1.1400	1.41.80	1.570
Cl	552.17	2.0700	2.55.57	2.850
Ca	11.96	0.0500	0.05.53	0.070
Mg	37.69	0.1400	0.17.43	0.190
C	0.41	0.0020	0.00.19	0.003
S	25.62	0.0900	0.11.87	0.125
K	11.07	0.0400	0.05.02	0.060
Br	1.88	0.0078	0.00.87	0.010
O	52.83	85.7900	....	118.400
H	......	10.6700	....	14.700
	100.00	100.0000	....	

1. Composition of sea salt—Diltman in Van Hise, p. 942.
2. Composition of ocean—Clarke in Van Hise, p. 944.
3. Bulk of salts in ocean divided by antilog 16 according to Van Hise, p. 944. I do not understand how he gets these figures; they seem to be 1.24 (× antilog 14) greater than column 2, whereas, according to Van Hise's figures, the multiplier should be 1.32×antilog 14.
4. Column 2 multiplied by 1.375 giving weight of salt in units of antilog 16 tons, if the volume of the ocean is 3,200,000 cubic miles.

ing or results materially. If there has been such an accumulation, there must have been such a change in the chemical character of the water as there really appears to be upon careful study of the analyses of deep waters.

If the amount of sodium now in the ocean be N, and of chlorine C, and there is brought in each year by the rivers n, of sodium, and c of chlorine, and if we subtract from n a quantity d to obtain the net increase of sodium after allowing for that blown inland by the breezes or buried in the sediments laid down, etc., and let rd be a similar correction to be applied to the chlorine, then the ratio of sodium to chlorine (let the ratio be R) in the ocean x years ago would be, accepting a uniform rate of accumulation,

$$R=\frac{(N-x(n-d))}{(C-x\,(c-Rd))}$$

and

$$x=\frac{N-CR}{n-cr\ -d\,(1-rR)}$$

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[1] After Van Hise, p. 193.

Substituting in this formula the numerical data used by Joly, one will get Joly's results as to the age of the earth. By assuming appropriate values of R one can assign a date to the burial of any brine.

N and C are reasonably well known. Sir John Murray's estimates, the only ones made as yet, for c and especially n are liable to be seriously in error. The quantity d $(1-rR)$ is likely to be a small correction, except in the case of volcanic emanations of chlorine, for in the case of most other allowance r is likely to be pretty nearly reciprocal to R.

Inserting Joly's numerical values we obtain

$$x = \frac{1.41 - 2.54R}{1.57 - .84R - \mathrm{d}\,(1 - rR)}$$

in hundreds of millions of years.

A formula involving a slightly different volume of the ocean may be as exact and is more convenient, for computation, and was used by the author.

A somewhat elaborate discussion of analyses and the probabilities of the case led to the conclusion that, while a similar formula, which was given, could be constructed for any two substances brought into the ocean by the rivers, among those abundant enough to be well determined by analysis the chlorine and sodium were the only ones likely to accumulate, and not be modified seriously in relative proportions even when buried.

Among the difficulties discussed were the high concentrations of the deeply buried waters, and the very low amount of sodium in the Keweenawan, which is by no means the base of the geological column.

The suggestion was made that perhaps the volcanic contribution to the ocean was by no means an unimportant one, and that there had been a continuous emanation of chlorinated water, adding to the volume of the ocean from the very earliest times.

The analyses upon which the paper was based have mainly been published in *Water-Supply Paper* No. 31 of the United States Geological Survey, and in the annual report of the Geological Survey of Michigan for 1903. Tables of analyses, in ionic form, were given for Murray's average river water, Lake Superior, and the Mississippi River; also of the ocean and Keweenawan mine-waters.

A diagram was also shown in which, alongside Dana's geological column (which is proportioned according to his estimates of the lengths of the geological periods), the sodium: chlorine ratio, and computed ages of various brines, were laid off horizontally, which diagram was constructed from Table I.

TABLE IV

(KEWEENAWAN WATER ANALYSES (grams per kilo)

	1	2		3		4
Sp Gr	......		......		1.0511	....
Insoluble silica....	0.0222		......		....	....
Insoluble $Fe_2 O_3$..	0.0127		......		....	....
Dissolved $Si O_2$...	0.0033		0.00005		....	....
$Fe Cl_2$ ..	0.0045		......	Mn.	0.5700	....
$Zn Cl_2$.	0.0290		......		....	....
$Cu Cl_2$..	0.0043		......		....	....
$Mg Cl_2$.	0.0875	NH_4Cl	2.457	$Mg_2 Br$	0.2400	....
Na Cl ..	1.8800		21.009		19.2900	....
K Cl ...	0.0740		1.595		0.5600	....
$Ca Cl_2$.	3.1380		130.508		44.5100	....
$Ca SO_4$	0.0555		0.320		......	......
$Ca CO_3$	0.2480		......		....	......
Loss on ignition...	1.0800		......		....	......
Sum.............					6.517	
Total solids on evaporation.....			154.4115			
Dissolved ions—						
NH_4............	......		0.830		.....	....
Fe.............	0.0020		......	Mn	0.57	....
Zn.............	0.0134+Ni	Ba, Sr	0		.....	....
Cu.............	0.0022		......		.....	....
Mg.............	0.0232		tr		0.03	0.0130
Na.............	0.7400		8.278		7.60	2.7310
K..............	0.0388		0.837		0.30	
Ca.............	1.2496		47.166		16.04	6.3000
Cl.............	3.265		97.963		40.42	15.2287
SO_4............	0.0392		0.226	Br	0.21	0.0724
CO_3............	0.1490		0			

1. Is the water from the boiler of the vertical shaft of the Calumet and Hecla Mine, about 5,000 feet deep, but containing more or less surface water, by Heath. See *Annual Report*, 1903, p. 166.

2. Tamarack cross-cut, 4,300 feet deep—A. C. Lane, sampler; F. B. Wilson, analyst.

3. Freda Well, *Annual Report*, 1903, p. 166.

4. Wolverine Mine—seventeenth level—A. C. Lane, sampler; F. B. Wilson, analyst.

THE FOLDING OF SUBJACENT STRATA BY GLACIAL ACTION

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A number of upthrust folds of stratified rocks subjacent to glacial deposits occur at several places in Minnesota. Formerly they were considered as well-recognized glacial phenomena, and accordingly I took no special interest in them. More recently doubt has arisen[1] as to their origin, and this has led to my making a closer study of some of these occurrences. Proof of their true nature as glacial phenomena can now be given. The folds are more or less regular arches from 2 to 30 feet wide, and half as high as wide. The strata of which they are composed belong to the Galena (Trenton) series, or to other formations in Minnesota, which lie as a rule horizontally throughout their extent. The folds and similar displacements are both exceptional and limited to the superficial part of stratified formation, so that no doubt need be entertained as to their being the result of surface agencies.

For example, three such folds were seen in quarries and gradings at St. Paul, Minn., along the 800 foot terrace which runs on the north side of the river from the city to Fort Snelling. This terrace is a limestone bench nearly cleared of glacial deposits by the glacial River Warren. The surface of the limestone lies now generally within the reach of the winters' frosts—i. e., less than 8 feet deep—and the folds in it either lie within reach of frost or may have been in that position at some time in the past. Their origin might therefore be supposed to be due either to the action of frost in water-filled joints of the limestone, or, on the contrary, to the mechanical action of a glacier. Saturation and drying of the strata might also be supposed to have caused them. It was, in short, difficult to prove which agency had caused them.

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[1] H. L. Fairchild, "Ice Erosion Theory a Fallacy" *Bulletin of the Geologica Society of America*, Vol. XVI, pp. 12–23.

Two of the same kind of folds have been disclosed more recently in Minneapolis, and these lie in such relations as to show very distinctly their origin from the mechanical action of glacial ice. Since I am now convinced that the folds seen in other places have, with one exception, not been produced by the action of frost, nor by the saturation and drying of the rock strata, I shall describe, for the sake of comparison merely, the one case of undoubted upheaval of a limestone fold by frost and weathering, and then, in particular, the two newly discovered cases of undoubted glacial folding. The case of folding by frost and weathering occurs in the old city quarry at Camden Place, in the northern part of the city of Minneapolis. Here the lowest limestone bed of the Galena (Trenton) series lies near the ground surface, within the reach of frost and humid agencies. A small spring issues from it on the face of a quarry wall, and above the spring the strata and subsoil are seen to be strongly arched (Fig. 1). The origin of this structure is evidently as follows: The stream once flowed on the limestone's surface; annual frosts have heaved the rock-bed so as to let the stream into deeper courses; weathering has aided in loosening the stones and in form-

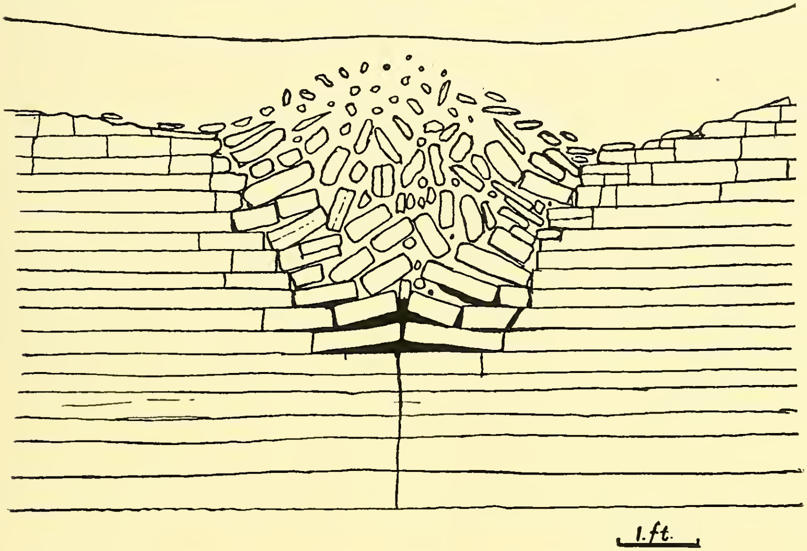

FIG. 1.—Limestone strata upheaved by the freezing of a stream, which now flows under them.

ing subsoil between them. The folds previously mentioned as seen at St. Paul are dry, and they differ from this one in being more uniform from top to bottom and in the less weathered condition of the stone. They resemble more closely the fold formed by glacial action, which will be next described.

This clearest case of glacial folding occurs at the site of the new lock and dam, No. 1, on the Mississippi River above the mouth of Minnehaha Creek, in the southeastern part of the city of Minneapolis. Here a new roadway is cut down the face of the river's bluff, exposing a fresh section of part of the limestone and shales of the Galena series and of part of the glacial drift. This section of the fold is represented in Fig. 2. The roadway passes the fold twice in descending the bluff in its first case cutting a gravel bed (*I*) and glacial till (*G*) lying over the fold, and in its second cutting obliquely across the fold and part of the undisturbed strata beneath it. From the first cutting the fold can be seen to extend a distance of several rods. The parts represented in the entire section (Fig. 2) are normally:

I.	Glacial gravel	8′	
G.	Glacial till	8′	
S	5. Gray crystalline limestone	0′	8″
	4. Green clay-shale	2′	6″
	3. Gray crystalline limestone	2′	4″
	2. Green clay-shale	0′	4″
	1. Dark crystalline limestone	1′	6″
B.	Massive granular limestone	5′+	

When folded up, the stratified rocks which in their normal position would comprise 3 feet of hard crystalline limestone and 2 feet 10 inches of compact clay-shale, or about 6 feet in all, in their disturbed condition make up 15 feet of broken limestone and shales. The overlying glacial deposits are made thinner than they are normally, as shown in Fig. 2. The limestone strata, *S* 1 and *B*, beneath the fold, are not disturbed.

It is evident from the section that the strata which are locally folded were thrust together, sliding upon the clay-shale layer, *S* 2, and that the upheaval resulted from the fracture and upheaval of the resisting layers. The overthrust on the right or northeast side, and the thinning of the till sheet over the axis of the fold, are thought to indicate that the fold was made under restraining pressure from on top. Since the folding effects the glacial till (*G*), and the gravel (*I*), is thinned over it, it was evidently made later than the time when the till was deposited, and perhaps later than the deposition of the gravel. A glacier has undoubtedly crept over this place within this period, as proved by its deposits, although these are absent from this particular spot, presumably because the glacial river Mississippi has cut away the upper sheet of till. Other sections in the same region show the till of the later glacier. It may be assumed, therefore, that glacial ice moving over the till bed, and perhaps over the gravel bed (*I*) gave the thrust that upfolded the limestones and shales at this point.

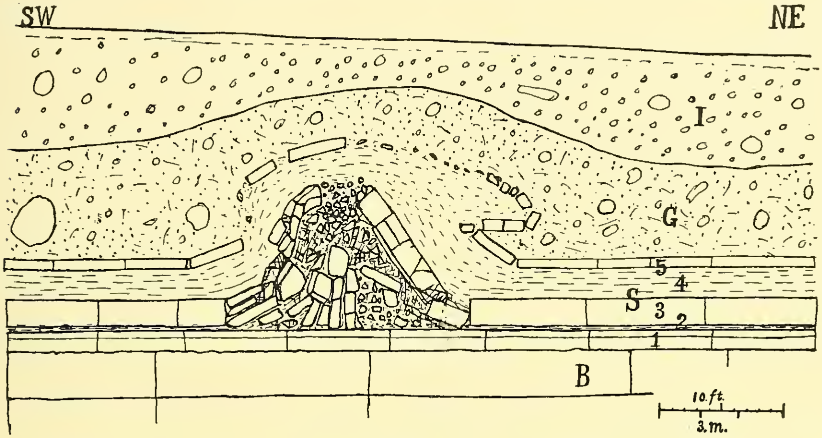

Fig. 2.—Profile of a fold in stratified rocks under glacial deposits.

How the glacial ice could do such heavy crushing of crystalline limestones may perhaps be explained by the friction of the glacier upon the field of gravel, which for a considerable area could accumulate great stress and transmit it to the subjacent strata sufficiently to cause the upper stratified rocks (*S* 3–5) to glide along a clay seam (*S* 2), and thus converge the power of a large portion of the glacier upon a small part of the rock strata. This hypothesis is the more plausible since in some places in this region the gravel bed rests immediately on the stratified rocks.

Why the rock was crushed and folded at this place rather than at any other is not evident in this exposed section. The reason is explained by another case which occurs four miles farther up the river's bluff, in the quarry next to Riverside Park. This case is shown in Fig. 3. The section here shows the following:

G.		Glacial till and soil	about	10′	
S	6.	Green clay-shale		3′	
	5.	Gray crystalline limestone		0′	6″
	4.	Green clay-shale		1′	
	3.	Gray crystalline limestone double stratum		2′	4″
	2.	Clay-shale, irregularly laminated		0′	4″
	1.	Dark crystalline limestone		1′	4″
B.		Massive granular limestone		4′+	

Since the till in this section now forms an ancient terrace of the river, it evidently has not its original thickness. Below the till the same rock strata appear as in the other section (Fig. 2) and therefore the parts of Fig. 3 are littered in the same order as those of Fig. 2. The main stratum (*S* 3) appears double here because of a thin irregular shaly lamina within it.

The noteworthy feature in the section is the reversed fault which appears in the top part of the main stratum (*S* 3). The fault is clearly the result of thrust and displacement along an oblique joint. The overlying strata are disturbed by lateral compression and by upward movement of the faulted piece, while the underlying strata are not disturbed. The phenomenon can be explained as the result of glacial friction upon the stratum at a distance from the point of faulting, causing the stratum to move from right to left—i. e., northwest to southeast—as far as the line at which an oblique joint in the rock led to its development of a fault. The fault, as seen on the surface of the rock, which has been cleared of drift in the quarry, runs from northeast to southwest in a reversed curve for about 40 feet. It extends indefinitely farther.

This and the previously described case may be considered as two stages of the same process of folding. Although they were probably not made by the same glacier, at the same time, since the strike of the one is nearly at right angles to that of the other, yet they occur in the same strata under the same till-sheet. Comparing Figs. 2 and 3, and noting that the direction of movement is from left to right in Fig. 2, and from right to left in Fig. 3, one can see how upfolding may be begun, and to what extent it could quickly develop in strata subjacent to a glacier which moved over a till- and gravel-covered surface. Why the disturbance ceased just where it did in either of these cases is not evident.

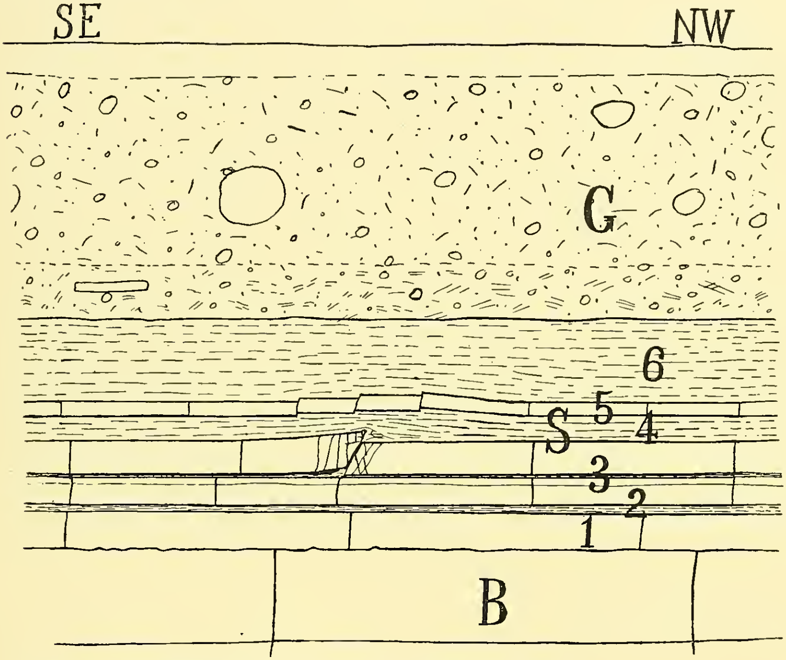

FIG. 3.—Profile showing a thrust fault in strata under till.

I imagine no other cause for the starting of the fold represented in Fig. 2 than that seen in the fault, Fig. 3. The stratified rocks in both places are fresh and not oxidized. In some other cases the cause may have been a little different, especially in the ones mentioned as seen in St. Paul, where there was much evidence of leaching and oxidation by surface water, and where the folds were of limestone strata alone. Those were each immediately over a vertical joint of the rock and contained some residuary clay. From these circumstances it appears that they may have been begun by the sliding of superficial strata toward a widened joint which had filled with residuary clay, and that the lateral compacting of the clay gave the initial upward thrust. The folds had, however, progressed too far for the conditions of their first stages to be discernible. The presence of residuary clay gave them some resemblance to the case of upfolding by frost as described (Fig. 1).

Regarding the general manner of upthrusting, presumably any weakness of rock structure could serve to determine the point where a folding of strata would begin. The other conditions for such folding are first a seam along which the strata might be caused to slide, and then the force necessary for such movement. This force appears to come through a gravel bed from a moving glacier.

In a former article[1] I have described a similar dislodging of stratified rocks, in a way which caused large masses to be rotated up into the glacier, and thus transported without complete loss of stratification. In the cases now described, the tendency is rather toward complete loss of stratification. One may readily imagine from the appearance of the fold (Fig. 2) that in nearly all such cases the disturbing of the strata when once begun, would end only with complete disruption of the loosened mass and an intimate mixture with glacial gravel and till. Many masses occur in the drift of this region which consists largely of crushed stone and shales with the colors and characteristics of the known stratified rock, but without the stratification or the fossils preserved in them.

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[1] *Journal of Geology*, Vol. XIII (1905), p. 351.

THE POSSIBLE GRANITIZATION OF ACIDIC LOWER HURONIAN SCHISTS ON THE NORTH SHORE OF LAKE SUPERIOR

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The Michipicoten and Pucaswa areas on the north shore of Lake Superior present the apparently extraordinary anomaly of containing a conglomerate well supplied with characteristic granitic pebbles, and of exhibiting no older granitic rock of similar structure from which these pebbles could have been drawn. There are, however, of earlier age, acid schists and gneisses of probable igneous origin, and apparently of like chemical composition, though of different structure from these granitic rocks. I would suggest the possibility of the derivation of the granitic pebbles in the conglomerate from a pre-existing rock of like characteristics, of which the granite which cuts the conglomerate is the regranitized equivalent. By a regranitized rock I mean one which, originally a granite, quartz-porphyry, or other rock of similar chemical composition and origin, has by metamorphism been altered into an acid gneiss or schist, and subsequent to the metamorphism—or perhaps in part during the metamorphism—recrystallized back into a granite. From our present knowledge of the origin of granite, this recrystallization cannot definitely be said to be refusion, and regranitization is perhaps a more correct and exact term. The original granite, the source of the granitic pebbles, may have been the plutonic equivalent of the rock from which the acid gneisses and quartz-porphyry or felsite schists were derived. It is possible that the gneisses may represent the metamorphic remnant of the original granite.

The Michipicoten Mining Division, which contains an area of some 5,000 square miles, is part of the District of Algoma, in Ontario, and is situated on the northeastern shore of Lake Superior, between latitudes 47° 30′ and 48° 30′. The division was first set apart by the government of the province of Ontario on account of the auriferous quartz veins which it contains, though it has within the last few years become more important as an iron-ore producer. One mine—the Helen—exports more ore annually than all the other iron mines in Canada put together. Lying within the boundaries of the division is the Michipicoten Huronian area, and to the southwest of the division, and in part within it, is the Pucaswa Huronian area, separated from the Michipicoten area by granite of later age than either.

The Michipicoten Huronian rocks constitute a band from four to twelve miles in width, which extends northward from a point a few miles south of Point Gargantua, on the Lake Superior Shore, to a point about 14 miles south of the main line of the Canadian Pacific Railway. From this point an arm extends both east and west. The western arm, which is the longest and most important, stretches westward from the Magpie River, which may be taken as the center of the north-and-south arm, for a distance of about 40 miles, where it is cut off by granitic rocks. The eastern arm extends eastward from the Magpie River for about 25 miles, and is intercepted by granitic rocks in the neighborhood of Dog Lake. South and southwest of the western arm lie small patches of Huronian rocks which compose the Pucaswa area. The Pucaswa[1] area would naturally be included within the Michipicoten area, because of the similarity in the lithology of each and on account of their proximity, were it not that the Pucaswa Iron Range is quite separate and distinct from the Michipicoten Iron Range in geographical position, and differs markedly in structural features.

The boundaries of the Huronian rock in both the Michipicoten and Pucaswa areas are extremely irregular, but everywhere the bordering rocks are composed of granite or rocks of allied petrographic species. The outer boundary is formed by granitic rocks which are apparently part of the great Laurentian acid eruptive complex of central Canada, which extends northward to within 60 miles of Hudson Bay, and southeastward to the original Huronian area of Logan and Murray—a distance of 120 miles. The inner boundary of the Michipicoten area is an immense granitic batholith with principal dimensions of 19 miles from north to south by 28 miles

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[1] In the paper by the writer in the Bureau of Mines *Report* for 1905 the Pucaswa area is called the North Michipicoten area.

from east to west. This batholith is joined to the main part of the acid eruptive complex by a narrow band of granite, which separates the Michipicoten Huronian area from the Pucaswa Huronian area. Another off-shoot from the batholith further divides the Pucaswa area.

The oldest rocks visible in both the Pucaswa and the Michipicoten areas are the so-called Lower Huronian. Above these lie Upper Huronian rocks which, though somewhat rare in the Pucaswa area, have abundant outcrops in the Michipicoten area. Cutting both Lower and Upper Huronian are granites and allied rocks, which have frequent outcrops in the shape of bosses and dykes, within the limits of the Huronian rocks proper, and which have also already been mentioned as forming the boundaries of the Pucaswa and Michipicoten areas. Piercing both the Huronian rocks and the granites are basic igneous rocks of somewhat varied lithological composition, which are very probably Keweenawan.

The Michipicoten Lower Huronian may be subdivided into two divisions—the Helen Iron Formation and the Michipicoten schists. The same rocks in the Pucaswa area may be similarly resolved into an Iron Formation and schists. The Iron Formation in the Michipicoten area and in the Pucaswa area may be regarded as the only definite horizons within the Lower Huronian of the areas. Above and below these formations lie the schists. In the Michipicoten area, and particularly in that part which lies west of the Magpie River, a very close connection between the Upper Huronian rocks and the Helen Formation is observable. The latter, generally, very closely underlies the Doré Formation which in Michipicoten makes up the Upper Huronian, but in some parts of the area thick masses of schists intervene between the Helen Formation and the Doré Formation, indicating either an unequal denudation of the Lower Huronian previous to the deposition of the Doré rocks, or otherwise an unequal deposition of volcanic material after the Helen iron-bearing rocks have been laid down. In some places the width of the Helen rocks appears to diminish, and at the same time there is a relative increase in the amount of schist which seems to suggest that in these parts of the area, toward the close of Lower Huronian times, chemical and aqueous sedimentation was overpowered by volcanic deposition, whereas elsewhere the former still continued. In the Pucaswa area no such close relation between the iron formation and the Upper Huronian is apparent.

The rocks of the Helen Formation consist of rusty, ferruginous, banded cherts, banded jaspers, banded magnetic cherts, pyritic cherts, sideritic cherts, and various grüneritic, actinolitic, and hornblendic schists, resulting from their metamorphism, together with phyllites, sideritic arkoses, and possibly quartzites. The Iron Formation in the Pucaswa area consists of similar rocks, though sideritic cherts are rare or wanting, and magnetic, banded chert is the most common iron-bearing rock, whereas in the Michipicoten area rusty, non-magnetic, banded chert is the prevailing species.

The schists of both areas comprise chloritic schists, mica schists, hornblende schists, carbonate schists, quartz-porphyry and felsite schists, schistose agglomerates, and amphibolites. All of the schists are intensely sheared, and some of them, particularly the finer-grained varieties, are so evenly laminated that they very closely resemble, and probably actually are, phyllites. Quartz-porphyry schist, a nacreous sericitic rock containing blebs of glassy quartz and sometimes gneissoid, very frequently borders the iron formation in the Michipicoten area, and carbonate schists are also often in close connection. Apart from this somewhat general definite position occupied by these two schists, no exact horizons are held by any other of the Lower Huronian schists.

The Upper Huronian in the Michipicoten and Pucaswa areas consists of the Doré Formation, comprising conglomerates, agglomerates, slates, and tuffs—the conglomerates being the commonest, most significant, and most characteristic. The Doré conglomerate is a very much mashed rock, with a fine-grained chloritic matrix, containing within it rounded fragments of pre-existing rocks of all sizes, from those scarcely visible to the eye, to others a foot or more in diameter. The ground-mass is exceedingly schistose, and the cobbles and pebbles included in it are all more or less elongated parallel to this structure. The harder pebbles show only flattening, parallel to the longer diameter, while the softer pebbles are often so attenuated that they resemble long narrow ribbons, or else are so thoroughly comminuted as to be indistinguishable from the matrix proper. The pebbles are of granite, quartz-porphyry, felspar-porphyry, felsite, of various cherty rocks derived from the iron formations of the Lower Huronian and of schists and phyllites. Of these perhaps those which stand out most prominently, and which are of most general occurrence, are of the granite rocks, and more especially of a light-colored grayish or pinkish and somewhat porphyritic granite. Sometimes pebbles are almost or entirely wanting, and then the conglomerate passes into the Doré slate—a somewhat rare phase of the Doré Formation, but occurring at several points, notably at the mouth of the Dog River. The Doré agglomerate is also rare, but occurs prominently at several points in the northern part of Michipicoten. It is a somewhat fine-grained chloritic or sericitic rock, containing sometimes a great many, but generally a very few, fragments of rocks, usually of the same chemical composition as the ground-mass, but more coarse-grained, and very frequently porphyritic. It is occasionally with difficulty distinguishable from the water-formed rock. When without fragments it becomes the Doré tuff—a form in general of very unusual occurrence.

The Post-Huronian acid eruptives consist of granites, felsites, syenites, and acid porphyries. Excepting toward the contact with other formations, the porphyritic or felsitic phase is rare, and by far the commonest species, both in the smaller bosses and in the main masses, consists of an even and medium-grained granite of light pinkish color. Though always weathered, it is often remarkably fresh considering its antiquity. It is a much-sheared igneous rock, but not so intensely so as are the igneous rocks which form so prominent a part of the Lower Huronian schists.

That these acid eruptives cut the Huronian rocks all along the line of contact, and are hence later than these rocks, seems almost undoubted, and though outcrops are often poor, owing to the quantity of drift or the thickness of vegetation, still the eruptive contact of the granite with the Huronian rocks is excellently shown in many places. In the compass of this paper no detailed account of many interesting contacts between the Huronian and the granitic rocks can be given. Several representative instances may, however, be cited. Very many points of contact were seen in which the irruptive nature of the granite into the Lower Huronian schists is apparent. Perhaps the most interesting observed is that seen north of Lake Charlotte, an irregular sheet of water about two miles long, lying within an embayment in granitic rocks just north of Kabenung Lake, and within a few miles of the Dog River. The rocks exposed along the cliffs which flank the northern shore of the lake consist of rusty and sometimes banded cherts, with quartz-magnetite, hornblendic schists and epidote schists, which represent metamorphosed Helen Rocks and Michipicoten schists. A short distance north from the shore, and interstratified with the metamorphic schists, are narrow bands of a light-colored felsite and of coarse-grained quartz-porphyry. Northward from the lake shore these sheets of acid igneous rock increase in width, become more granitic, and are of more frequent occurrence. Moreover, they are often joined one to the other by narrow apophyses of similar rocks. About one half-mile north from the lake granites alone are seen, though occasional small inclusions of schist are of somewhat common occurrence within them, especially close to the contact. Immediately south of the "final contact" the schists are so much metamorphosed that they consist almost entirely of epidote and similar metamorphic minerals, or else are so dense and fine-grained that they are indistinguishable from a hornfels. The granite is of the usual medium-grained, light-pinkish type, and, though distinctly sheared, is not perceptibly laminated, and so could hardly be called gneiss. This granite is apparently part of the great area of acid igneous rocks which stretches northward to within a few miles of Hudson Bay.

An excellent contact between the granitic rocks and the Helen Formation is shown at Mount Raymond, one of the most prominent hills in the Michipicoten area, and which lies just west of Paint Lake and within a mile of the Frances Mine. At this point the Helen Formation is cut by a wide dyke of porphyritic granitic rocks, which forms the most prominent part of Mount Raymond. The iron-bearing rocks are metamorphosed into actinolitic and grüneritic magnetite schists. Contact deposits of impure magnetite occur close to the border of the dyke, and a wide vein of quartz, which is decidedly pyritous and slightly auriferous, has developed within the adjoining rocks. Compared with the intense metamorphic effect exerted by this granite, the decided lack of visible metamorphic influence generally exercised by the granite, cutting the iron formation in the Pucaswa area, stands in very marked contrast. For instance, the iron formation there is intruded by a huge granitic batholith on the eastern branch of the Pucaswa River, about four miles above its confluence with the western branch. The eruptive contact is abrupt and decided, but the iron formation, which consists of banded magnetic chert, is relatively practically unaltered. The granite is bright red and somewhat coarse-grained, though of even texture.

Visible contacts between the Upper Huronian and the intruding granites are rare as compared with those with the Lower Huronian. This is due probably to the much smaller surface area occupied by the Upper Huronian rocks. There is a good contact showing distinctly the eruptive relations of the granite on the southern shore of Lake Charlotte. Another is on the western shore of Western Lake Kabenung, and still another, and one which is perhaps better shown than either of the others just given, on the shore of Lake Superior, near the mouth of the Doré River.

Somewhat interesting is the geologic section exhibited along the Lake Superior shore from Otter Head eastward. Here the ceaseless washing of the waters has kept the rocks well exposed, and the relations existing between the different formations is easily observed. At Otter Head the rocks, named in order of their age, consist of small areas of evenly banded gneiss, ordinary light-reddish granite, coarse-grained pegmatite, quartz and calcite veins, and dykes of basic igneous rocks. The gneiss is composed of alternating bands one-quarter of an inch and less in width, of dark-colored minerals, chiefly biotite, and similar bands of light-colored minerals, chiefly orthoclase, oligoclase, and quartz. There is apparently not much differentiation into laminæ of the felspar minerals and quartz. The light-reddish granite, which is the prevailing rock, is exactly similar to the Post-Huronian granite described above. The pegmatite, consisting chiefly of large individuals of microcline, orthoclase, plagioclase, quartz, and biotite was probably formed as the result of the action of steam acting upon the hot granitic magma, either during or immediately following its intrusion. The veins are later than either granite or pegmatite, but probably owe their origin to the circulating thermal waters, which followed, and were the result of, the granitic intrusion.

Eastward from Otter Head the inclusions of gneiss appear of finer grain, though always very evenly banded. Gradually these inclusions become more and more common and widen into definite bands, alternating with areas of granite, and more closely resemble the ordinary types of schist. Sometimes the bands of schist are joined to each other by strips of granite. Finally, at about nine miles east of Otter Head, at the prominent point just east of Richardson's Harbour and about four miles west of the mouth of the Pucaswa River, schists alone appear, and are the prevailing rock as far as Ganley's Harbour.

Now, the points which I wish to emphasize are these:

1. A prominent part of the Lower Huronian schists is composed of felsite and quartz-porphyry schists which have sometimes a gneissoid appearance.

2. An Upper Huronian conglomerate contains many granite, quartz-porphyry, and felsite pebbles which are unlike the Post-Huronian acid eruptive rocks. The pebbles of quartz-porphyry and of felsite were probably derived from flows of quartz-porphyry and felsite, now represented by their metamorphic equivalents, the quartz-porphyry and felsite schists. No rock earlier than the conglomerate at present outcrops from which the granite pebbles could have been derived, unless it is the acid gneiss.

3. Immense masses of granites and other acid eruptives cut the Huronian, and are hence later than these rocks. These granites form at least a very prominent part of the acid-eruptive complex, known as Laurentian. Contained as inclusions, sometimes of considerable size, within these acid eruptives, are earlier acid igneous rocks which are typical gneisses.

May not the areas of gneiss be of the same age as the Lower Huronian, and represent merely an intensely metamorphosed felsite or quartz-porphyry, or the deep-seated equivalent of these rocks? Again, is it not possible that the granite pebbles which occur in the Doré conglomerate were derived from a rock no longer existing, but of which the Post-Huronian granite is possibly the regranitized equivalent? Of this Pre-Upper-Huronian rock it is possible that the small patches of gneiss within the Post-Huronian granites are the metamorphosed remnant.

My reasons for thinking that the gneiss areas within the Post-Huronian eruptives are of the same age as the Lower Huronian schists and not earlier (as was the original idea of Sir William Logan and the earlier Canadian geologists) is perhaps a negative one, namely: there is absolutely no evidence of an unconformity between the gneisses and the schists.[1]

Of course, the gneiss may not be, as I suggest, a highly metamorphosed granite, or rock of similar lithological composition and origin. It may be a metamorphosed aluminous sediment, but, judging from the extreme rarity of rocks of such character in the Lower Huronian, this hardly seems likely, though dynamic agencies competent to cause regranitization of Lower Huronian acid eruptives may with considerable justice be considered capable of utterly destroying the identity of water-laid sediments.

Since there are no granites now outcropping similar to those exhibited by certain of the pebbles of the Doré conglomerate, it stands to reason that the granite from which they were derived must either be entirely covered by more recent rocks, or else have altered its state. The former hardly seems likely, because the area is large, and the granite pebbles of this particular sort occur everywhere within the Doré conglomerate. In favor of the second hypothesis—namely, a change of state—it may be said that wherever gneiss and granite areas occur together (which is very frequently the case) there seems to be some slight evidence that the latter is derived from the former. The evidence consists in a peculiar ragged, though sometimes gradual, transitional contact and in the numerous dykelets of granite which ramify through the smaller inclusions of gneiss. It may be objected that this contact is simply one characteristic of any eruptive contact between granite and gneiss. It is of course not my contention that the contact is not an eruptive one, but simply that the granite may be derived from the gneiss. A somewhat homely illustration of a similar phenomenon in nature to that of regranitization may be observed in the recrystallization of ice so frequently seen on the surface of a glacier. Here one may often find a very much banded mass of ice—the banding being due to compression—

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[1] According to the International Committee, these schists would be called Kee watin. It will be seen that the geology as sketched in this paper is slightly different from that given by the committee.

veined and slashed with irregular and lensoid areas of more coarsely crystallized ice which show no banding, and represent small crevasses or irregular holes filled with water derived from the melting of the banded ice, and subsequently frozen. What little has been done by the writer seems, however, to prove the hypothesis. It is chiefly in the hope that microscopic and chemical work will be undertaken on this interesting problem, in a careful and systematic way, that these suggestions are now made.

If the theory which is here proposed with regard to the origin of the granites is correct, the geological history of the Michipicoten and Pucaswa areas may be briefly summed up as follows: First, were laid down the series of acid and basic volcanics, with the sedimentary phyllites and iron-bearing cherts, which compose the Lower Huronian on some pre-existing floor, of whatever character that may have been. These were gently folded, and in the consequent synclines were deposited the conglomerates and slates of the Doré Formation. Evidently volcanic activity continued during Upper Huronian times, allowing the deposition of the Doré agglomerates and tuffs. Succeeding the laying down of the Upper Huronian, both Upper and Lower Huronian rocks were intensely corrugated. During this corrugation, and in the main as the direct result of it, came the regranitization of the Lower Huronian acid igneous rocks, which must have existed in quantities largely predominating over all other rocks, and the consequent intrusion of vast masses of granites and allied rocks.

THE IRON CONCRETIONS OF THE REDBANK SANDS

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In the accompanying illustrations (Figs. 1–4), reproduced from photographs, are shown forms of iron concretions which seem to deserve notice alike for their peculiar structure, great length, uniform orientation, and effect on local topography.

These concretions are to be found in immense numbers in the Redbank sands of Monmouth County, New Jersey, a formation which is here a quite structureless bed of loose, rather fine quartzose sand about 100 feet thick, generally red in color from the decomposition of glauconite formerly disseminated through it. The concretions are most numerous near the upper part of the formation, and occur as isolated individuals imbedded in the sand, as well as more or less densely packed in groups.

The primary type of these concretions is a very long, more or less regular, hollow cylinder, which is generally straight and of unvarying diameter, but which sometimes tapers very gradually and may be of indefinite length. Single tubes have been observed which were more than 20 feet long, but it is impossible to remove unbroken such great lengths from the sand in which they are imbedded, owing to the occurrence of transverse cracks which divide them into irregular segments. Fig. 1 is from a photograph of such a segment; the diameter of the tube is 1½ inches. The smallest tube yet observed had a diameter of ¼ inch; the largest tube of *circular* cross-section so far seen had a diameter of nearly 1 foot. The interior of the cylinder is generally filled with sand differing in no respect from the sand without; the wall of the cylinder is merely the ordinary material of the sand-bed, cemented together by iron oxide. While the cross-section of the cylinder is often circular, more frequently it is quite irregular. Still more frequently the concretion is not a closed tube at all, but a corrugated sheet.

Besides simple tubes like that shown in Fig. 1, there are the polychambered types represented in Figs. 2 and 3. Fig. 2 has two unequal and somewhat dissimilar chambers. Fig. 3 shows an end view of a fragment of a three-chambered specimen. In Fig. 5 are shown cross-sections of a number of selected specimens. Fig. 6 is a sketch of the projecting ends of a group of concretions as they appeared in the bank of a railroad cut. Fig. 4 is from a photograph of a bluff in the Highlands of Navesink also showing projecting ends.

In the compound concretions there is usually one primary chamber which is more or less accurately circular in cross-section, and sometimes more than one. The cross-sections of the secondary or parasitic chambers are only arcs of circles. It is in fact a notable characteristic of all these concretions, of whatever dimensions or however otherwise irregular, that they show in cross-section practically no other lines than greater or smaller arcs of circles.

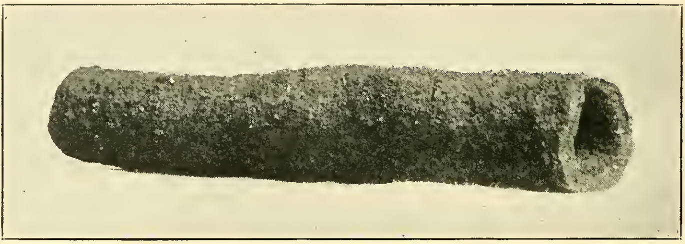

Fig. 1

As may be seen from Figs. 5 and 6, the number of secondary chambers in a single specimen may be large. Often in a compound individual the ratio of the dimensions of the primary and secondary chambers is rigidly maintained throughout its observed length, but this is not invariable. Frequently a secondary chamber will end abruptly in a *cul-de-sac;* just as frequently it will diminish gradually until its wall merges imperceptibly with the wall of its primary, so that a concretion which is compound at one end may dwindle down to a single primary tube at the other.

A noteworthy but puzzling feature is the fact that, without observed exception, these concretions all occupy a horizontal position, and lie with their longer axes parallel to the strike of the formation, which is

E. N. E., the dip being slight. In some exposures they are seen to occur in parallel zones which are considerably inclined to the normal dip of the strata in this region. As noted above, their distribution through the sand is, in general, irregular. In some large areas they appear to be totally absent, and occur but sparsely in others. In still other areas they are found in crowded aggregations containing an enormous number of individuals, all having the characteristic orientation. Where the concretions lie thickly crowded together, this common orientation gives them an appearance suggestive of great piles of cord-wood partially covered with sand. Such aggregations, which are often elongate in the same direction as the concretions themselves, are locally so numerous and large as to impress a peculiar stamp upon the topography, as they serve to protect the loose sand beneath from erosion; the resulting uniformly oriented hills of circumdenudation have somewhat the shape of drumlins. Such hills are numerous on the outcrop of the formation in the eastern part of Monmouth County.[1] The most interesting specimens are not usually found in these situations, as the abundance of iron has led to a thickening of walls and a running together of outlines. The best ones are to be obtained where the glauconite was sparingly disseminated, as in the large cut on the New York & Long Branch Railroad one mile west of Redbank. In this and many other localities the concretions may be dug out of the sand with no other implement than the bare hand; the interior filling may be removed by shaking, or with the aid of a straight stick.

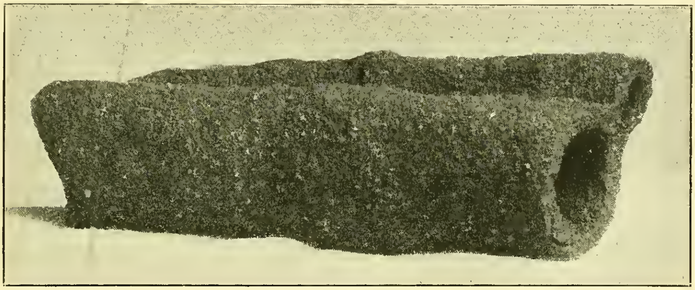

FIG. 2

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[1] See Sandy Hook Sheet, U. S. Geological Survey (topographic map) south of Eatontown and thence east to Long Branch.

If the removal of the interior filling be cautiously effected, best with the help of a gentle stream of water, there may sometimes be seen fragile, calcified, arborescent forms which ramify through the concretion in complete disregard of the interior partitions, and which are sometimes, but not often, preserved beyond the outer periphery. The dotted lines across two of the cross-sections in Fig. 5 indicate such arborescent forms. They are doubtless fossil stems of plants which were evidently present in the sand before the concretions were formed, and owe their preservation within the concretions to the exclusion of the underground circulation, which has no doubt in most cases removed by solution the parts not so inclosed. If this be the true interpretation, their presence is significant as showing that organic matter was formerly more abundant in the sand, yet they make it exceedingly difficult to believe that these concretions are fossilized remnants of elongate forms of animal or vegetable life, since it is inconceivable how such forms could have inclosed these calcified plants (if such they be) in the manner observed; besides, they bear no resemblance to any known form of life.

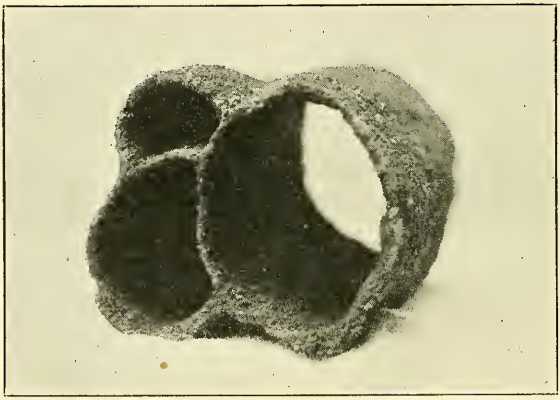

FIG. 3

Neither is there any reasonable probability that they have resulted from the filling of cracks and subsequent hardening of the filling material. In the first place, they are found in loose sand, which is certainly not a material in which to expect cracks of any kind; in the second place, the formation of long, straight, horizontal, tubular cracks, or such systems of cracks as would be necessary to give the observed forms to the compound concretions, would be a mechanical marvel under the most favorable circumstances. They are clearly not of stalactitic origin. The Redbank formation is ideally porous; where the concretions display their most typical characteristics the formation does not now, at any rate, possess any structural feature which may have served to guide convection currents. All the evidence obtainable seems to show that the material which supported the growth of the concretions was transported to them by diffusion rather than by convection. Transportation by diffusion here refers to movement of dissolved matter in obedience only to the molecular activities of the substance in solution, while transportation of the same by convection implies a bodily movement of the solution in a determinate direction. The distinction is important in this connection, since if water currents, along with other mechanical agencies, are denied any part in the formation of these objects, they must be regarded as an expression of a molecular tendency of the cementing material.

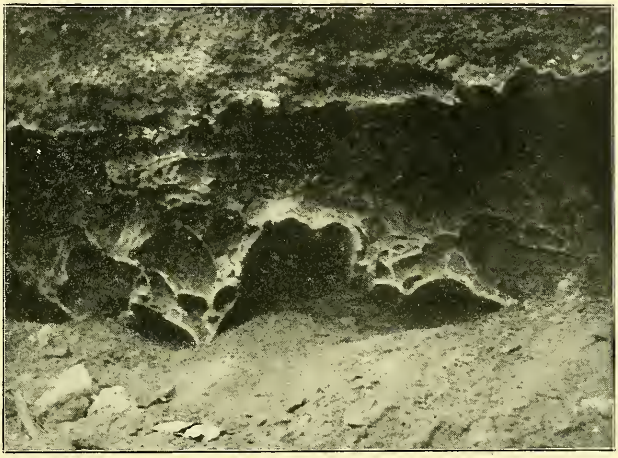

FIG. 4.—Bluff in the Navesink Highlands, showing irregular tubes and corrugated sheet.

The evidence in favor of transportation by diffusion is clear and positive. Where the concretions are absent the ferruginous coloring-matter is in general more or less evenly distributed through the sand; in the vicinity of the concretions the red color is much less pronounced, and may even disappear altogether, leaving the sand clean and white. This at least goes to show that the supply of cementing material was local. Further, many of the isolated concretions, compound as well as simple, lie in sheaths of pure white sand, which they have decolorized as decaying roots might have done. Fig. 7 illustrates a phenomenon often observed in the Redbank formation. There is here shown a segregation of the iron into more or less parallel bands, which locally give the sand a prominent but deceptive appearance of being finely stratified. However, the bands anastamose in a manner which shows that they are not the result of ordinary processes of bedding. The sand of the light bands is poorer, that of the dark bands richer, in iron than sand where segregation has not occurred. The iron oxide in the dark bands is sufficient in amount to occasion differential weathering, but real cementation has not yet taken place; the sand is still so loose that it may readily be excavated with the bare hand. These segregations probably represent a first concentration of the iron by the mutual attraction of like particles. In the sand-bank not far from where the photograph was taken is a large nest of concretions which have absorbed to themselves the iron of all the bands in their immediate vicinity.

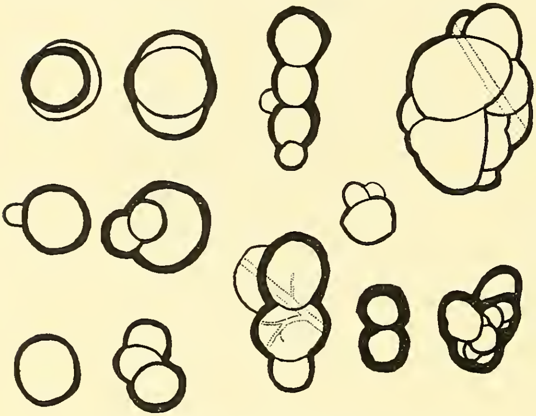

FIG. 5.—Cross-sections of selected concretions.

It is not maintained that convection currents have never circulated through the sand, but it is clear that they must have been quite subordinate when and where the concretions were actively forming.

Finally, a study of the interior structure of numerous compound concretions has shown relations for which the author confesses his inability to offer explanations based on hypotheses involving fortuitous mechanical circumstances, or possible modes of circulation of water containing the iron in solution. There is among all the phenomena associated with these concretions but one, in producing which mechanical influences can be suspected of having played a tangible part. This is the noteworthy parallelism of their longer axes with the strike of the formation, which suggests that shore currents or waves, acting parallel to or impinging upon the ancient Cretaceous shore, may have sorted into some definite arrangement the material the decomposition of which was later to furnish the cementing bond of the concretions. But the influence of waves or currents must have stopped with the action requisite to govern the orientation of the concretions, and could have played no further part in giving them their observed characteristics.

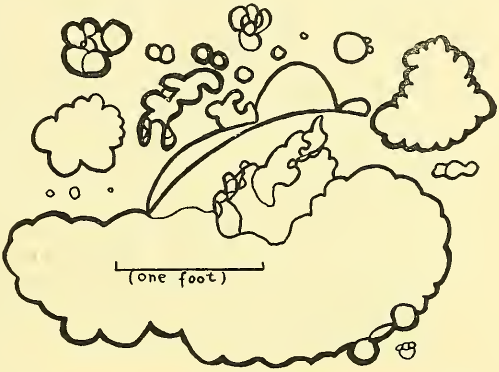

Fig. 6.—Sketch of the ends of a group of concretions seen in a railroad cut.

The author is therefore inclined to the hypothesis which regards these objects as forms proper to the cementing material, which will, under proper circumstances, be assumed in obedience to impulses residing in its molecules. There is evidence tending to show that these concretions have a fairly definite morphology. In many cases it is possible to show with great probability that the various tubes of the polychambered individuals were not synchronous in their origin. In Fig. 8 is given a generalized cross-section of a three-chambered concretion. The relations shown are thoroughly typical. It will be observed that only one—the largest—of the chambers, *A*, is really cylindrical in cross-section; the next largest, *B*, has the outline of a segment of a circle which is cut by the circle *A;* the smallest, *C*, has the outline of a segment of a circle cut by both *A* and *B*. From these relations, and from the relative thickness of the exterior walls and interior partitions, the history of the concretion is inferred to be somewhat as follows: The concretion probably consisted at first only of the tube *A;* in this condition it must have resembled the concretion shown in Fig. 1. As to what induced the formation of this tube, the concretion itself affords no direct evidence. It may be presumed that, once formed, the wall of the tube was thickened by addition of material chiefly from the outside, and that the rate of addition was practically the same at all points on the periphery. When the wall of *A* had attained the thickness represented by *a*, the arched chamber *B* barnacled itself on *A;* the arch *a*, thus cut off from outside supplies of material, suffered an arrest of growth. The concretion was now two-chambered, like the one shown in Fig. 2. By the time the exterior wall of *B* had attained the thickness of *b*, that of *A* had reached the thickness of *c*. A second parasitic chamber, *C*, was then arched across one of the sulci between *A* and *B;* *b* and *c* were thus cut off, and their further growth prevented while the exterior walls of the concretion, as it now appears, were taking on their present proportions. The existence of still more complex individuals, in which analogous relations between the several chambers and their walls obtain, shows that the process need not stop with the formation of a three-chambered concretion, but may be continued indefinitely. It is possible to col-

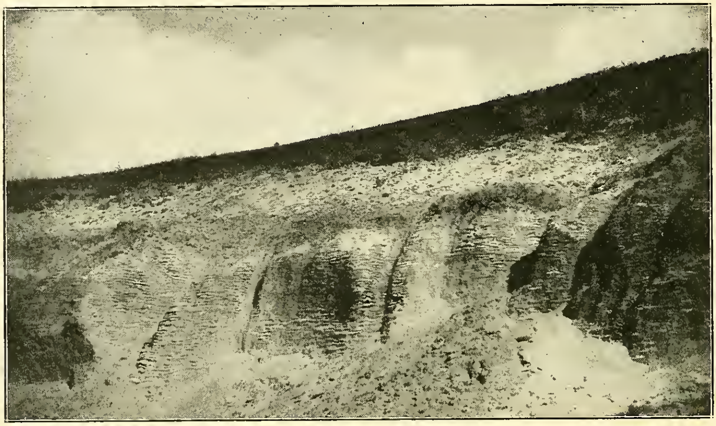

FIG. 7.—Sand bank in Long Branch, showing tendency of the iron (originally disseminated as glauconite) to segregate into anastamosing bands.

lect any number of suites of specimens having from one to a dozen chambers in which the order of the formation of the different arches may be made out with reasonable certainty. It will be observed that for each new chamber added to the concretion, a new curve is added to its outer boundary, so that in the more complex individuals this boundary becomes exceedingly tortuous.

The uni-chambered tubes of very large and very irregular cross-section, such as those shown in Fig. 6, are to be accounted for under two suppositions. The general appearance of their walls suggests that they were originally very complex individuals which had been built up in the regular way—i. e., by successive additions of secondary chambers—but which have lost their interior partitions through resolution. While this explanation of their origin has a certain plausibility, it is not regarded as the correct one. It is more likely that we have to recognize here the results of a process analogous to, if not identical with, the familiar "twinning" by which the different parts of a crystal may be oriented in contrary ways. If it be granted that the molecular tendencies residing in the cementing material be competent to cause it to assume the cylindrical form, it may be taken for granted that the cross-section of the young concretion will be an arc of a circle before it becomes a full circle. It is well-known that in the process of crystallization growing crystals are not always guaranteed against twinning; the molecular forces which govern crystallization are capricious. In the case of the young concretion there is no reason to suppose that the arc would always become a complete circle. From what is to be seen in numerous cross-sections, it appears that the centers and degrees of curvature were subject to change at frequent but irregular intervals. It must be regarded as in some degree accidental that the composite line formed by the numerous arcs should eventually form a closed area. In fact, in the majority of cases, the line did not so close upon itself. In

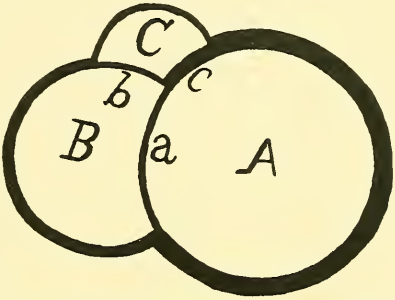

FIG. 8.—Diagrammatic cross-section of a three-chambered concretion.

such cases the concretion is not a closed tube, but is a more or less corrugated sheet, the corrugations, however, having the usual orientation. Such a corrugated sheet may be observed in the upper part of Fig. 4.

The formation of the secondary chambers of the compound concretions is to be ascribed to the same tendency to change the center of curvature. Ordinarily, new molecules coming in contact with the wall of a concretion simply went to increase the thickness of that wall, but not always. At any time some innovating molecule was likely to align itself so as to form a starting-point for a new arched surface, which would compel additional molecules to arrange themselves in conformity to its general scheme, until succeeding arches cut it off from further growth.

EDITORIAL

In the deaths of Dean Nathaniel Southgate Shaler, of Harvard, and of Professor Israel Cook Russell, of the University of Michigan, American geology has lost two of its best-known and most popular writers on geology, as well as two of its most active and attractive personalities. The closeness of succession of these calamities, and the singular similarity of the fatal illnesses, give keenness to our regret. It is our hope to publish, in an early number of the *Journal*, full sketches of the services of these two men to our science. Awaiting the publication of these sketches, we wish to voice now the universal sorrow, not only of geologists and educators, but of the multitudes of intelligent people who have read with profit and delight the sketches of earth-lore that have come so freely from their fluent pens.

T. C. C.

Because of business engagements which will take him out of the state for some time to come, Dr. Frank G. Wilder has resigned his position as State Geologist of Iowa, and has been succeeded by his honored predecessor, Professor Samuel Calvin. Changes in the administrations of state surveys are to be deprecated generally, except when inefficient men retire; but in this case the parties most immediately concerned have worked together so intimately and in such perfect accord that the transition will be accomplished without even momentary interruption in the work of the survey, just as it did when Dr. Wilder succeeded Professor Calvin. Since a change in the administration was necessary because of Dr. Wilder's absence, both Iowa and the science of geology are to be congratulated that Professor Calvin is willing to resume the duties of an office which he filled so long and so well, and from which he voluntarily retired some years ago.

R. D. S.

Reviews and Book Notices

A Register of National Bibliography, with a Selection of the Chief Bibliographical Books and Articles Printed in Other Countries. By William Prideaux Courtney. 2 vols., 8vo. Pp. viii + 639. London: Archibald Constable & Co., 1905.

This book is not on geology, but it contains so much of value to geologists, mineralogists, and paleontologists that it seems well worth while to call attention to it. It is a bibliography of bibliographies, and though one might infer from the title that it was confined to British bibliographies, this is far from being the case. The author lives in London, and for some twenty years he worked more or less at this task, while during the last four years he devoted his time entirely to it. He has besides had the aid of many persons interested in special lines of bibliographic research, to say nothing of purely clerical work provided by himself.

The general titles are arranged in alphabetic order, and besides these there is at the end a full index covering seventy pages of closely printed names and subjects. Under the head of geology, besides the general bibliographies, there are given bibliographies of over one hundred countries, states, and special topics.

J. C. Branner.

The Dynamics of Faulting. By Ernest M. Anderson. (Transactions of the Edinburgh Geological Society, Vol. VIII, Part III [1905], pp. 387–403.)

By treating the subject in a mathematical and theoretical method the following conclusions are drawn:

Faults may be grouped roughly into three classes, known as reversed faults, normal faults, and wrench-planes.

a) Reversed faults and thrust-planes originate when the greatest pressure in the rock mass is horizontal, and the least pressure vertical. They "strike" in a direction perpendicular to that of the greatest pressure, and dip in either direction at angles of less than 45°.

b) Normal faults originate when the greatest pressure is vertical, and the least pressure in some horizontal direction. They "strike" in a direction perpendicular to that of least pressure, and dip in either direction at angles of more than 45°.

c) The third type of faults, to which the name of wrench-planes has been applied, originates when the greatest pressure is in one horizontal direction, and the least pressure in another horizontal direction, necessarily at right angles to the first. They "strike" in two possible directions, forming acute angles which are bisected by the direction of greatest pressure; their hade is theoretically vertical. E. W. S.

The Copper Deposits of Missouri. By H. Foster Bain and E. O. Ulrich. (United States Geological Survey, Bulletin No. 267, 1905.) Pp. 52, 1 plate, 2 figures.

Copper is widely distributed in Missouri in the form of sulphides and carbonates, but the deposits are not large, and only four mines have found it in workable amounts. The total value of copper so far produced has been variously estimated at from $20,000 to $50,000. The ores are believed to have been widely disseminated in crystalline and sedimentary rocks, and to have been concentrated by underground waters. The copper seems related to original shallow water conditions. It also shows a preference for certain horizons. This is believed to be due to unequal distribution at the time the rocks were formed. E. W. S.

The Geology of the New England Plateau, with Special Reference to the Granites of Northern New England (New South Wales). Part II, "General Geology;" Part III, "The Genesis of Ore Deposits." By E. C. Andrews, B.A. (Extract from Records of the Geological Survey of New South Wales, Vol. VIII [1905].) Pp. 45, 11 figures, 1 plate.

These papers treat of the geology of New South Wales; the occurrence of gold, wolfram, tin, monzite, bismuth, and other ores; and the close relation between their occurrence and certain acid intrusives. E. W. S.

The Geology of the Diamond and Carbonado Washings of Bahia, Brazil. By Orville A. Derby. Translated by J.C. Branner.

The diamonds occur in various formations, but principally associated with a heavy conglomerate, 6–10^{m} thick. About 250^{m} of sandstone lie above this conglomerate, and an equal thickness underlies it. Where diamonds occur in other formations in the region, they are thought to have been transported there from the conglomerate. The structure is Appalachian in type, and there has been much faulting and folding and erosion. The age of the conglomerate is unknown, but undisturbed Cretaceous sandstone is found near the folded conglomerate. E. W. S.

The University Training of Engineers in Economic Geology. By J. C. Branner. (Reprint from *Economic Geology,* Vol. I, December–January, 1906, pp. 289–94.)

This paper discusses the training necessary for success in economic geology. The author points out the desirability of considerable preliminary study of other subjects, and the necessity of training in pure geology.

E. W. S.

Red Beds of Southwestern Colorado and Their Correlation. By Whitman Cross and Ernest Howe. (Bulletin of the Geological Society of America, Vol. XVI [December, 1905]. Pp. 447–98, Plates 82–85.)

A marked unconformity occurs in the Red Beds of this area, and several photographs of it appear in this article. The formation above the break is classified as Triassic on the basis of vertebrate fossils; that below is assigned to the Permian. E. W. S.

Taconic Physiography. By T. Nelson Dale. (U. S. Geological Survey, Bulletin No. 272, 1905.) Pp. 52, 14 plates, 3 figures.

There have been three periods of folding in the region—first, at the close of the Lower Cambrian; second, at the close of the Ordovician; and third, in Devonian or Carboniferous time. The topography is the result of the erosion of rocks which vary in composition and structure. The lakes and some other features are due to glaciation. E. W. S.

Underground Waters of Eastern United States. By Myron L. Fuller. (Water Supply and Irrigation, Paper No. 114, U. S. Geological Survey, 1905.) Pp. 272, 18 plates, 40 figures.

This report is prepared primarily for drillers and treats of the occurrence of underground waters. It is a compilation of material from numerous local geologists. E. W. S.

Fire Tests of Some New York Building Stones. By W. E. McCourt. (New York State Museum, Bulletin No. 100.) Albany, 1906. Pp. 38, 26 plates, and index.

The purpose of testing the building stones was to acquire definite information regarding their fire-resisting qualities. The rupturing caused by heat, with slow, or with sudden cooling, varies considerably with different rocks. The order of the refractoriness of rocks tested is: (1) sandstone, (2) fine-grained granite, (3) limestone, (4) coarse-grained granite, (5) gneiss, and (6) marble. E. W. S.

Contributions to the Hydrology of Eastern United States, 1903. By MYRON L. FULLER. (Water Supply and Irrigation, Paper No. 102, U. S. Geological Survey, 1904.) Pp. 512.

This paper covers the hydrologic work done in the eastern United States in 1903. The statistics are arranged by states. The information was collected by many local geologists, and compiled and prepared by Mr. Fuller.

E. W. S.

The Sources of Water Supply in Wisconsin. By WILLIAM GRAY KIRCHOFFER, C.E. (Bulletin of the University of Wisconsin, No. 106.) Pp. 113, 3 plates, 3 diagrams, and 21 tables and index.

The bulletin is a compilation of data regarding the water used by cities and villages in Wisconsin, together with many interesting observations thereon. The sources are classified, and the factor entering into occurrence and use are discussed. E. W. S.

The Geology of the New Hebrides. By D. MAWSON, B.E., B.Sc., Lecturer in Mineralogy and Petrology at the University of Adelaide. Pp. 85, 14 plates, 7 figures. (Proceedings of the Linnean Society of New South Wales, Part III, October, 1905.)

Little has been known of the New Hebrides because of the hostility of the natives and the prevalence of malaria. The group of islands was developed as a fold in the Miocene, and intrusion and extrusion of andesitic lava accompanied the folding. About Middle Pliocene there was renewed volcanic activity along a new line, and this has continued to the present. This later flow is basic, and was probably immediately preceded by faulting. Recent uplift has carried coral reefs up to 2,000 feet. These are underlain by tuffaceous beds. The uplift is one-sided, being less on the east side, where the centers of eruption are.

Biological evidence points to connection of the islands with other land masses early in their history.

The author points out that the South Pacific Islands are lined along great fold-chains, concentric with Australia, and puts the New Hebrides, Sumatra, New Caledonia, and New Zealand in one of these chains. The discontinuity of the land is referred to cross-faulting, incident to folding. He believes that the land area was much larger and more continuous in the early Tertiary, and that the breaking up began then. From evidence of coral reefs, it appears that in these and many other islands of the South Pacific the first movement was true folding, and this was followed by horizontal uplift. The petrology, paleontology, and other features of the islands are treated in some detail. E. W. S.

A Dictionary of Altitudes in the United States, Fourth Edition. Compiled by Henry Gannett. (Bulletin No. 274, U. S. Geological Survey, 1906.)

The material of previous editions has been revised, and many new data have been added. E. W. S.

Twenty-sixth Annual Report of the Director of the United States Geological Survey, 1904–5. Pp. 322, 25 plates (maps), 1 figure.

A classified report of the work of the United States Geological Survey for the year. E. W. S.

The Economics of Mining. By T. A. Rickard. Pp. 421; cloth.

This volume is composed of nearly a hundred editorials and short articles which have appeared since January, 1903, in the *Engineering and Mining Journal*. E. W. S.

Mesozoic Section on Cook Inlet and Alaska Peninsula. By T. W. Stanton and G. C. Martin. (Bulletin of the Geological Society of America, Vol. XVI [June, 1905].) Pp. 391–410, Plates 67–70.

Upper Trias, Lower, Middle and Upper Jurassic, Upper Cretaceous, and probably Dower Cretaceous are found to be represented, and, except the Middle and Upper Jurassic, are usually, at least, separated by unconformities. Nearly 10,000 feet of strata are referred to the Jurassic. The fauna at this period is also well developed, and is Russian or boreal in type.

E. W. S.

THE

JOURNAL OF GEOLOGY

MAY–JUNE, 1906

VOLCANOS AND RADIOACTIVITY[1]

MAJOR C. E. DUTTON, U. S. A.

One of the commonest, and perhaps the most impressive, of natural phenomena, the volcano, has hitherto been without any explanation of its cause, though it has been before the world a subject of theory for many centuries. The reason for this is quite apparent. We perceive the action of the volcano upon the surface, and we know what it does. But the theater of its origin and the development of its energy are far below the surface of the ground, out of reach of inspection or direct observation. Human ingenuity has been baffled in its efforts to explain the phenomenon because of the want of observed facts and the impossibility of obtaining them. But, while we are, and probably always shall be, unable to directly inspect the seat of origin of the volcanos, there are certain inferences in connection with them which have attained a degree of probability which entitles us to use them as facts which may limit speculation and confine it within very narrow boundaries. I purpose to mention these inferences in order to see the general nature of the solution to which they point; for, unless I am greatly mistaken, they will show us that we are close upon the verge of a solution.

1. The first fact to be mentioned is the solidity of the earth. It is so well known that I shall not dwell upon it, and merely mention it in order to bring it, together with other facts, into the same series or group.

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[1] Read before the National Academy of Sciences, April 17, 1906.

2. The second fact is the comparative smallness of the extravasated masses in any single volcanic eruption. In order to obtain an idea of the relative magnitude of an erupted mass, let us draw upon a true scale, a segment of 1° of the earth's surface, of an arbitrary thickness—say thirty miles. Upon this segment draw the profile of Vesuvius. About a mile below the surface, beneath the volcano, draw the reservoir of lava, having the same mass as the volcano itself. It may have any thickness and any form, and is subject only to the condition that the capacity of it is the same as the mass of the erupted material. Now, Vesuvius is built of I know not how many individual eruptions, but let us say one hundred; though I presume that there were, in reality, very many more. A single average eruption would be the hundredth part of the volume of this reservoir. But there are eruptions known which are many times greater than the average of those of Vesuvius. The largest known in the United States are in the Snake River valley, and while we are not in a position to compute with accuracy their dimensions, we can say with confidence that the volume of the largest of them does not exceed two cubic miles. The great eruption of the Skaptar Jökul, in Iceland, in the year 1783, was estimated by Dr. Thoroddson to have outpoured twelve or thirteen cubic kilometers, or three cubic miles of lava. The greatest eruption of which we have any estimate—and that is a very crude one—was at Tomboro, on the island of Sumbawa, which was estimated to have discharged about six cubic miles of lava. This estimate is very excessive, and is probably two or three times too large.

On the same scale as before these two eruptions are represented, and you perceive how insignificant they are in mass in comparison with the whole of the surrounding earth.

3. The third general fact is the repetitive nature of volcanic eruptions. A single outbreak, with none following, is an exceeding rare phenomenon. Many eruptions, going often into the thousands, occur before the climax is reached and the decline of activity follows. The reason why a volcano, when its vent is once open, does not discharge all the material in its reservoir in one stupendous belch, and then close up forever, will be shortly brought up.

4. The next general fact, which we cannot claim to be proven, but

for which there is a growing mass of strong and highly concordant evidence, is that the seat of the reservoir is very shallow and seldom more than three miles deep. Very rarely is there any indication of its being more than two and one-half miles deep, and it is certain that in many cases the depth is less than one mile. The indications are that most of the volcanic eruptions originate at depths between one mile and two and one-half miles. The evidence of this is furnished by the earthquakes which almost always accompany them, and which are associated with them in such a way as to leave no doubt or question that they are produced by the volcanic action. The radiation of the tremors of an earthquake from their source in the earth is governed by substantially the same law as sound. The intensity of these tremors, where they reach the earth's surface, varies in a manner which is dependent upon their depth of origin. In the discussion of the Charleston earthquake I pointed out one method by which that depth can be approximately computed from the distribution of critical points of the surface intensity. The method has been sharply criticized by able seismologists as being liable to error through refraction of the rays of propagation through rocks and media of variable density. But I observe that all of them use that method with surprising consistency and satisfactory results.

The efficiency of this method depends mainly upon the accuracy with which the intensity can be estimated along a line radiating from the epicentrum. It often happens that the intensity is so much affected by the local nature of the soil and rocks that all estimates become so uncertain as to be very misleading, and all attempts to draw conclusions from them must be affected by large errors, or may fail entirely. On the other hand, in many cases the results are safer and surer than would be supposed, and we are able to give a graphic representation of the curve of intensity which must be very near the truth. In general, when an earthquake is very strong at the epicenter and quickly fades out away from it, we can say with confidence that its centrum is very shallow. If the intensity fades out slowly and the quake is felt at great distances, we can rely upon its centrum being very deep. When, therefore, we have not the means of estimating the intensity at the critical points, if we have the means of estimating the maximum intensity of the quake and of knowing how far it is felt, we can still form, not indeed a precise or accurate estimate of its depth, but a roughly approximate one.

A qualification of the foregoing may be introduced here. The earthquake is no doubt the fracturing or sudden yielding of the rock masses immediately above the lava reservoir. We can only vaguely conjecture the distance which separates the zone of fracture from the zone of melting. But in no case could it be so great as a mile without making itself sensible in the greater depth of the quake. We must, however, increase slightly our estimate of the depth of the lava beyond the estimated depth of the quake.

We may now proceed to state the probable cause of volcanic eruptions. They are caused, I conceive, by a development of heat, resulting from radioactivity, in limited tracts at a depth of one to three —at the very utmost not over four—miles from the surface, which is sometimes sufficient to melt the rocks affected by it. The melting is gradual, and when a sufficient quantity is melted, the water which it contains becomes explosive and usually suffices to break through the covering, constituting an eruption. When all the lava is erupted, and the reservoir is exhausted, it closes up for a time. If the heat continues to be generated, more lava is melted, and in due time another eruption occurs. The process may be repeated again. It may be repeated hundreds or thousands of times. The volcanic action may continue in the same place for hundreds of thousands, or even millions, of years, or it may repeat itself only a few times, or may even occur only once. Indeed, it may fail altogether to erupt to the surface, and in many cases does fail. In other words, it goes through the entire process of preparing for an eruption and does not consummate it.

This view enables us to explain the repetitive character of volcanic eruptions, which is, perhaps, their most striking and characteristic feature. It is in strong contrast with the view long held that the lava reservoirs are a part of the original constitution of the earth, and have lain in their present position through all the vast period of the earth's evolution, waiting for a convenient occasion to explode and pour forth their fiery contents. It regards the reservoirs as having no real existence as such, and as containing no liquid eruptible contents until some source of heat acts upon them and liquefies a portion of the strata, thus giving rise to the reservoir. When a sufficient quantity of the lava is melted to rupture its covering, the eruption follows. It continues until all the lava which exists for the time being in the reservoir is extravasated. And when all of its ammunition is expended, it must close its action until a fresh supply is provided.

By an increase of heat, we can readily understand the existence of the lava reservoirs in such anomalous positions near the surface of the earth. The horizon of melted lava, which has a temperature of about 1,000° or 1,200° C., if it depended wholly upon the secular cooling of the earth would be more than thirty miles below the surface, or even forty miles below. We cannot suppose that the cooling of the earth is so extremely unequal as to bring the isotherm of 1,000° C. at one place within two miles of the surface, and in another place carry it thirty or forty miles below. It is equally difficult to imagine any subterranean disturbance or displacement which could mechanically thrust up near the surface a portion of the solid nucleus of the earth. Such a displacement is not warranted by the geological facts; for while volcanic eruptions occur frequently in localities where the strata are much displaced, they also occur quite as often where there has been no displacement of any moment since the Cambrian age.

A singular class of phenomena is found in the so-called mud volcanos, which have always been a great puzzle, but which are easily explained by this cause. We find them in Central America and in Java, and the remarkable case of Bandai San, in Japan, is well remembered. These volcanos must have their origin at less depth than the lava eruptions. The temperature of erupted mud is not accurately known, but it cannot be less than 400° or 500° F. The generation of heat half a mile below the surface would be a sufficient explanation of their origin and action.

Why should eruptions always emanate from shallow reservoirs and never from deeper ones? Or, according to the view here put forth, why are eruptive masses formed only at depths of two or three miles, and never at greater depths? I do not contend that no lava pools are formed at greater depths than three or four miles, but if they are formed, the lava is never erupted, and for the following reason. The pressure of the overlying rock at a depth of three miles is about 18,000 pounds to the square inch. At a depth of four miles it is about 25,000 pounds to the square inch. At such a pressure (25,000 pounds) it would be impossible for water vapor to lift its covering and force a way to the surface, unless it had a temperature greatly exceeding 1,200° C. It would have to be heated to a considerably higher temperature to do it. But with increasing temperature the heat is conducted away more and more rapidly, until the loss of heat is equal to the quantity generated and thereafter there is no increase of temperature. The generation of radioactive heat is a slow process, and the only method of its escape is by conduction away from the radioactive source. The rate of heat generation is constant and independent of the temperature, but the rate of loss increases rapidly with the temperature. Ultimately, as the temperature rises, a point would be reached at which the loss of heat becomes equal to the gain.

If an eruption from a deep source, say five or six miles, were to occur, we should expect that the temperature of the lava would be very high—probably a white heat—and that its mass would be very great. Its consequences might be disastrous beyond all precedent.

That volcanism is caused by the generation of heat near the surface was a belief which I expressed over twenty years ago in a chapter of the work on *Hawaiian Volcanos.* Long study of the volcanic problem, in which every other theory failed and went to pieces under criticism, and this alone not only survived, but grew more probable and in accordance with the facts, led me to the hazardous step of venturing to express it. At that time no cause could be cited for the increase of heat, and the proposition met with no response—and, no doubt, justly. Geologists continued to look for the explanation of volcanoes in the gradually waning remnants of the earth's internal heat. Within the last five or six years, however, physical science has made discoveries of a wonderful nature, which open a new field—indeed, a new world—in our views of the constitution of matter, and may throw a flood of light on the very subject of our inquiry.

The subject of radioactivity is so new and so surprising that it has had time only to establish a very few of the fundamental principles which lie at the basis of it. But so hotly is the matter pursued by many of the ablest specialists that each year shows a large increase in our knowledge. As this is familiar to all physicists, I shall allude here briefly only to such as are essential to our discussion. We have to regret that some of the most fundamental questions concerning radioactivity are as yet unsolved, though we cannot expect that a new and and far-reaching science should in six years have accomplished all of its immense possibilities.

A good many efforts have been made, by the use of the extremely sensitive quadrant electrometer, to ascertain by measurement the quantity of radioactive substances in the accessible portions of the earth. By taking samples of earth from varying depths and testing them by the electrometer, widely variable quantitative results have been obtained, but in every instance the amount of radioactivity indicated much exceeds the amount required to compensate the loss of heat from the earth by conduction and radiation into space. For instance, Professors Elster and Geitel, of Berlin, who have made many discoveries and contributed many observations in radioactivity, placed 3,300 ^{cc} of garden soil within a closed vessel with an electroscope to determine the conductivity of the inclosed gas. Allowing it to stand for several days, the conductivity of the air became constant at three times the normal amount. This increase of conductivity, Professor Rutherford estimates, would be equivalent to that produced by the emanation from 7×10^{-10} grams of radium. If the density of the soil be taken as 2, this corresponds to the emanation from 10^{-13} grams of radium per gram of clay. Now, Professor Rutherford computes that the earth's loss of heat by conduction and radiation is equivalent to what would be supplied by 4.1×10^{-14} grams of radium per cubic centimeter of its mass. According, then, to the results obtained by Elster and Geitel, twice as much heat would be supplied by radioactivity as is lost by conduction and radiation into space.

This experiment with a small quantity of soil taken up in somebody's back-yard will hardly be regarded as an accurate determination of such a quantity as the earth's supply of radioactive heat. But the question has been tested by many observers, whose results vary considerably, yet all are of the same order of magnitude. By sinking a pipe into the ground anywhere, and sucking up a sample of the air from the soil, it is found to possess a much higher degree of radioactivity than the free air at the surface. It also has a marked degree of conductivity; and this conductivity falls to half of its initial value in a little less than four days, which is regarded as proving that it is due to radium emanation. The air of caves and cellars has been observed to have a marked degree of ionization, greatly exceeding the open atmosphere and the air in closed vessels. This is attributable only to the presence of radium emanation diffused from surrounding rocks or soils. Many common well waters give satisfactory tests of the presence of radium emanation, which is soluble in water—more so than most gases.

The most pronounced occurrence of radium is in hot springs. Their waters always give evidence of its presence, and sometimes in quantities many times exceeding the air taken from the soil or cellars. Hon. R. J. Strutt, of Trinity College, has devoted much attention to the Springs of Bath, and finds not only radium emanation in their waters, but actual radium in the deposits of the springs. The hot springs of Baden Baden have been found to contain radium salts. M. Curie has tested a large number of the mineral springs of central and southern France, and finds radium emanation in nearly all of them. Mr. Boltwood, of New Haven, has devoted considerable attention to the study of radioactivity in mineral springs, and finds that many of the waters of America contain radium emanation.

It does not appear that any extensive or systematic investigation of the emanations of active volcanoes and volcanic gases has been made. The only one I can discover is the observation of Rausch von Trauenburg on the crater of Vesuvius. The gases from that orifice produced marked ionization and a prompt discharge of the leaves of the electroscope. The subject, however, needs thorough investigation at many other volcanic vents.

The general result of the investigation, so far as it has gone, has been to make clear the fact that the amount of radioactivity in the earth much exceeds the amount which is necessary, so far as the heat generated by it is concerned, to compensate the loss of heat by conduction and radiation. In fact, it appears that the thermal condition at present is one of continual increase of internal temperature of a large portion of the earth, or is so in part, or else is one of equilibrium between loss and gain. Undoubtedly the amount of radioaction varies somewhat widely in different portions of the earth's interior, in some portions permitting a loss of heat, in others permitting a gain. And when there is a gain, it may proceed in the portions near the surface so far as to liquefy the rocks, and thus furnish all the conditions necessary to volcanic eruptions.

One of the problems at present unsolved is: Whence comes this radioactive material, and what maintains its activity? For the most part, it gives us the characteristics of radium, and in smaller degree those of thorium and uranium. The action of actinium has not yet been sufficiently pronounced to be recognized. Polonium is believed to be one of the transitional forms of radium. No other radioactive substances are yet known. The most important one thus far identified is radium. But the life and activity of radium are, from a geological standpoint, very brief. According to Professor Rutherford —and he is sustained by nearly all other physicists—radium is half consumed in a period of 1,300 years. In 13,000 years only the thousandth part of what now exists will be left, and in 26,000 years only the millionth part will remain. Quite independently of geological reasons, the belief has been that radium is generated as the product of decay of some other element, and that the amount of it in nature is sensibly constant. It is generated as rapidly as it decays. The parent element from which it may be derived is not yet decided, but there are some who suspect it to be uranium, which has immensely long life. It requires nearly 120,000,000 years to be half consumed by its own decay.

But we are not interested in pursuing and trying to test these unsolved problems. It is enough for us that radioaction exists in sufficient quantity and intensity to furnish heat enough to meet the wants of the vulcanologist.

Let us now look for a moment at the presumable details of the process. At a depth of two or three miles in the earth let us assume that radium is in process of being generated. It starts at once upon that process of transfomation of which one stage is the production of the so-called emanation, which is a gas of very high density and great penetrating power and diffusability. We know that the upper strata and soils everywhere contain it, and no reason appears why the same should not be the case with the rock beneath. Wherever the emanation penetrates, the breakup of its particles generates heat, and the temperature rises in proportion to the amount of emanation which undergoes transformation in a given time, and falls in proportion to the rate at which it is conducted away. So long as the gain of heat exceeds the loss, so long will the temperature rise until it becomes sufficient to melt the rocks.

All volcanic lavas contain water, and those whose reservoirs are near the surface contain a large amount of it Those which have a deeper origin contain a smaller amount of it. The deeper lavas are hotter, and are erupted with less violence and in greater mass, than the shallow ones, and the reason is obvious.

The foregoing is a brief abstract of a portion of a book now in preparation on volcanism.

CONDITIONS OF FOSSILIZATION[1]

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Introduction.
Superficial Consideration of Fossils.
Conditions in Which Fossils Occur.
Difficulties Encountered.
Authors' Definitions of Molds and Casts.
Definitions of Molds and Casts Followed.
Definitions of "Original," "Mold," and "Cast" Proposed.
Lithological Character of Formations, as Affecting the Preservation of Invertebrates.
General Character of Invertebrate Skeletons.
General Mineral Character of Living Invertebrates.
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INTRODUCTION

In the study of a fossil the first important point to determine is its state of preservation—whether the fossil under consideration be the *original*, a *cast* of the original, or a *mold* of the original.

By not observing this precaution, errors have been made, and will continue to be made unless it be definitely understood what is meant by these terms and the conditions they represent in fossils.

SUPERFICIAL CONSIDERATION OF FOSSILS

A superficial consideration of a fossil is often apt to lead to a misinterpretation of its condition of preservation, for fossils vary in this respect. *Molds* may be taken for *casts*, and described as exhibiting the external structure of the original.

[1] This paper was largely prepared in 1898–99, under the direction of the late Professor Charles E. Beecher, when the writer was a graduate student at Yale, and was submitted for the degree of master of science. Its publication has been delayed because the writer wished to collect further data, which he has done in Europe and America. Another paper is in course of preparation, in which an attempt to formulate laws governing conditions of fossilization will be made.

The writer also wishes to take this opportunity to thank Professor S. L. Penfield, of Yale, for valuable suggestions during the preparation of the original manuscript.

We find the same organisms preserved in all manner of conditions, and only by a careful comparative study of the exterior and interior markings are misinterpretations to be avoided.

Fossils of the same species have been referred to different species, and the same genera to different genera. For example, *Michelinia clappii*, Hall,[1] was misinterpreted by Edwards and Haime, and referred to *Chonostegites clappii*[2] and also to *Emmonsia* (?) *cylindrica*,[3] and by Billings to *Haimeophyllum ordinatum*[4] and also to *Michelinia intermittens*.[5] (See Figs. 1, 2, 3, 4, 5, 6, 7.) This misinterpretation was due to the peculiar ways in which this genus occurs. At times the walls are coated with silica, and then filled in with calcite. At times only the siliceous coatings are left, which give a mold of the inner walls. Then again we find that they were filled with calcite, the walls having disappeared; and in this case we have a solid mold instead of a hollow one. At times the form is partly destroyed, leaving molds, casts, and parts of the original in the same specimen.

FIG. 1.—*Chonostegites clappi.* (After Edwards and Haime.)

We find fossils of the same species preserved (*a*) in their original condition, (*b*) as casts, and (*c*) as molds. In regard to the first condition little difficulty will present itself. The second and third, however, may lead to confusion, for they may not exhibit the external form.

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[1] Hall, *Geology of the State of New York* (1876), "Illustrations of Devonian Fossils," Plate XVII.

[2] Edwards and Haime, Pal. Fos. d. Ten. Pal. (1851), p. 299, Plate XIV, Figs. 4, 4*a*.

[3] *Ibid.*

[4] Billings, Can. Jour. U. S., Vol. IV (1859), p. 139.

[5] *Ibid.*, p. 113.

CONDITIONS IN WHICH FOSSILS OCCUR

The following illustrations will show the various conditions in which fossils are found, and they will also serve to show the necessity for close observation and comparative study.

A. The original skeleton may be preserved. If there be hollows or spaces, they may become filled with infiltrating material. In a case of this kind little difficulty will present itself in the determination of the fossil.

FIG. 2.—*Chonostegites clappi.* (After Edwards and Haime.)

B. The original skeleton may be replaced by some mineral and the cavities filled with the same, or some other material.

If the skeleton were composed of aragonite, and were replaced by calcite, the external form and markings would be preserved; but the internal organic structure would be lost, and hence not seen under the microscope. In this case we should depend upon external markings for identification.

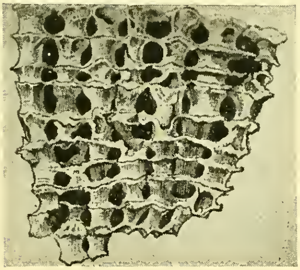

FIG. 3.—*Chonostegites clappi.* (After Miller.)

If a skeleton composed of calcite were replaced by pyrite, we could not ascertain in thin section whether the internal organic structure were lost or preserved, because of the opaqueness of the pyrite, and again we should depend upon external markings. A broken section, however, will show on the fractured surface the minutest details, in many cases.

If the organism were replaced molecularly by a mineral which transmits light, the internal organic structure would be so well preserved as to be readily distinguished under the microscope. In a case of this kind we should have a double check—the internal as well as the external structure—and its identification would be doubly sure.

C. The organism may disappear after its cavities or hollows were filled by infiltrating material. In this case we should have only the impression of the interior of the original, and it would be necessary to compare this with the interior of skeletons already known. This is at times difficult; but it is the only alternative. To make this comparison it might be necessary to take an impression, or *cast*, from the *exterior* of this filling, which cast would show the markings of the *interior* of the original. Unless we could find a fossil or a living form showing the same, or nearly the same, internal markings, we should be baffled in any attempt to adjust it to its zoölogical position, and hence its identification would remain unsolved until one of these two conditions was satisfied.

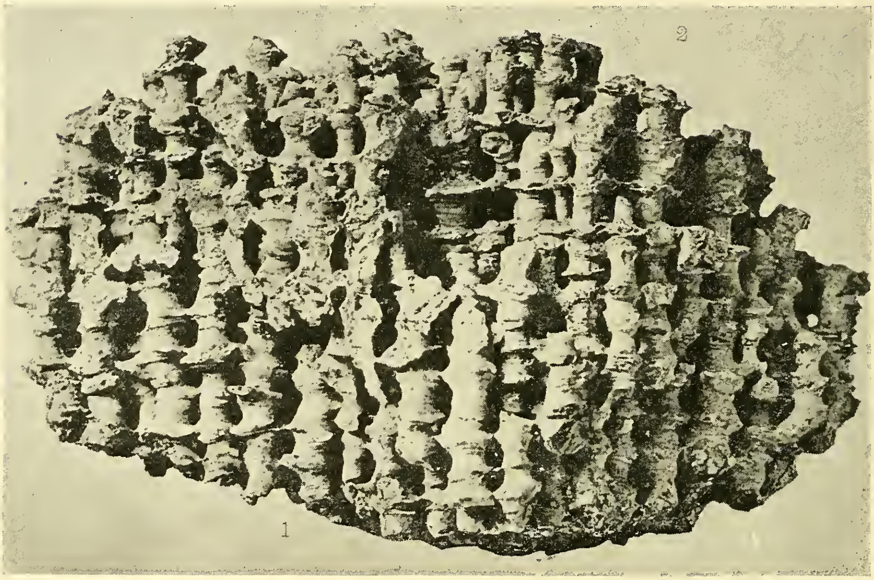

FIG. 4.—*Michelinia clappi.* (After Hall.)

D. The hard parts of an organism may leave only an impression of its exterior in the matrix. It will then be necessary to take an impression, or *cast*, from this first impression, or *mold*, and upon the markings shown on this cast will depend the identification of the fossil.

E. The exterior of the skeleton may become coated with some mineral such as silica, after which the skeleton may disappear. In this case we should have a hollow mold. It would then be necessary to take an impression, or cast, from this mold in order to ascertain the external markings of the original, and by comparing this cast with known forms we can determine its identity. At times the corallites in a compound coral will become coated with silica, and the spaces between the corallites filled with calcareous material the entire corallum having disappeared, leaving a mass filled with these hollow siliceous tubes, the inner surfaces of which will be molds of the exteriors of the corallites. (See *Michelinia*, previously referred to.)

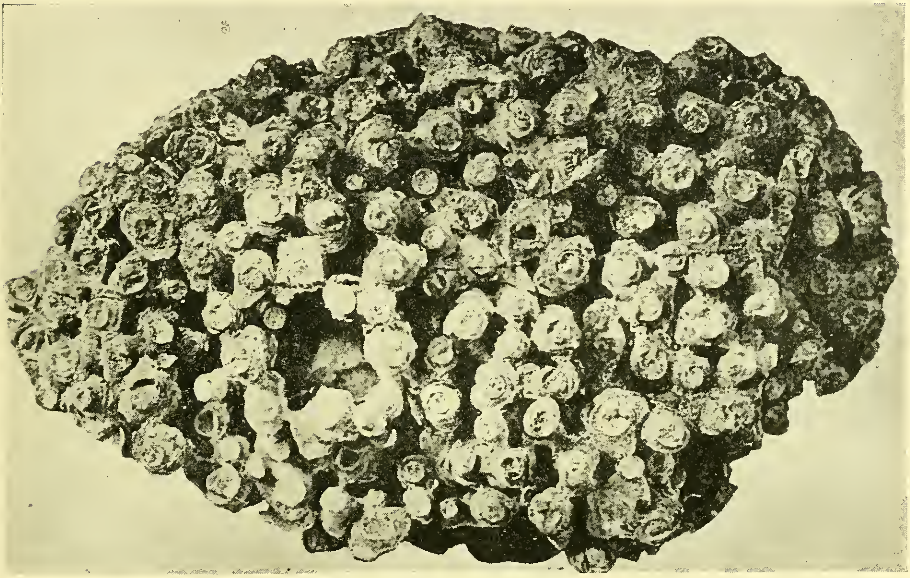

FIG. 5.—*Michelinia clappi.* (After Hall.)

We may have the exterior coated with silica, the skeleton then disappearing, and the space left filled with calcite. In a case of this kind we have molds of the exterior, and it is impossible to identify the fossil without first dissolving out the calcite, after which the procedure will be as already described.

The interior cavities or hollows of a coral may become coated with silica, after which the skeleton may disappear, leaving molds of the *interior* which will have the appearance of a sponge. If we had a coating which had been deposited upon the inner surface of the shell, it might be easily determined by taking a cast for comparison with other shells; but in the former case its identification would be extremely difficult, for we might not be able to secure casts from these molds. Even if this could be done, we might still have difficulty in its identification, for we should have only casts of the interior of the cavities or hollows of the original for comparison.

DIFFICULTIES ENCOUNTERED

From the foregoing it is plain that difficulties present themselves even when it is known that the fossil in hand is the *original,* a *mold,* or a *cast;* but the difficulties increase if it be not known what the condition of preservation is. Cases present themselves in which it is a very difficult matter to decide whether the fossil is a cast or a mold; but in the majority of cases this difficulty is obviated by close observation and an understanding of the meaning of *casts* and *molds.*

It is only by a study of casts and molds in their various conditions—found as fossils or made in the laboratory—that we may with a certain degree of exactness determine the condition of preservation of a fossil. The internal markings of some forms resemble the external markings of other forms, and it is only in the above way that we may be certain that we are dealing with external or internal markings.

There is a wide difference between a cast and a mold. Casts vary in that some do and some do not show the structure of the organism. *Receptaculites oweni,* Hall, from the Galena (Lower Silurian) at McGregor, Iowa, represents the inner surface of the skeleton, and is a cast. (See Figs. 1 and 8.) "In most specimens . . . . the remains consist of the filling of the intermural space, with casts of the outer surface of the inner wall, the inner surface of the outer wall, and of the connecting tubes."[1] This is a calcite

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[1] Bernard, *Principles of Paleontology,* Fourteenth Annual Report, New York Geology (1895), pp. 89, 90.

cast of the interior, and has been regarded as having the structure of the original organism. The conditions were evidently such as to preclude its preservation in its original condition, or in such a condition as to render its determination certain.

AUTHORS' DEFINITIONS OF MOLDS AND CASTS

Authors differ in their definitions of molds and casts. Some make the terms synonymous. Others define them separately, but are not consistent in their application.

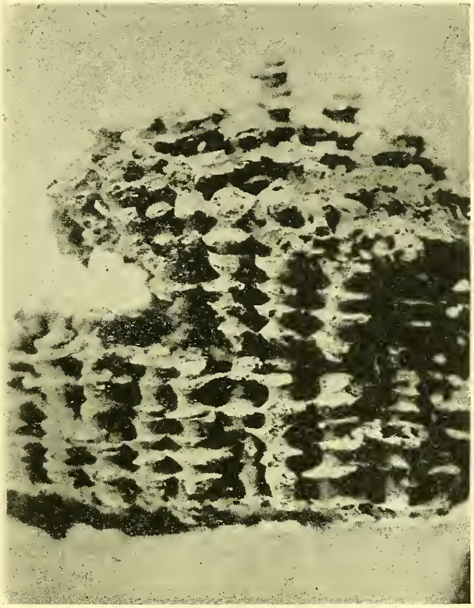

FIG. 6.—*Michelinia clappi*. (After Rominger.)

Darwin[1] considers the *mold* as a matrix, and the impression made by an organism in this matrix he terms a "cast."

Bernard[2] applies the term "mold" to three distinct results: (*a*) to an impression made by the exterior or the interior of a shell; (*b*) to molecularly replaced organisms; and (*c*) to fillings of impressions.

Gratacap[3] applies the term "cast" to (*a*) fillings which take the place of organisms, to (*b*) the material filling the space occupied by the soft parts. The term "mould" he applies to impressions of the exterior of an organism.

White[4] applies the term "mold" to impressions made by the organism. To the material filling this "mold" he applies the

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[1] Darwin, *Geological Observations*, Vol. II, p. 414.

[2] Bernard, *op. cit.*

[3] Gratacap, "Fossils and Fossilization, *American Naturalist*, Vols. XXX, XXXI, pp. 288, 902, 903.

[4] White, Con. of Pres. of Inver. Fos., Bull. U. S. G. & G. S., Vol. V, No. 1, p. 135.

term "cast." He[1] also uses the term "histometabasis" for the condition which produces a molecular replacement or substitution or paramorphism.[2] He uses the term "fossil pseudomorphs" for the materials occupying cavities formerly occupied by shells, the occupation having taken place by precipitation due to infiltration. He uses the term "fossil molds" for "cavities in sedimentary rocks which were originally occupied by fossils," and says that "the original surface features and markings are often minutely preserved in molds." He also uses the term "casts" for "counter-parts of fossils," and also for the material which may occupy the animal chamber. He further speaks of making "artificial casts of natural molds" in order to get "the original form and surface features."

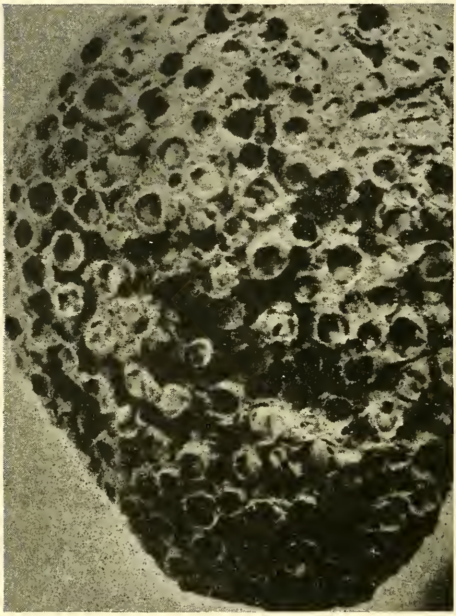

FIG. 7.—*Michelinia clappi.* (After Rominger.)

Geikie[3] applies the term "mold" to impressions made by the organism. To the material filling this "mold" he applies the term "cast." He[4] also applies the term "cast" to the material occupying the animal chamber.

Von Zittel[5] applies the term "mold" to impressions. The term "cast" he applies to the material which occupies the "interior of a shell or hollow body."

[1] White, "Relation of Biological and Geological Investigations, *Proceedings of the* U. S. *N. M.*, Vol. XV, pp. 264–67.

[2] Dana, *Text-Book of Mineralogy*, (1898), p. 293.

[3] Geikie, *Text-Book of Geology*, 3d ed., p. 651.

[4] Geikie, *Outlines of Field-Geology*, 5th ed., p. 78, Fig. 14.

[5] Von Zittel, *Text-Book of Palaeontology*, Eastman translation, Vol. I, Part 1, p. 2.

Woods[1] applies the term "mold" to (*a*) the impression, to (*b*) the material filling the space occupied by the animal. The term "cast" he applies to (*a*) the material filling the space occupied by the organism, and to (*b*) the material filling the internal cavity or cavities.

Nicholson and Lydekker[2] use the terms "mold" and "cast" interchangeably.

Lyell[3] applies the term "mold" to the matrix in which an impression of the exterior has been made. The term "cast" he applies to (*a*) the material filling the interior of the organism, and to (*b*) the material filling the space left by the organism.

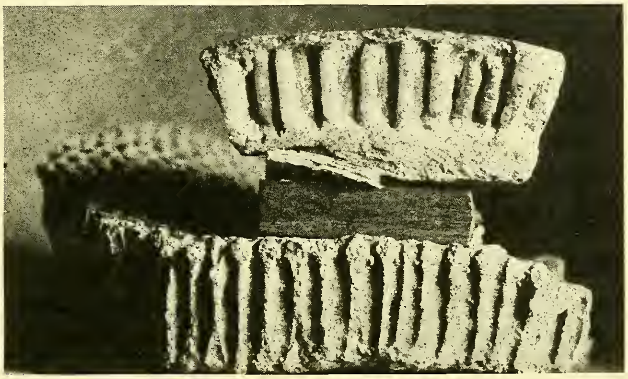

FIG. 8.—*Receptaculites oweni*, Hall. (From specimens in Yale Museum.)

Penning[4] uses the term "unchanged fossils" for unaltered shells or valves, or those which have lost only the animal matter. "Replaced fossils" he applies to the material which has been substituted for original material of the shell. "Internal cast" he uses for "the impression or *reversed facsimile of the external form of the organism*[5] that once filled the empty space" of the shell. The term "external cast" he uses for impressions made by the exterior of the shell, and says that "by taking an artificial cast from the

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[1] Woods, *Palaeontology*, 2d ed., pp. 6, 7.

[2] Nicholson and Lydekker, *Manual of Palaeontology*, 3d ed., Vol. I, pp. 5, 6.

[3] Lyell, *Students' Elements of Geology*, 3d ed., pp. 42–46.

[4] Penning, *Text-Book of Field-Geology*, 2d ed., pp. 208–12, and Fig. 29, p. 211.

[5] The writer's italics.

external impression" we obtain "an accurate representation of the pre-existing shell."

Williams[1] is perplexing in his use of the terms "mold" and "cast." He says:

> Thus a fossil . . . . may consist of the shell now removed, in which case it may be the reverse or cavity over the exterior of the shell, or . . . . similar impressions of the inner surface; or the cavity may be again filled with detrital matter, forming a cast of either the inner or outer form of the shell or object fossilized; in the former case it would be called a mold; in the latter, a cast.

Schuchert[2] applies the term "mold" to impressions of the exterior and speaks of the mold as "preserving the exterior form and ornamentation" of the shell. He is ambiguous in his use of the term "cast" for he may be referring to a matrix which contains concave impressions (impressions of the exterior of a valve) or convex impressions (impressions of the interior of a valve), or to the material which replaces a valve.

DEFINITIONS OF "MOLDS" AND "CASTS" FOLLOWED

The definitions followed in this paper are the following: A *mold* is "a form or model pattern of a particular shape, used in determining the shape of something in a molten, plastic, or otherwise yielding, state." "In founding, a *mold* is the form into which a fused metal is run to obtain a *cast.*"[3]

The *mold* determines the shape of the material put in or upon it, and this material, when removed, will be an exact duplicate of the object from which the mold was made. This removable material is termed a *cast.* The depressions in the original object will appear as protuberances in the mold, and the protuberances as depressions. The cast will show the depressions and protuberances as they appear in the original.

The surface of the original object upon or around which the mold is made may be either convex or concave. If it be concave, the mold will be convex, and *vice versa.* A mold with a convex surface is called by some authors a "cast." If the skeletal part

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[1] Williams, *Geological Biology* (1895), p. 79.

[2] Schuchert, "Directions for Collecting Fossils," Part k, *Bulletin No.* 39, U. S. N. M., p. 13.

[3] *Century Dictionary,* "Mold."

of an organism be hollow or has a concavity, this space is considered a "mold" from which a "cast" is taken. This is obviously wrong, for in this case the "mold" is the *object*, and the "cast" the *mold* from which a *cast* may be taken, and *this* cast will be a duplicate of the object.

Then, again, an impression from a convex object is termed by some a "cast." This is also obviously wrong, for the "cast" would have the markings of the object in reverse order; hence it would be a mold.

The general concavity or convexity of a surface will not determine it as a mold or a cast. Such determinations depend upon the markings of that surface.

DEFINITIONS OF "ORIGINAL," "MOLD," AND "CAST" PROPOSED.

In attempting to fix the meaning of the terms "original," "mold," and "cast," it is hoped the following definitions will prove acceptable, especially the latter two:

I. The term *original* is used to designate an organism[1] that has not lost its original structure or composition, to any appreciable extent, in the process of fossilization, except the organic matter which may have filled the interstitial spaces. (See Fig. 9 *a* and *b*.)

FIG. 9.—(*a* and *b*) originals; (*c*) mold of interior.

II. The term *mold* is used to designate the imprint of the exterior or interior of an organism. (*a*) If the organism leave an imprint of the exterior, this imprint is a *mold of the exterior*. (See Fig. 10.) (*b*) If the hollow organism become filled with material this material

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[1] Strictly speaking, a lifeless animal is not an organism; but in common parlance the lifeless body is an organism because it is that which at one time functioned. Likewise, we speak of the products of life as organic. Therefore, for lack of a beter term, *organism* is used to denote the harder parts of animals which we term *fossils*, the softer or destructible parts of which have decayed and passed away. The term "organism" can in no sense, however, be applied to molds and casts, although these are fossils as much as the unaltered skeletal parts of animals.

is a *mold of the interior.* (See Figs. 9*c*, 11, 12.) (*c*) It follows from the above that, if the hollow organism become filled with and imbedded in material of the same, or different, composition, and then disappears, we have left a mold of the exterior in the matrix and a mold of the interior in the form of a kernel. (See Figs. 9*c*, 10.)

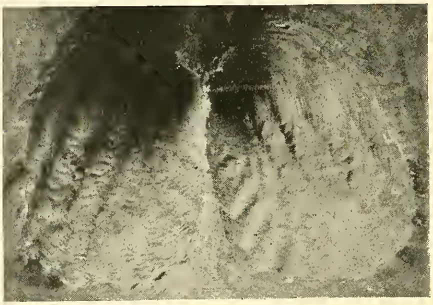

FIG. 10.—Mold of the exterior.

III. The term *cast* is used to designate the material which takes the place of the *original*, whether by replacement due to a molecular process or to infiltration. It is also used to designate the material occupying the mold made by the exterior or interior. (See Figs. 10, 12, 13, 14.)

If the mold described under II (*a*) becomes filled, we have a cast of the exterior. If the mold described under (*b*) becomes imbedded, its imprint will be a cast of the interior. If the space between the two molds described under (*c*) becomes filled, we have a cast of the exterior and interior, and therefore an object the same in shape and outline as the original. If the original be gradually replaced molecularly by some mineral, we have a cast which will show its shape, outline, and internal structure.

FIG. 11.—Mold of the interior.

From the foregoing it is obvious that an *original* is the organism itself; a *mold*, the reverse of the *original;* and a *cast*, the counterpart of the *original.* The latter may or may not show the internal organic structure.

It follows, therefore, that the only way one may know whether the markings on certain molds or casts represent the exterior or interior of known forms is, as has been previously said, to make a study of molds and casts, and thus reduce the liability of mistakes to a minimum.

THE LITHOLOGICAL CHARACTER OF FORMATIONS AS AFFECTING THE PRESERVATION OF INVERTEBRATES

The conversion of an organism into a fossil depends upon the character of its skeletal parts, the material in which it is buried, and the material brought in, in solution, by infiltration. The material of which the skeletal part is composed varies in different groups, being more durable in some than in others, and therefore plays an important part in the preservation of the organism. The variation in the lithological character of the material in which the organism is buried also plays an important part in its preservation. Certain organisms are preserved as originals; others as molds and casts, in the same formation and locality. In this same formation, but in a locality of different lithological character, those groups which were lost under the former condition may be retained under the latter, and *vice versa.*

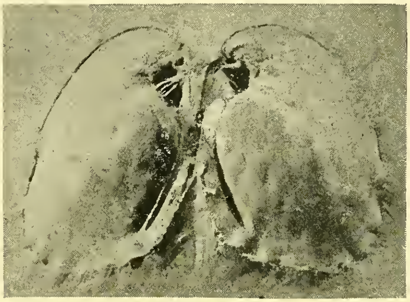

FIG. 12.—Mold of the interior.

Apparently a law could be formulated to the effect that organisms of the same mineral composition will be preserved in the same manner, as originals, molds, or casts. In reality, however, this is not true. Organisms are more completely preserved as originals in limestone; yet it is in limestone that we find the most casts by molecular replacement. Molds and casts are very common in sandstones. As limestone approaches dolomite, the molds and casts increase, although we also find originals. We find molds in hematite; but they are more rare than in sandstones.

The most perfect fossils are found in sandy and clayey shales. The Niagara group at Waldron, Ind., is made up of fine calcareous shales which are overlain by limestone. In these shales we find quantities of corals, bryozoans, and crinoids. The brachiopods are more or less preserved as originals. The sponges, gastropods, annelids, and crustaceans are well represented. The lamellibranchs and cephalopods, however, are absent.

FIG. 13.—Cast of the exterior.

The Paleozoic hexactinellids occur in groups of strata containing other organisms; but in their own particular beds the absence of other forms is striking. In Steuben county, N. Y., the formation is a sandstone which is fine-grained and argillaceous, and contains very few crinoids and brachiopods; but *Hydnoceras tuberosum* occurs in abundance.[1]

The fossils in the sandy and gravelly deposits of the Potsdam, the Medina, the Chemung, the Catskill, the coarse conglomerates of the Lower Carboniferous, or the calcareous grit of the Schoharie and Oriskany, all show different conditions of preservation.

The trilobites in the Potsdam of Wisconsin and Minnesota are badly broken up. In the Cambrian of Wisconsin we find argillaceous layers in which are molds and casts. The Medina sandstone contains poorly preserved fossils, and shows molds of the interior.

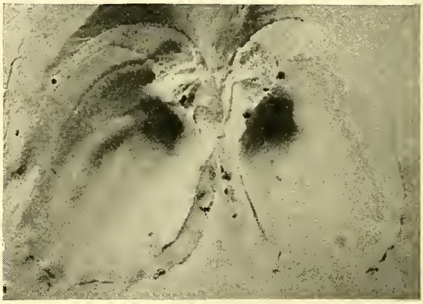

FIG. 14.—Cast of the interior.

In the calcareous sandstones of the Chemung we find well-preserved organisms; but in the Catskill sandstones they are poorly preserved.

The Utica, Marcellus, and Genessee slates show well-preserved originals; but the majority of the fossils are molds.

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[1] Beecher, *Memoirs of the Peabody Museum*, Yale University, Vol. II, Part 1.

The articulate Brachiopoda, the Anthozoa, and the Bryozoa of the New York Hamilton Shales are well preserved; but the Mollusca occur as molds and casts. Trilobites, inarticulate brachiopods, and ostrocods are well preserved. In the Carboniferous shales of Illinois the Mollusca are well preserved.

In the Mesozoic sandstones of the West the fossils are casts and molds generally, with the exception of the Ostrea and allied genera.

The best fossils, as a rule, are found in those limestones which contain more or less argillaceous or siliceous ingredients, as in the Waldron beds of Indiana, the Hamilton layers of New York, and the Lower Carboniferous of Crawfordsville, Ind.

The Schoharie grit, the Oriskany sandstone, and the Calciferous beds along Lake Champlain give siliceous molds on weathering.

The Upper Helderberg limestone gives molds and casts better than sandy deposits in general. At Cumberland, Md., however, the brachiopods are perfectly preserved as casts of silica in the Oriskany sandstone.

In the Galena limestone many of the fossils are preserved as casts composed of galena. The coal-measures show molds coated with pyrite. In the Clinton of Oneida County, N. Y., we find limonite casts. In the Trenton of Wisconsin and Tennessee we find casts of silica. In the Niagara limestone of western New York we find calcite casts; but on the weathered surfaces they are siliceous. In the Schoharie grit we find siliceous molds of the interior of brachiopods.

In general, calcareous skeletal parts show an unequal persistence as fossils in their original condition. Chitinous skeletons are never preserved in their original condition.

GENERAL CHARACTER OF INVERTEBRATE SKELETONS

Chitin is confined to the Arthropoda and a few brachiopods which are made up of alternating layers of phosphate of lime and chitinous material, as in *Lingula anatina* and in the graptolites.

Silica is confined to the arenaceous Foraminifera, the Radiolaria, the Silicispongia, and Diatoms.

Calcareous material is confined to the porcellaneous and vitreous

TABLE I

HORIZON, LOCALITY, AND LITHOLOGICAL CHARACTER OF FORMATIONS, AND THE CONDITION OF PRESERVATION OF CLASSES, STUDIED

Horizon	Locality	Lithological Character	Class	Condition of Preservation	Remarks
Carboniferous	Yellow Cr., Ohio	Shale	Brachiopoda	O M*	M exterior and interior
Subcarboniferous	Crawfordsville, Ind.	Limestone	Spongiae	C	Pyrite
	Mazon Cr., Ill.	Limestone	Arachnide	M C	Exterior
	Burlington, Ia.	Limestone	Anthozoa	C	Silica
			Crinoidea	C	Calcite, silica
			Brachiopoda	O C	C siliceous
(Waverly)	Warren, Pa.	Sandstone	Anthozoa	C	Exterior, sandstone
			Crinoidea	M	Heads and arms, sandstone
			Ophiuroidea	M	Exterior, sandstone
			Brachiopoda	O M C	M exterior and interior, silica; exterior, sandstone; interior, sandstone, calcite. C exterior, silica
			Lamellibranchiata	O	Slightly changed
			Gastropoda	M	Exterior, sandstone
			Cephalopoda	M C	Sandstone
(Chester, top of)	Pulaski Co., Ky.	Limestone	Bryozoa	O	Slightly changed
(St. Louis Upper)	Breckenridge Co., Ky.	Limestone	Anthozoa	C	Silica
			Brachiopoda	O	Slightly changed
	Mt. Vernon, Rockcastle Co., Ky.	Limestone	Brachiopoda	C	Exterior, silica
			Gastropoda	C	Silica
(St. Louis)	Taylor Co., Ky.	Limestone	Anthozoa	C	Silica
			Brachiopoda	C	Silica
	Scaffold Cone Ridge, Madison Co., Ky.	Limestone	Anthozoa	C	Silica
			Brachiopoda	C	Silica
(Keokuk)	Russellville, Ky.	Limestone	Blastoidea	C	Silica
	Kings Mt., Lincoln Co., Ky.	Limestone	Anthozoa	O	Spaces filled with calcite
	Keokuk, Ia.	Shale	Anthozoa	O	Spaces filled with calcite
			Crinoidea	C	Silica Calcite
			Bryozoa	M C	Calcite
			Brachiopoda	C	Exterior, silica, calcite
			Gastropoda	C	Calcite
			Trilobita	C	Exterior, calcite
(Burlington, Upper)	Burlington, Ia.	Shale	Crinoidea	C	Calcite
Devonian, Upper (Genesee)	Livingston Co., N. Y.	Slate	Brachiopoda	O C	O slightly carbonized C exterior, pyrite
			Pteropoda	C	Slate
(Chemung)	Cohocton, N. Y.	Sandstone	Spongiae	M C	M exterior, argillaceous sand; C sandstone
		Shale	Anthozoa	O	Slightly changed
	Loan Valley, N. Y.		Crinoidea	C	Calcite
			Brachiopoda	O	Slightly changed
Devonian, Middle (Hamilton)	Widder, Can.	Shale	Anthozoa	O	Spaces filled with calcite
			Brachiopoda	O	Spiralia pyrite; in some cases absent; shell filled with calcite and at times with mud
	Geneseo, N. Y.	Shale	Anthoza	C	Calcite; spaces filled with same

*O—original; M—mold; C—cast.

TABLE I.—*Continued*

Horizon	Locality	Lithological Character	Class	Condition of Preservation	Remarks
Devonian, Middle (Hamilton) —*Continued*			Crinoidea	C	Exterior, calcareous
			Bryozoa	C	Calcite
			Brachiopoda	O M C	M and C calcite
			Lamellibranchiata	O C	C exterior
			Gastropoda	C	Exterior and interior in mud; of original in mud
			Cephalopoda	C	Calcite; spaces filled with same
			Trilobita	M C	Exterior
	Pratts Falls, N. Y.	Shale	Brachiopoda	O M C	M in shale; C calcite
			Gastropoda	C	Calcite
			Cephalopoda	C	Calcite
	E. Bethany, N. Y.	Shale	Anthozoa	C	Calcite
			Brachiopoda	O	Slightly changed
			Gastropoda	O M	O slightly changed; M of exterior
	Michigan	Limestone	Hydrozoa	C	Replacement; spaces filled with calcite
	Thunder Bay, Mich.	Limestone	Anthozoa	M C	Both siliceous; C calcite
			Hydrozoa	M C	M siliceous; C calcite
			Crinoidea	C	Siliceous
			Bryozoa	M C	M siliceous; C calcite
			Brachiopoda	O M C	O slightly changed; C siliceous and calcite; M exterior and interior
			Cephalopoda	C	Siliceous
Devonian, Lower (Corniferous)	Columbus, Ohio	Limestone	Anthozoa	C	Calcite and spaces filled with same; silica, and spaces filled with same; also partly calcite and silica; calcite in matrix, but weather out silica
			Brachiopoda	O M C	M and C calcite; M exterior, silica, and also calcite
			Gastropoda	M	Interior, calcite
			Cephalopoda	C	Calcite
			Trilobita	M	Exterior, silica
	Jeffersonville, Ind.	Limestone	Anthozoa	C	Calcite
			Crinoidea	C	Calcite
			Bryozoa	C	Calcareous
			Brachiopoda	C	Calcite, also calcareous
	Charleston, Ind.	Limestone	Anthozoa	C	Calcite; Silica
			Crinoidea	C	Siliceous
			Brachiopoda	C	Siliceous
Silurian, Upper (Lower Helderberg)	Albany Co., N. Y.	Limestone (Shaley)	Anthozoa	C	Silica
			Bryozoa	C	Silica
			Brachiopoda	C	Silica
			Ostrocoda	C	Silica
			Trilobita	C	Silica
		Limestone	Trilobita	O M C	O slightly changed; M interior calcareous, exterior limestone; exterior and interior limestone; also clay; C exterior silica; interior silica
		Waterlime Limestone	Anthozoa	C	Silica
			Brachiopoda	O M C	O slightly changed; M exterior silica; C carbonized
			Pteropoda	C	Exterior, limestone
			Merostomata	M C	M exterior; shields and segments of abdomen; C carbonized
	Albany, N. Y.	Siliceous Limestone	Anthozoa	C	Siliceous
			Bryozoa	C	Siliceous
			Brachiopoda	C	Siliceous

TABLE I.—*Continued*

Horizon	Locality	Lithological Character	Class	Condition of Preservation	Remarks
Silurian, Upper (Lower Helderberg) —*Continued*	Jerusalem Hill, Herkimer Co., N. Y.	Waterlime Limestone	Crinoidea	O C	O slightly changed; C stems, calcite
	Cedarville, Herkimer Co., N. Y.	Limestone	Anthozoa	C	Calcite; silica
			Brachiopoda	O C	C calcareous; siliceous
			Gastropoda	C	Exterior, calcareous
			Trilobita	O	Tests of pygidium slightly changed
	Indian Ladder, Albany Co., N. Y.	Limestone	Spongiae	C	Siliceous Calcareous
			Anthozoa	C	Siliceous
			Crinoidea	C	Ring formed of silica and filled with calcite
			Bryozoa	C	Siliceous
			Brachiopoda	C	Siliceous
(Niagara)	Lockport, N. Y.		Anthozoa	C	Silica; calcite
			Crinoidea	C	Calcite
			Brachiopoda	O	Slightly changed
			Crustacea	O	Tests; slightly changed
	Charleston, Ind.	Siliceous Limestone	Anthozoa	C	Calcite; silica
			Crinoidea	C	Siliceous
			Brachiopoda	C	Siliceous
Silurian, Lower (Hudson River)	New York	Shale	Graptolitoidea	C	Carbonized
	Cincinnati, O.	Limestone	Anthozoa	C	Calcite
			Brachiopoda	O	Slightly changed
			Cephalopoda	C	Calcite
(Lower Hudson)	Clarksville, N. Y.	Shale	Spongiae	M C	M arenaceous; pyrite; manganese; C spicules replaced by silica and canals filled with calcite
	Franklin Co., Ky.	Shale	Spongiae	C	Spicules and walls of canals of silica; also calcite; canals filled with chert
(Trenton)	Kentucky	Limestone	Spongiae	C	Silica

Foraminifera, the Cœlenterates, except the Silicispongia, the Echinodermata, some of the Vermes, the Molluscoidea, and the Mollusca.

Chitin undergoes more or less alteration. In some cases it is replaced by calcite.

Silica secreted by organisms is dissolved with comparative ease. It is at times replaced by calcite. The siliceous sponges are very commonly replaced by calcite. If a siliceous organism be found as a siliceous fossil, the original silica has probably been either altered or replaced by silica.

Carbonate of lime is easily dissolved. It is made use of in two forms by organisms. In the form of calcite it is more durable than in the form of aragonite. This is due to the differences in compactibility, hardness, and specific gravity. Gastropods, many lamellibranchs, corals, and other organisms composed of aragonite crumble down and pass into calcite, or disappear, while many composed of calcite may remain. In some strata the aragonite skeletons have entirely disappeared. This is most likely to occur in pervious beds. The presence of calcite forms does not necessarily imply that they were not associated with aragonite forms. The conditions of preservation also vary. In the Mesozoic clays we find cephalopods as originals, while in the Palaeozoic clays they are calcite casts. *Mytilus edulis* secretes aragonite as its inner layer and calcite as its outer layer. Fossils occur in which the inner layer is gone. Calcite replaces aragonite at times; but in such cases the internal organic structure is gone. As yet no example of aragonite replacing calcite has been reported.

Under Table I is given the horizon, locality, and lithological character of the formations studied, and also the class, conditions of preservation, and remarks in connection with certain forms found in these formations.

GENERAL MINERAL CHARACTER OF LIVING INVERTEBRATES

Foraminifera.—The vitreous and porcellanous forms are calcite. The arenaceous forms are siliceous throughout, or have a sandy-siliceous layer incrusting an interior calcareous layer. The *Gromidae* are chitinous.

Radiolaria.—Some are composed of acanthine and some of silica.

Spongiae.—The *Myxospongiae* are composed entirely of soft tissues. The *Ceratospongiae* are made up of spongin fibers. The *Silicispongiae* are made up of siliceous elements or contain siliceous spicules. The *Calcispongiae* contain calcareous spicules.

Anthozoa.—The *Madreporaria* are aragonite, and the *Alcyonaria* are calcite.

Hydrozoa.—The *Hydrocorallinae* are calcite (?) and the *Tubulariae* calcite (?) and chitin. The *Graptolitoidea* are chitin.

Echinodermata.—Calcite.

Vermes.—Calcite (?).

Bryozoa.—Calcite and aragonite (?).

Brachiopoda.—Calcite.

Lamellibranchiata.—Some are calcite, some aragonite, and some both calcite and aragonite in layers.

Scaphopoda.—Aragonite (?).

Gastropoda.—Aragonite. Some are composed of aragonite and calcite.

Cephalopoda.—Mainly aragonite. *Nautilus pompilius* has calcite for its inner layer and septum, instead of aragonite as heretofore reported.

Crustacea.—Mainly calcite.

REPLACING MINERALS

The hard parts of invertebrate organisms are composed of more or less soluble mineral matter, and are often replaced by other minerals which fill the cavities left by the hard parts. There may be molecular replacement as the original gradually disappears, or the cavity may be filled by precipitation after the original has entirely disappeared. Chemical reaction may take place, producing new minerals as the elements in the original unite with the elements in the matrix, or elements brought in due to the porosity of the imbedding material.

The imbedding material always contains minerals that are easily dissolved under such conditions as heat, pressure, and moisture, and they may be deposited separately or in combination. The predominating mineral is apt to be found forming molds or casts of the lost parts.

In calcareous shales we find calcite casts. In siliceous limestones we find siliceous casts. In ferruginous formations we find siderite, pyrite, limonite, etc., casts and molds. In galena-bearing formations we find casts composed of that sulphide. These illustrations might be extended; but they suffice to show how the character of a formation affects an original skeletal part in its preservation.

The most common replacing minerals are calcite, pyrite, silica, limonite, sphalerite, vivianite, barite, malachite, siderite, and hematite. The list of replacing minerals is quite large, thirty-five being the number. Others undoubtedly occur, and sooner or later will be added to our present list. Under Table II is given the replacing minerals found, and their symbols, Dana's system being followed in their classification.

In the paper to follow will be given a table showing the mineral composition of the more closely related living and fossil forms studied.

TABLE II

Minerals Replacing Minerals Secreted by Invertebrates[1]

Carbonates, Anhydrous: Calcite ($CaCO_3$), Cerussite ($PbCO_3$), Magnesite ($MgCO_3$), Siderite ($FeCO_3$), Smithsonite ($ZnCO_3$).

Carbonates, Basic Hydrous: Malachite ($CuCO_3.Cu(OH)_2$).

Chlorides, Anhydrous: Cerargyrite ($AgCl$).

Fluorides, Anhydrous: Fluorite (CaF_2).

Metals: Copper (Cu), Silver (Ag).

Non-metals: Sulphur (S).

Oxides, Anhydrous: Cassiterite (SnO_2).

Oxides, Hydrous: Limonite ($2Fe_2O_3.3H_2O$), Psilomelane (H_4MnO_5 (?).

Oxides, Sesqui: Hematite (Fe_2O_3).

Phosphates, Anhydrous: Apatite ($(CaF)Ca_4P_3O_{12}$).

Phosphates, Hydrous; Vivianite ($Fe_3P_2O_8$).

Sulphates, Anhydrous: Barite ($BaSO_4$), Celestite ($SrSO_4$), Anglesite ($PbSO_4$).

Sulphates, Hydrous: Gypsum ($CaSO_4.2H_2O$).

Sulphides, Di: Pyrite (FeS_2), Marcasite (FeS_2).

Sulphides, Mono: Sphalerite (ZnS), Galena (PbS), Chalcocite (Cu_2S), Cinnabar (HgS).

Silicates, Hydrous: Kaolinite ($H_4Al_2Si_2O_4$), Gümbelite ($SiO_2.Al_2O_3.Fe_2O_3.MgO.K_2O.Na_2O.H_2O$), Glauconite (Hydrous silicate of Fe and K), Margarite ($H_2CaCl_4Si_2O_{12}$).

Silicates, Sub: Calamine ($H_2Zn_2SiO_5$).

Silicon, Oxides of: Flint (SiO_2), Silica (Sio_2), Sand (SiO_2).

REFERENCES TABLE II

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[1] The writer is indebted to the late Professor Beecher for valuable material from his private collection; to Rt. Rev. Joseph C. Hartzell, Bishop of Africa, for material from that continent; to Rev. Morton Culver Hartzell, for material from Germany; and to Major Ebenezer Thresher, for material from France.

CAMBRIAN FOSSILS FROM THE PIOCHE MOUNTAINS, NEVADA

FRED J. PACK

THE FOSSILIFEROUS HORIZONS

The fossils which are used as a basis for this contribution were collected by the writer in the fall of 1905 and the early part of 1906. Mr. Charles D. Walcott visited the district in 1885, and discovered a very fossiliferous horizon which he has correlated with the Middle Cambric. He also gathered a supposed Lower Cambric fauna from a point about six miles east of Pioche. From both these places he obtained several forms that had not been previously described. He has recorded the results of his investigations in *Bulletin No. 30* of the United States Geological Survey. So far as the writer is aware, no other study has been made of this fauna.

Some interesting problems have arisen in the attempt to correlate the Pioche section with the horizons elsewhere. In America the Cambric of the eastern states has received by far the most attention; it has been divided into zones, each of which is represented by a characteristic fauna. The following subdivisions are generally recognized:

Upper Cambric—Dikellocephalus zone
Middle Cambric—Paradoxides zone
Lower Cambric—Olenellus zone

In Nevada the upper and the lower zones are represented by forms which are almost identical with those of similar horizons in the East, but the middle one is characterized by an almost entirely new series. Olenellus and Dikellocephalus are separated in every case by more than 1,000 feet of conformable strata, which carry in places the new forms and some old ones, none of which are elsewhere typically representative of any definite horizon. This condition has made correlation difficult; Walcott, however, has referred these formations to the Middle Cambric. Dr. G. F. Matthew does not concur in this opinion, but thinks that they properly belong to the Upper Cambric.

He further believes that a proper correlation would place the Olenellus fauna above the Paradoxides, and therefore at least as high as upper Mid-Cambric.[1] Throughout western America the Olenellus zone is preceded by thick quartzite beds, which Matthew believes are equivalent to the Protolenus and Paradoxides zones. Chamberlin and Salisbury state that "in the Hudson-Champlain valley the Olenellus fauna appears to have lived on until the advent of the Dikellocephalus fauna."[2] They consider it possible "that the Olenellus of the West and of the Hudson-Champlain valley may have been contemporaneous with the Paradoxides of the East," although they incline to the opinion that it was contemporaneous with the Holmia. At Newton, N. J., Mr. Stuart Weller found a supposed Olenellus species in the undoubted Dikellocephalus zone. In speaking of the value of this specimen, he says:

> It suggests the possibility of a much longer range for the genus Olenellus in geologic time than has been ascribed to it. This genus is usually considered as particularly characteristic of the very lowest Cambrian strata, but here it seems to be associated with the fauna which bears unmistakable marks of the upper Cambrian age.[3]

The exact stratigraphic position of the Olenellus zone is not therefore established. With our present knowledge it is impossible to state whether it is Upper or Lower Cambric, but it appears that Walcott's view is supported by the more evidence. The writer has collected several new forms, but they give no further information as to the position of this series. At present, however, we shall adopt the classification of Mr. Walcott.

In the Pioche Mountains the Lower and Middle Cambric only are represented; the Upper has been removed by erosion. Faulting has so complicated matters that a continuous section cannot be obtained, but one made up from different places is as follows:

5.	Limestone	800 feet
4.	Shale	75 "
3.	Limestone	600 "
2.	Shale	400 "
1.	Quartzite	1500 "

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[1] *Transactions of the Royal Society of Canada*, 1899, Second series, Vol. V., pp. 67, 68.

[2] Chamberlin and Salisbury. *Geology*, Vol. II, p. 245.

[3] Geological Survey of New Jersey, *Paleontology*, 1902, Vol. III, p. 13.

The Olenellus fauna is confined to the lower 100 feet of No. 2, a part which is not exposed in the area covered by this report. Walcott gives the following list of fossils which he collected at a point five or six miles east of Pioche:

Eocystites ? ? longidactylus
Lingulella ella
Kutorgina pannula
Acrothele subsidia
Acrotreta gemma
Orthis highlandensis
Hyolithes billingsi
Olenellus gilberti
Olenoides levis
Crepicephalus augusta
Crepicephalus liliana

No. 4 of the section given above comprises the second strongly marked faunal horizon. It is best exposed in the Half Moon Gulch about two miles west of Pioche. It forms part of the south member of the anticline, and is nearly horizontal, although occasionally it is slightly tilted. Mining operators have thrown large quantities of this material over their dumps; it was from these places that most of the writer's fossils were collected. The shale also occurs near the city water-tank on the hill southwest of Pioche; the outcrop, however, is highly altered and consequently most of the fossils are destroyed. The following is a list of the species thus far obtained at this horizon:

Eocystites ? ? longidactylus
Lingulella ella
Kutorgina pannula
Hyolithes billingsi
Ptychoparia piochensis
Zacanthoides typicalis
Bathyuriscus productus
Bathyuriscus howelli
Lingulella genei
Ptychoparia kempi
Zacanthoides grabaui

DESCRIPTION OF SPECIES

ECHINODERMATA

GENUS **EOCYSTITES,** Billings

Eocystites, Billings, 1868: *Acadian Geology*, p. 643, Fig. 220.

Eocystites?? longidactylus, Walcott

(Plate I, Figs. 1, 1*a*, 1*b*)

Eocystites ? ? longidactylus, Walcott, 1886: *Bulletin No. 30*, U. S. Geological Survey, p. 94, Plates 5, 6.

In 1886 Mr. Walcott tentatively referred the species *longidactylus* to the genus Eocystites, awaiting a further description of *Eocystis*, Billings, (1868), and *Protocystis*, Hicks (1872). These forms, however, have never been properly described or figured, and, according to Bather, "since they cannot be well distinguished from *Eocystites* (*?*)

longidactylus, that species must be taken as an example of the genus." The most important features are: "the presence around the mouth of not less than ten biserial brachioles with long covering-plates ('short pinnulæ' of Walcott); the varying development of radiating stereom-folds on some of the plates;" the disposition of the plates "without apparent order, and varying in form, size, and surface characters on the same body." The specimens collected by Walcott are well preserved in some parts and badly crushed in others. Those in the writer's collection are in some respects very good; they do not, however, show all the features noted by Walcott, but in addition they possess some very interesting points not before revealed. Among these are a very primitive form of stem, and highly lobate plates.

The writer's collection of these species consists of several arms (all of which show the covering-plates), some loose plates, and a very beautiful specimen showing the lower part of the calyx with the stem attached. The plates are considerably misplaced, and the proximal part of the stem is somewhat crushed; otherwise the specimen is in a very good state of preservation. The drawing in Plate I is that of a cast.

None of the arms, with but one exception, shows the biserial nature of the brachioles; this may be due to the position from which they are viewed. Walcott observed one "pinnule" to each arm plate, but the writer's best-preserved specimen shows two to each plate (Fig. 1*a*).

As noted above, the plates are described as "numerous, disposed without apparent order, and varying in form, size, and surface characters;" and further, "the margin of many of the plates appears to be so indented as to have an opening or pore that passed into the central cavity." The plates in the writer's specimen are also numerous, of varying size, and are irregularly placed, but the surface characters described by Walcott are entirely absent. The plates are all smooth and slightly concave. The marginal indentions are carried so far that the plates are completely lobed (Fig. 1*b*). At first sight the lobes of the various plates appear to interlock, and thus form a rather rigid connection; but a closer examination has convinced the writer that this apparent interlocking is due to the intrusion of foreign material. Some few plates, however, appear to show this condition. It is probable that the plates were so arranged that only the extreme ends of the lobes touched. They vary in size and form; in general outline many of them are decidedly hexagonal, others are pentagonal, and still others are nearly circular. The ones nearest the stem do not show the presence of lobes. The lobate plates closely resemble those of the embryonic Antedon.

The stem is composed of numerous sac-like plates, varying in size and irregularly placed (Fig. 1). The diameters of about eight of these appear to equal the circumference of the stem. The stem tapers slightly from the calyx down, and near the lower end turns gently to one side. It is probable that the stem was flexible throughout and possibly prehensile in the lower portion. The extreme tip is not revealed.

The greatest value of this fossil lies in the stem or pedicle. It is known that some of the primitive cystoids, as *Aristocystis* (Barrande, 1887), possess no stem whatever. Others, as *Dendrocystis* (Barrande, 1887), have a rudimentary stem, the plates of which are irregular near the calyx, but pass into comparatively large solid plates farther down. In such forms as *Trochocystis* (Barrande, 1859–87; syn. *Trigonocystis*, Haeckel) the stem is short and tapering and composed of regularly arranged plates. In the species under discussion the plates composing the calyx, as well as the stem, appear to have been arranged with no regularity whatever. *Eocystites ?? longidactylus*, therefore, appears to be the earliest form of stemmed cystoid yet described.

Location and formation: Two miles west of Pioche at the Abe Lincoln Mine, on the southwest slope of the mountains, in a pinkish shale of Mid-Cambric age.

PTEROPODA

GENUS **HYOLITHES**, Eichwald

HYOLITHES, Eichwald, 1840: *Sil. schicht. Syst. in Ehstl., p. 97.*

Hyolithes billingsi, Walcott

Salterella obtusa, Billings, 1861: *Geology of Vermont,* Vol. II, p. 955.

Hyolithes primoirdialis? White, 1874: *Geographical and Geological Exploration and Survey, West of the 100th Meridian,* Preliminary Report, Invertebrate Fossils, p. 6.

Hyolithes billingsi, Wallcott, 1886: *Bulletin No.* 30, U. S. Geological Survey, p. 134, Plate 13.

This form was not collected by the writer, although Walcott has described it from this locality.

BRACHIOPODA

GENUS **LINGULELLA**, Salter

LINGULELLA, Salter, 1861: *Memoir, Geological Survey of Great Britain*, p. 333.

Lingulella ella, H. & W.

(Plate 1, Figs. 2, 2*a*)

Linguelepsis ella, Hall and Whitefield, 1877: *Geological Exploration of the Fortieth Parallel*, Vol. IV, p. 232, Plate 1.

Lingulella ella, Walcott, 1886: *Bulletin No. 30*, U. S. Geological Survey, p. 97, Plates 7, 8.

Walcott has recently described this form under the name *Obolus* (*Westonia*) *ella*. It is found in great abundance wherever the shale member is available, and is probably the best-preserved of any of the fossils.

Location: Himon Mine, Chisholm Mine, Half Moon Mine, and Abe Lincoln Mine.

Lingulella genei, n. sp.

(Plate I, Figs. 3, 3*a*, 3*b*)

Small shell, rarely exceeding 2^{mm} in length, elongate ovate or semielliptical; about one-fifth longer than broad; widest portion a little nearer the front which is broadly rounded. Dorsal valve generally ovate and rounded at the beak. Both valves moderately convex.

The interior cast of the dorsal valve is well marked by three scars, the middle one of which extends more than half-way toward the front, the outer ones not quite so far.

In general this species resembles *Lingulella granvillensis*, found at Whitehall, N. Y. It differs in the ovate form, in the surface markings, and in the muscular scars.

This fossil occurs abundantly in the shales at the Half Moon Gulch. It is associated with *Zacanthoides typicalis*, *Ptychoparia poichensis*, and *Eocystites ? ? longidactylus*. In fact, the writer has one slab carrying these four fossils. It is preserved in beds of pink and brown calcarcous shale; the fossil is of the same color as the inclosing rock, but a little darker.

Location: Abe Lincoln Mine.

GENUS **KUTORGINA**, Billings

KUTORGINA, Billings, 1861: Pamphlet and *Geology of Vermont*, Vol. II, p. 948.

KUTORGINA, Davidson, 1871: *Manual of British Fossil Brachiopods*, Vol. III, p. 342.

Kutorgina pannula, White.

(Plate II, Figs. 1, 1*a*, 1*b*, 1*c*)

Trematis? pannula, White, 1874: *Geographical and Geological Exploration and Survey West of the 100th Meridian*, Preliminary Report "Invertebrate Fossils," p. 6.

Kutorgina pannula, Walcott, 1886: *Bulletin No. 30*, U. S. Geological Survey, p. 105, Plates 7, 8.

The writer's collection contains but one specimen of this species, and it differs slightly from all of the forms thus far figured. In the genus *Kutorgina* the hinge line extends nearly the whole width of the shell. The outline of *K. pannula* is "apparently subcircular or a little broader than long; apex moderately pronounced and situated near the posterior margin." This condition, as well as the characteristic surface markings, are well shown in the specimen at hand. It differs chiefly from the ones described and figured in being larger and in having almost square shoulders. The writer has produced in outline Walcott's figures, which, with the one of the writer's, form a complete series, ranging from the type with very sloping shoulders to the one with square shoulders. This feature is accompanied with an increase in size.

Location: Abe Lincoln Mine.

CRUSTACEA

TRILOBITA

GENUS **BATHYURISCUS**, Meek

BATHYURISCUS, Meek, 1873: *Sixth Annual Report*, U. S. Geographical Survey of the Territories, p. 484.

Bathyuriscus howelli, Walcott

(Plate II, Figs. 2, 2*a*)

Bathyuriscus howelli, Walcott, 1886: *Bulletin No. 30*, U. S. Geological Survey, p. 216, Plate 30.

Emblominus rotunda, Roem., 1887: *Proceedings of the Academy of Natural Sciences*, Philadelphia, 1887, p. 16, Pl. I.

The entire head of the creature has not been found. The pygidia, which occur in abundance, show considerable variation in form and size. Walcott originally figured the head with three pairs of glabellar furrows, but it was later shown that four were present. The writer found two heads somewhat resembling the type. They differ from it mostly in the presence of a frontal margin, which is well developed in the antero-lateral portion. There are four pairs of well-defined glabellar furrows; the posterior pair points obliquely backward; the second pair points almost directly across; the third and fourth pairs point obliquely forward. The glabella is broadly expanded in front of the eyes. The postero-lateral limbs are not preserved. The two heads were collected at the Half Moon Mine. The writer tentatively refers them to this species.

Location: Himon Mine, Abe Lincoln Mine, Half Moon Mine.

Bathyuriscus productus, H. & W.

(Plate II, Figs. 3, *3a*, *3b*)

Ogygia producta, Hall & Whitefield, 1887: *Geological Exploration of the Fortieth Parallel*, Vol. IV, p. 244, Plate 2.

Bathyuriscus producta, Walcott, 1886: *Bulletin No. 30*, U. S. Geological Survey, p. 217, Plate 30.

This species occurs in great abundance; its remains are largely fragmentary, the pygidia being the most common.

Location: Himon Mine and Abe Lincoln Mine.

GENUS **PTYCHORPARIA**, Corda

PTYCHOPARIA, Corda, 1847: *Prodram. Mon. böhm. Trilobiten*, p. 141.

Equals *Conocephalus*, Zenker, 1833.

Equals *Conocephalus*, Barrande, 1852.

Ptychorparia piochensis, Walcott

(Plate II, Figs. 4, *4a*, *4b*, *4c*)

Ptychoparia piochensis, Walcott, 1886: *Bulletin No 30*, U. S. Geological Survey, p. 201, Plate 28.

This is a very characteristic form; it occurs throughout the entire shaly stratum, and usually is abundantly represented. The heads are most commonly preserved, but almost perfect fossils are frequently found. In all of the specimens figured by Mr. Walcott the frontal rim appears to bend downward. This is probably a fault of the drawing, as not a single form in the writer's collection shows this condition. The frontal margin turns somewhat abruptly *upward* into the frontal rim (Fig. *4a*).

Location: Himon Mine, Chisholm Mine, Abe Lincoln Mine, Half Moon Mine, and at the upper water tank near Pioche.

Ptychoparia Kempi, n. sp.

(Plate III, Fig. 1.)

This form is known only by the head inside of the free cheeks.

General outline of the head moderately quadrate; width, exclusive of postero-lateral limbs, about equal to height. Glabella short, conical, with straight lateral sides converging from base forward to gently rounded front; slightly longer than one-half height of head; one and one-half times longer than posterior width; marked by three pairs of glabellar furrows, pointing directly across and nearly uniting at center; moderately well-marked occipital groove, which deepens into pit near lateral margin of glabella; occipital ring slightly convex, and provided with well defined knob, or perhaps spine.

Frontal limb broad, and concave toward front, where it turns slightly upward, forming a narrow frontal rim; half as high as wide; marked with fine stria radiating from front of glabella and extending about half-way to anterior rim; antero-lateral portion broadly rounded.

Fixed cheeks separated from glabella by deep dorsal furrows; elevated inside eye-lobe, and forming a cone or rounded pyramid the apex of which is nearly twice as high as glabella; anterior slope more gentle than posterior, which pitches abruptly down into postero-lateral groove; fixed cheeks moderately broad, slightly contracted just in front of eye, and then expanded into broad anterior limb.

Eyes narrow, reaching from front of glabella to opposite elevation on fixed cheek.

Postero-lateral limbs elongate, narrow, curving gently backward, and traversed part way out by groove.

The species *P. subcoronata* is a closely allied form, but *P. kempi* may be readily distinguished from it by the absence of the peculiar boss in front of the glabella, and by the presence of the elevations on the fixed cheeks.

The one specimen by which this form is known preserves only the glabella, frontal margin, free cheeks, and postero-lateral limbs. It is fairly well preserved, and is contained in a brown shale tinted with green.

Location: Half Moon Mine.

GENUS ZACANTHOIDES, Walcott

Zacanthoides, Walcott, 1888: *American Journal of Science*, Third Series, Vol XXXVI, p. 165.

Zacanthoides typicalis, Walcott

(Plate III, Figs, 2, *2a*, *2b*, *2c*, *2d*, *2e*, *2f*)

Olenoides typicalis, Walcott, 1886: *Bulletin No. 30*, U. S. Geological Survey, p. 183, Plate 25.

Zacanthoides typicalis, Walcott, 1888: *American Journal of Science*, Third Series, Vol. XXXVI, p. 165.

This is the most widely distributed and characteristic fossil of the Mid-Cambric horizon at Pioche. Several almost perfect specimens were collected. The heads, free cheeks, and fragments of the body are extremely abundant. The material at hand, however, differs in a number of details from the type specimen as figured, but these differences are not all constant, as there is considerable variation in the collection. The writer has found no specimen that shows the exact arrangement of the pleural lobes, as indicated in the figure of the type. It will be seen by reference to this figure[1] that from posterior to anterior each lobe overlaps the succeeding one. This is probably a fault of the drawing, as all the specimens at hand show the opposite condition.

Of the entire collection of no less than twenty-five free cheeks and the attached genal spines there is not one specimen comparable to those in the figure to which reference has just been made. The most common spine is much straighter, and makes a larger angle with the axial lobe (Fig. 2). Several others, somewhat resembling those of the type, show a decided outward flexure in the backward extension (Fig. *2e*). There are three or four nearly perfect specimens, in which the genal spines pass back as far as the extremity of the pygidium. In this form the spines on the postero-lateral limbs are also unusually long (Figs. *2b*, *2c*). Another very spinose specimen shows the presence of a long spine on the next to the last pleural segment (Fig. *2d*). These conditions are rather confusing, as otherwise the specimens are all alike. The differences, however, can hardly be considered sufficient to justify the making of a new species. It may be that these variations in spinosity are simply sexual peculiarities, as suggested by Barrande in the case of *Paradoxides harlani*.

Location: Half Moon Mine, Chisholm Mine, Abe Lincoln Mine, and at the upper water-tank above Pioche.

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[1] *Bulletin No. 30*, U. S. Geological Survey, Plate 25, Fig. 2.

Zacanthoides grabaui, n. sp.

(Plate III. Figs. 3, *3a*, *3b*)

This species is known only by the head, free cheeks, and some fragments of the thoracic segments with spines attached. Two of the specimens (Fig. 3 b) were collected by Mr. Charles Of.

General form of the head triangular; glabella elongate, a little more than twice as long as broad; sides parallel; front broadly rounded; surface moderately convex; slight ridge extending lengthwise at summit; three pairs of well-marked glabellar furrows, the posterior pair pointing obliquely backward, the second pair directly across, and the anterior pair slightly forward; occipital furrow fairly well marked, and occipital ring provided with a knob or spine; postero-lateral limb provided with short thick spine.

Frontal margin expanded into broad triangular area, one of the apices pointing directly forward; rim on either side of anterior apex slightly concave backward; triangular area, provided with well-pronounced frontal rim; area flat with slight elevation near center; marked with stria radiating from front of glabella; frontal rim marked with fine stria extending longitudinally.

Fixed cheeks moderately broad inside on the eye-lobe, highly contracted just beyond front of eye, and then expanded into triangular frontal margin.

Free cheeks broad and flat, bordered anteriorly and laterally by heavy rim extending backward into a slightly curved genal spine, which apparently does not pass beyond the fifth thoracic segment.

Eyes narrow and long, reaching from opposite anterior pair of glabellar furrows to opposite occipital ring.

Axial lobe apparently same width as glabella, and rather highly convex; first pleural lobe extends through an abrupt angle into a short stout spine; in the second the spine is longer and the angle less abrupt; in the third the angle disappears, the lobe and spine forming a gentle curve.

In some ways this form resembles *Z. typicalis*, but differs from it in the general shape of the head, the frontal margin, and the genal spines.

Location: Half Moon Mine.

PLATE I

FIG. 1.—*Eocystites ? ? longidactylus*, Walcott.

1. View of specimen showing the sac-like stem and the lobed plates; twice natural size. Collection Columbia University Museum, No. 20001.

1a. An arm showing the arrangement of the covering-plates; twice natural size. Collection Columbia University Museum, No. 20002.

1b. Slightly concave plate showing the lobate arrangement at margin; four times natural size. Collection Columbia University Museum, No. 20003.

FIG. 2.—*Lingulella ella*, H. &. W.

2. View of a well-preserved specimen; twice natural size. Collection Columbia University Museum, No. 20004.

2*a*. Elongate specimen; twice natural size. Collection Columbia University Museum, No. 20005.

FIG. 3.—*Lingulella genei*, n. sp.

3. View of dorsal valve showing distribution of the concentric lines; seven times natural size. Prototype. Collection Columbia University Museum, No. 20006.

3*a*. Ventral valve; seven times natural size. Paratype. Collection Columbia University Museum, No. 20006.

3*b*. Internal mold of dorsal valve; seven times natural size. Paratype. Collection Columbia University Museum, No. 20002.

PLATE II

FIG. 1.—*Kutorgina pannula*, White.

1. View of a large square-shouldered specimen; twice natural size. Collection Columbia University Museum, No. 20009.

1*a*. Outline drawing of type specimen as figured in *Bulletin No. 30*, U. S. Geological Survey.

1*b*, 1*c*. Outline drawings of specimens as figured in *Bulletin No. 30*, U. S. Geological Survey.

FIG. 2.—*Bathyuriscus howelli*. Walcott.

2. Specimen showing the four pairs of pleural grooves extending nearly to the margin; natural size. Collection Columbia University Museum, No. 20011.

2*a*. Specimen tentatively referred to this species; it shows four pairs of glabellar furrows, also well-developed antero-lateral frontal margin; twice natural size. Collection Columbia University Museum, No. 20012.

FIG. 3.—*Bathyuriscus productus*, H. & W.

3. View of well-preserved head, natural size. Collection Columbia University Museum, No. 20014.

3*a*. View of pygidium showing well-defined, broad, flattened border; no rings on axis; natural size. Collection Columbia University Museum, No. 20015.

3*b*. View of pygidium showing rings on axis; border not so flat as in 3*a*; natural size. Collection Columbia University Museum, No. 20016.

FIG. 4.—*Ptychoparia piochensis*, Walcott.

4. View of typical specimen; twice natural size. Collection Columbia University Museum, No. 20018.

4*a*. View of typical head showing the elevated frontal rim; twice natural size. Collection Columbia University Museum, No. 20019.

4*b*. View of free cheek; natural size. Collection Columbia University Museum, No. 20020.

4*c*. View of what appears to be an hypostoma with doublure attached; twice natural size. Collection Columbia University Museum, No. 20021.

PLATE III

FIG. 1.—*Ptychoparia kempi*, n. sp.

1. View of prototype showing character of frontal margin and elevations inside eye-lobe; natural size. Collection Columbia University Museum, No. 20023.

FIG. 2.—*Zacanthoides typicalis*, Walcott.

2. View of specimen closely resembling the type; twice natural size. Collection Columbia University Museum, No. 20024.

2*a*. View of head showing the postero-lateral limbs attached; twice natural size. Collection Columbia University Museum, No. 20025.

2*b*. Specimen showing remarkably long genal spines, long spines on postero-lateral limbs, but, so far as revealed, no spines on thoracic segments; twice natural size. Collection Columbia University Museum, No. 20026.

2*c*. Specimen showing considerable spinosity, twice natural size. Collection Columbia University Museum, No. 20027.

2*d*. Specimen with long genal spines, also long spine on the next to the last thoracic segment; natural size. Collection Columbia University Museum, No. 20028.

2*e*. Very commonly associated free cheek showing outward flexure toward the end of spine; twice natural size. Collection Columbia University Museum No. 20003.

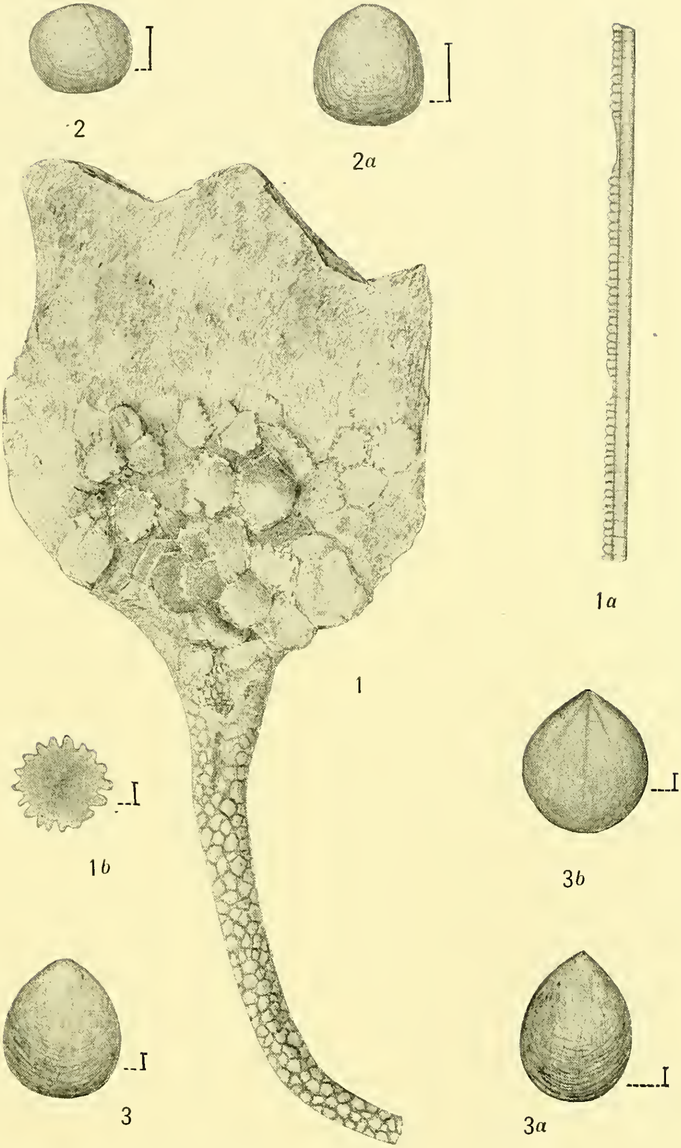
2*f*. Hypostoma associated with this species; natural size. Collection Columbia University Museum, No. 20029.

FIG. 3.—*Zacanthoides grabaui*, n. sp.

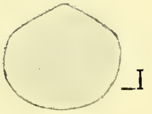
3. Prototype showing the general form of head, triangular frontal margin, and nearly straight genal spines; natural size. The free cheek has been slightly adjusted. Collection Columbia University Museum, No. 20031.

3*a*. Paratype showing the general nature of the head, also the knob or spine on the occipital ring; natural size. Collection Columbia University Museum, No. 20031.

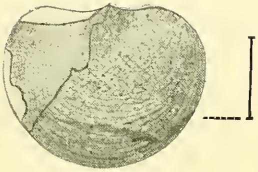
3*b*. Cast of paratype showing nature of third pleural lobe and the attached spine, natural size. Collection Columbia University Museum, No. 20032.



F. J. Pack and R. B. Johnson, Del.



1*a*



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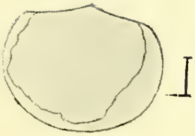
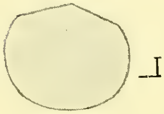
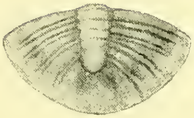


1*c*



1*b*

4*b*



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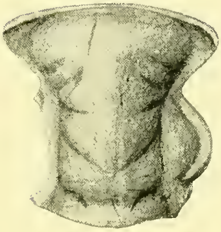
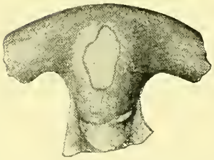


2*a*

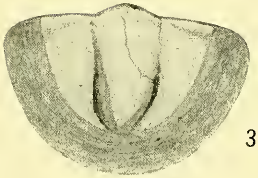
4*a*

3*b*



4*c*

4



3*a*

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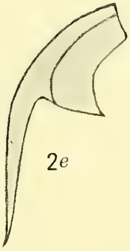
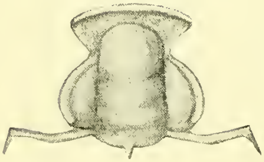


2*e*



2*a*

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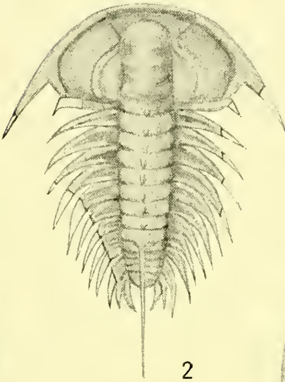

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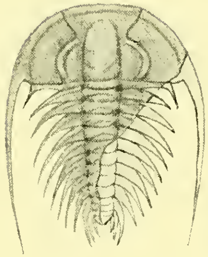
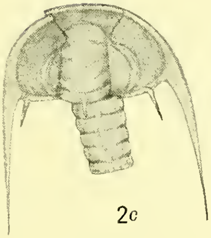


2*b*

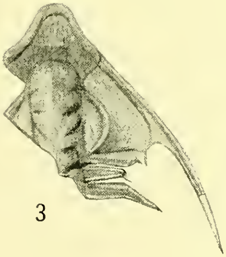


2*c*

2*d*

3*a*

3*b*



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F. J. Pack, Del.

SOME LOCAL EFFECTS OF THE SAN FRANCISCO EARTHQUAKE

STEPHEN TABER
Leland Stanford Junior University

The principal damage done by the San Francisco earthquake of April 18, 1906, was confined to a long, narrow area extending along the Pacific coast in a northwest-and-southeast direction, with the city of San Francisco near its center. The area in which the greatest damage was done is a little over 200 miles in length and scarcely 40 miles in width. The earthquake may be accounted for by the geological structure. The principal valleys of California have been formed by a system of parallel faults running in a general northwest-and-southeast direction, and the disturbance occurred along one of these old fault-lines.

The particular fault which caused the earthquake is the Stevens Creek fault; it has been traced across the Santa Cruz quadrangle by Dr. J. C. Branner and Dr. J. F. Newsom, and is described by them in the unpublished Santa Cruz folio of the United States Geological Survey. It runs from Crystal Springs Lake through Woodside and the Portola Valley, over the saddle that joins Black Mountain with the crest of the Santa Cruz Range, down the Stevens Creek canyon, crosses Campbell Creek about 2 miles southwest of Saratoga and continues in the same southeasterly direction toward Loma Prieta. From Crystal Springs Lake the fault has been traced toward the northwest by Professor A. C. Lawson through San Andreas Lake and out into the ocean near Mussel Rock, about 7 miles south of the Cliff House at San Francisco.

The topography appears to indicate that the fault-line continues its northwesterly course through Bolinas Bay and Tomales Bay, and that it finally leaves the coast near Point Arena in Mendocino County.

The present paper deals only with the movements that took place along this fault-line between Crystal Springs Lake and Black Mountain, and with the effects of the earthquake on the district lying on both sides of the fault-line and extending from San Francisco Bay to the Pacific Ocean.

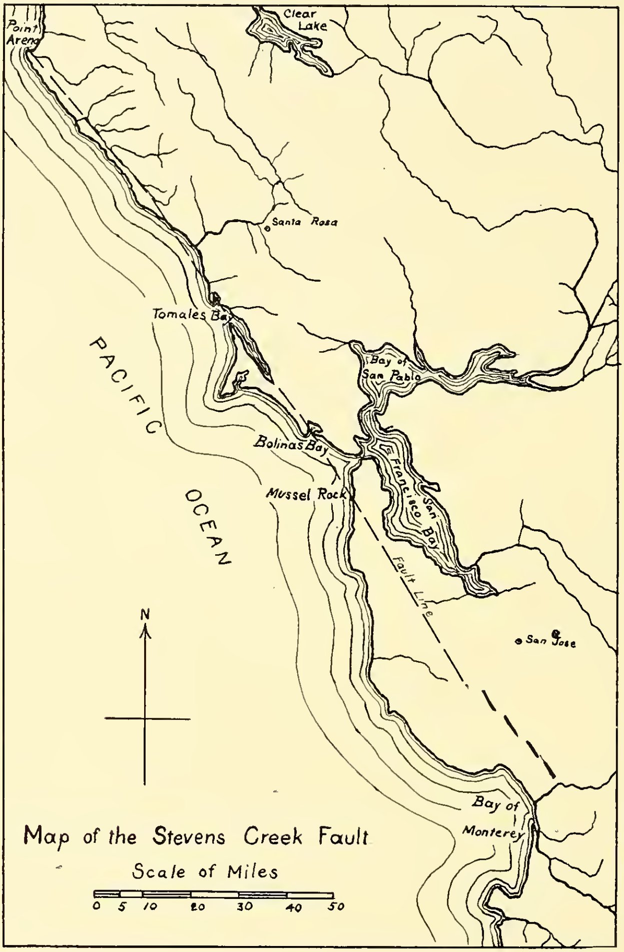


FIG 1.

The Stevens Creek fault is one of the most recent, for it cuts gravel beds that were laid down as late as the Pliocene or perhaps Pleistocene period. The old uplift along the Stevens Creek fault is on the northeast side, and the rocks on both sides of the fault dip in a northeasterly direction. The Miocene sandstones that form the greater part of the Santa Cruz Range come down to the fault-line on the west, but on the east side erosion has removed the overlying beds and exposed the Franciscan series, so that it is only at some distance away from the fault toward the east that the Miocene sandstones and gravels reappear.

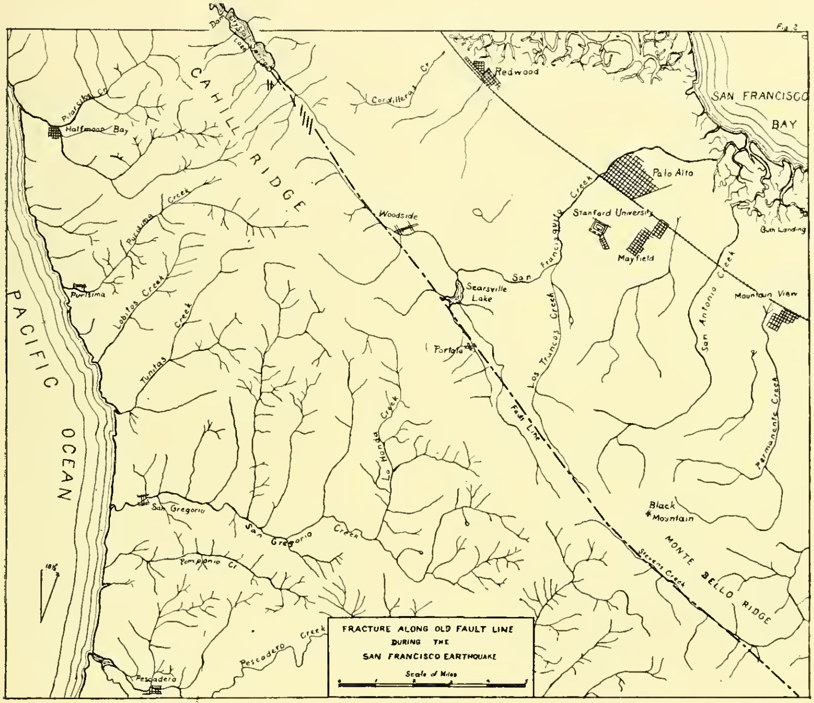


FIG. 2.

At about fifteen minutes after five o'clock on the morning of April 18, 1906, the Stevens Creek fault was suddenly refractured, and a new displacement occurred along the old fault-line, producing the earthquake that shook the adjacent region.

This new displacement is chiefly lateral, the southwest side of the fault having moved toward the northwest, or *vice versa;* and in some places this has been accompanied by a small uplift on the northeast, or a small downthrow on the southwest, or both. The lateral displacement is well defined, as far as it has been traced, and at some points amounts to as much as 9 feet. The vertical displacement in most places is not so evident, but about a mile southeast of Portola there is an uplift of 2 feet on the northeast side, and the same amount of vertical displacement has been observed on Black Mountain.

The valleys through which the old Stevens Creek fault runs are filled with silt and gravels, so that it is impossible to get at bed-rock along the fault-line, but it is probable that the rocks along this line have been so broken and crushed by past movements that they would offer little or no additional information in regard to the recent displacement.

Fig. 3.—Road crossing the fault-line two miles southeast of Portola. There is a vertical uplift on the northeast side of the fracture at this place.

Through the Portola Valley, and for about 3 miles northwest of Woodside, the fracture runs in a continuous and almost straight line. At a little distance it looks as though a furrow had been run down the valley with a big plow. In places the earth has been piled up into ridges 2 or 3 feet high, and at other places fissures have been opened that measure 2½ feet in width. Two and a half miles southeast of Portola the fissure is 3 feet across. The ground is usually cracked and broken for a distance of 10 or 15 feet on both sides of the main fracture, which in places splits up into numerous minor cracks.

Two miles southeast of Crystal Springs Lake the resistance to displacement appears to have been greater, and, instead of slipping along a straight line, the ground has been broken into a belt of parallel, north-and-south, shearing cracks, running at an angle of approximately 45° with the general movement. Some of these shearing cracks are from 1½ to 2 feet wide, and the belt of cracks extends for a quarter of a mile or more.

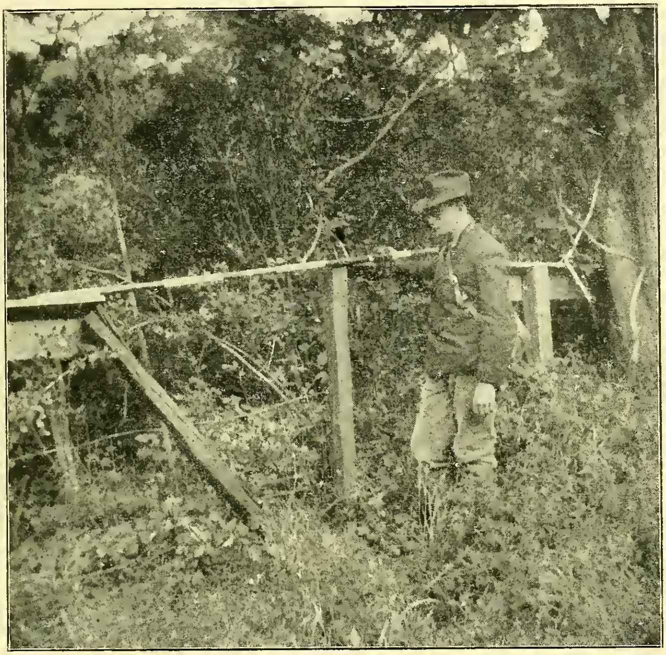


FIG. 4.—Showing a fence that crossed the fault at an oblique angle. The post shown in the photograph was split and pulled apart and the wires broken.

Black Mountain was badly shattered, and there are numerous cracks running over it in all directions. Fences crossing the fracture are broken; those that run in a north-and-south direction have their boards bent into arches or crushed, and the ends shoved past each other, while those that cross in a northwest-and-southeast direction have been pulled apart, and wire fences have been broken by tension. Fences that cross the fracture at right angles have been broken and displaced 8 or 9 feet.

The photograph (Fig. 6) shows a line fence crossing the fault

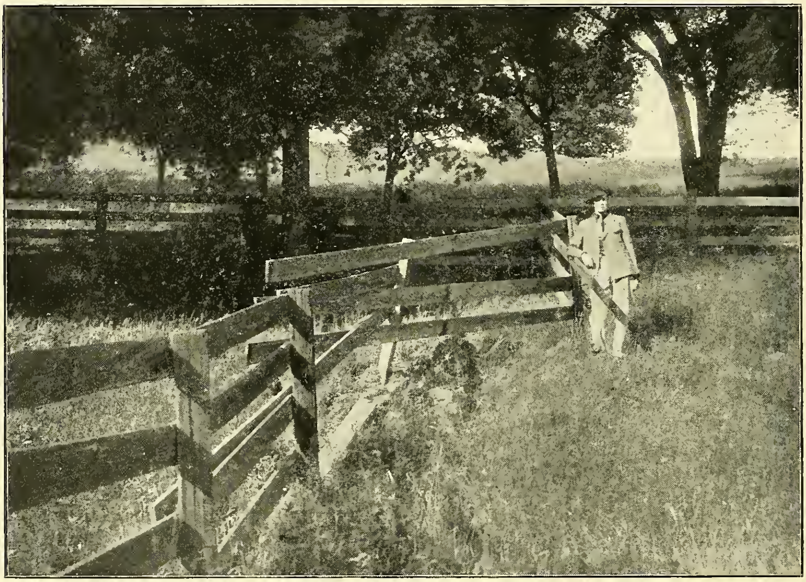


Fig. 5.—Showing a fence that was broken and offset eight feet where it crossed the fracture.

a mile southeast of Woodside. This fence was broken and displaced over 8 feet, but had been repaired before the photograph was taken. The man at the right in the picture is holding an 8-foot transit rod, and he is standing in line with the continuation of the fence on the far side of the fracture. The crack crosses the fence just back of where he is standing.

A striking evidence of displacement is shown in the earth dam that divides the Crystal Springs Lake. This dam is about 500 feet in length, and the road from San Mateo to Half Moon Bay runs along its crest. The accompanying sketch (Fig. 7) shows the position and direction of the cracks that were formed in the dam. The larger cracks are about 6 inches wide and are parallel with the dam. Smaller intersecting cracks were formed near the northeast end of the dam along the probable line of the fault, and the road was offset about 6 feet at this point. The fences on both sides of the road were broken in a number of places, and the unbroken boards were bent and arched so as to give a serpentine appearance to the fences. The wires of a telephone line crossing the dam sag in great loops.

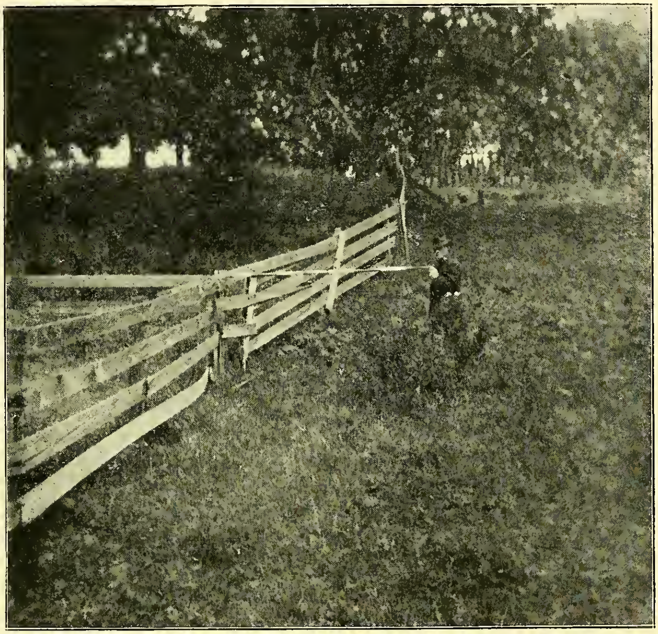
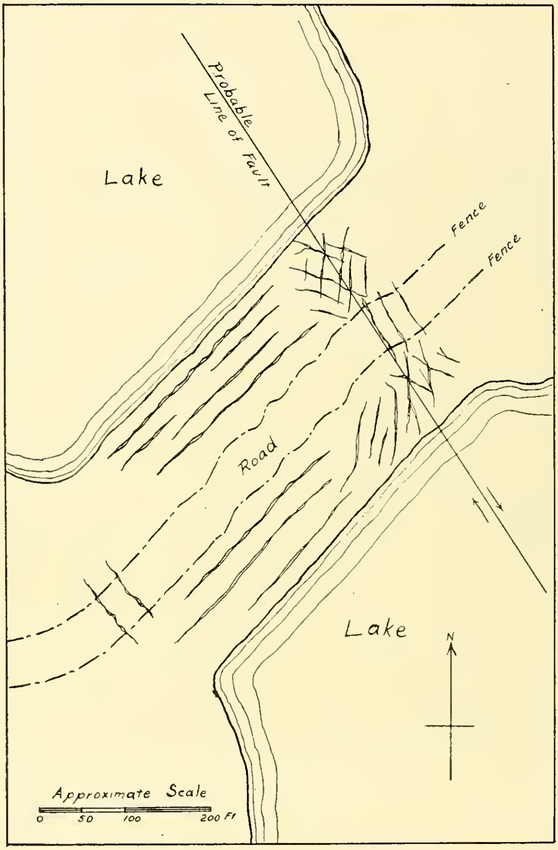


Fig. 6.—Photograph of a fence crossing the fault-line at right angles. The man is holding an eight-foot transit rod and stands in line with continuation of the fence on the far side of the fracture. The fence was repaired before the photograph was taken.

It seems probable that the total displacement is greater than the amount that may be directly measured at any place along the line of the fracture, for there is evidence of drag in the soil for a considerable distance on both sides. Water-pipes at a distance of several hundred feet from the fault-line have been pulled apart, telescoped, or bent in the direction of the movement, and fences formerly straight



Dam at Crystal Springs Lake
showing cracks formed by the displacement

FIG. 7.

have been bent into a slight curve for a distance of 200 or 300 yards from the fracture.

The intensity of the shock was greatest along the line of faulting, and decreases as one goes away from this line. In comparing the intensity of the shock at different places, the best evidence was supplied by the oak trees broken and uprooted where the intensity was greatest, by the percentage of country water-tanks thrown down, and, as the intensity decreased, by the condition of plastering in houses and the number of brick chimneys found standing.

There are many white oaks (*Quercus lobata*) growing in the valleys through this section of the country, and in a belt extending for not more than 400 or 500 yards on each side of the fracture many of these trees have been uprooted or have had large branches whipped off. Sound limbs 2 feet thick were broken off by the shock, and there are trees having a diameter of more than 6 feet that were overturned during the earthquake. About 300 yards southwest of Searsville Lake a live oak (*Quercus agrifolia*), growing within a few feet of the fracture, was split down the trunk by the violence of the movement, but is still standing.

FIG. 8.—An oak tree six feet in diameter uprooted by the earthquake three hundred yards from the fault line.

On Cahill Ridge, 2 miles southwest of the fault-line, there are redwoods (*Sequoia sempervirens*) that had their tops snapped off 75 or 100 feet above the ground. The intensity of the shock was much less at this point than near the line of fracture, but the redwood is brittle compared with the oak.

Frame houses, strongly built and having good foundations, stood the shock well, even when close to the fault-line, but brick and stone structures were badly damaged at distances of more than 12 miles from the fracture. Fortunately for the inhabitants, most of the houses near the fault-line were one-story frame buildings.

Most of the water-tanks that stood within 3 or 4 miles of the fracture were thrown down, but farther away the percentage of tanks that are standing gradually increases. With but few exceptions, all brick chimneys within 3 or 4 miles of the fault-line were thrown down, but at a distance of 8 or 9 miles probably more than 50 per cent. are still standing.

Within the area under discussion the earthquake seems to have consisted of two separate and distinct kinds of movement: one a violent vibration in a northwest-and-southeast direction, parallel to the fracture, and probably caused by the sudden displacement; the other a wave-motion, traveling at right angles to the fracture and generated by the rocks slipping past each other along the fault-line.

It was the first motion that snapped off branches, overturned oak trees and wrecked buildings in the immediate vicinity of the fault-line; and although this motion extended for a considerable distance, the damage it caused was limited to a belt not over a mile distant from the fracture.

The following facts appear to bear out the theory of a violent initial movement parallel to the fault-line. Most of the trees that were overturned fell toward the northwest or southeast, and the buildings that were destroyed near the line of fracture tended to move in the same direction; but frame buildings do not furnish very reliable data. Beds and furniture rolled back and forth in directions parallel to the vibration. The strongest evidence is furnished by the movement of liquids, such as milk and water. In the immediate vicinity of the fracture many places were found where the water had splashed out of reservoirs and tanks on the northwest and southeast sides, and at one place the motion had been so violent that the water in a large wooden tank had splashed against a roof placed over it with sufficient force to drive shingles from the northwest side. In some places large water-tanks holding 3,000 or 4,000 gallons were almost emptied by the splashing.

The wave-motion was responsible for most of the damage done outside of the narrow belt along the line of fracture. Several people, who were out of doors at the time of the earthquake and several miles from the fault-line, state that the ground appeared to move like the waves of the sea. While these statements cannot be used as conclusive evidence, there are many facts that indicate a true wave-motion, having distinct crests. Water in reservoirs and tanks, standing at a distance of several miles from the fault-line, splashed out on the northeast and southwest sides. At King's Mountain House, a little over 2 miles southwest of the fracture, there were a number of milk-pans setting on shelves. All of the cream went out on the southwest side of the pans, and afterward the milk splashed back and forth, spilling out on both the southwest and northeast sides. At a barn 3 miles northeast of Woodside, heavy carriages standing with their wheels parallel to the fault-line were moved sideways a distance of 6 inches, but did not roll forward on their wheels.

At Stanford University, 4½ miles northeast of the fault-line, the sandstone buildings afford evidence of the wave-motion. Walls running northwest and southeast, when free to fall, fell by toppling over, and the stones lie on the ground in nearly the same relative positions that they occupied while standing. Walls running more nearly parallel to the direction of wave-motion were crushed, and the stones fell in irregular piles, while the walls that are still standing show 45° shearing cracks. Perhaps the best evidence of a true wave-motion is to be found in the arches. When the crest of a wave struck an arch running northeast and southwest, the arch was pulled apart, allowing the keystones to drop a short distance. There are forty-six arches running approximately northeast and southwest in which the keystones dropped, while only twelve arches running northwest and southeast had their keystones lowered, and some of the latter may be accounted for by the falling of neighboring walls. It might be well to state that there were more arches running northwest and southeast than at right angles to that direction. Most of the keystones dropped only 5 or 6 inches, but some fell out completely.

There are several strongly built, low, one-story frame houses, of the bungalow type, standing within a few hundred feet of the fault, which scarcely had their plaster cracked, excepting where chimneys fell through. Broken oak trees growing close to these houses indicate the intensity of the shock. This suggests that the wave-motion, with its shearing action, was more damaging to walls than a back-and-forth vibration. Another interesting fact in this connection is that most two-story frame buildings at a distance of 5 or 6 miles from the fault-line did not have the plaster cracked on the second floor, although the plaster on the first floor was usually badly cracked and broken.

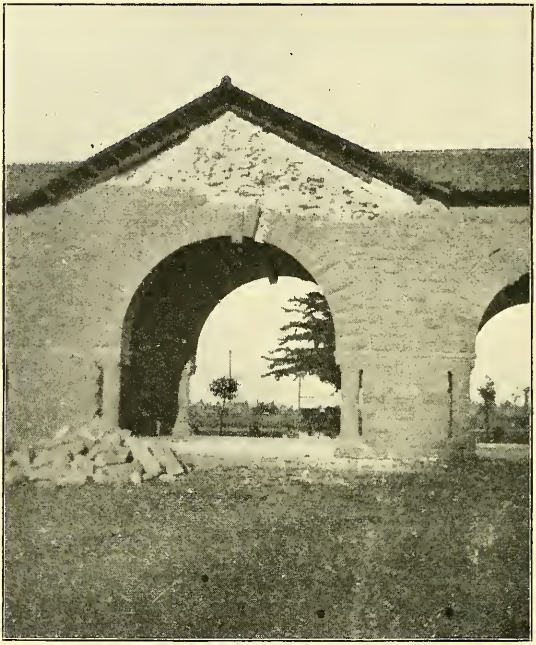


Fig. 9.—Photograph of arches at Stanford University, showing keystones lowered during the earthquake. These arches were nearly at right angles to the fault-line.

Brick buildings at a distance of 10 miles from the fault-line showed the effects of a wave-motion. At Guth Landing, on San

Francisco Bay, 9½ miles northeast of the fracture, there was a large brick warehouse, with its ends parallel to the fault-line. The upper half of each end toppled over, but the side walls, although badly cracked, were left standing.

The effects of this wave-motion have not been traced more than 12 miles from the fault-line, but it probably continued with diminished intensity to a considerable distance. In other districts, having a different geological structure, the distances to which these movements could be traced would undoubtedly vary greatly. The wave-motion appears to have been more intense in the soft alluvial deposits of the valleys than in the consolidated beds that form the high ground, but there are not enough houses in the mountains of this district to furnish conclusive evidence on this point.

At Half Moon Bay the intensity of the earthquake was about the same as at Stanford University; but as one goes down the coast, and therefore away from the fault-line, the intensity decreases. At Pescadero, which is about 12 miles from the fault-line, there was scarcely any damage done, but there were no brick or stone buildings in that village.

In regard to the geological effects of the earthquake, there are a few facts of general interest that might be mentioned. Most of the landslides that occurred at this time were on the west side of the Santa Cruz Range. This is probably to be attributed to the greater rainfall on that side of the watershed. The springs and streams on both sides of the range increased in volume after the earthquake, and some creeks on the west side were nearly doubled. All of the streams were muddy for several days after the earthquake.

A marked effect was produced on the artesian belt near the head of San Francisco Bay. Wells that had previously been dry began flowing, and wells that flowed before the shock greatly increased in volume and pressure. The following is one illustration out of many that were recorded: A well near Alviso, at the head of the bay, formerly required a wind-mill to pump the water. At the time of the earthquake the casing was driven 2 feet out of the ground, wrecking the pump, and since that time the well has been flowing under a heavy pressure. In some of the lowlands small cracks were formed, out of which water issued, bringing up mud and sand.

STUDIES FOR STUDENTS

RELATIVE GEOLOGICAL IMPORTANCE OF CONTINENTAL, LITTORAL, AND MARINE SEDIMENTATION[1]

JOSEPH BARRELL

PART I

ADVANCE SUMMARY

The purpose of the following articles is to give a proportionate view as to the relative geological importance of continental, littoral, and marine deposits, and to discuss the use of some criteria for separating them. This is in accordance with the movement which is now taking place from the preliminary qualitative state of geological science to a more balanced quantitative state. To this end, use has been made of the facts of observation concerning present

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[1] The contents of the three parts are outlined here. Parts II and III will appear in later numbers.

sedimentation already recorded in the geological literature of the past fifty years, rather than to new observations; and it is thought that a certain value will be attained by bringing together this widely scattered body of information. The references are frequently given to the most accessible source, rather than necessarily to the original statement of facts, frequently difficult of access and sometimes in foreign languages; but the effort has been, not to found arguments upon commonly quoted generalizations, but to go back to their sources, often largely lost sight of, and to examine from this starting-point the quantitative value of those generalizations. The ultimate conclusions will be found to be sometimes in accordance with, sometimes at variance with, views which have frequently been expressed in geological literature. The outline of the work is as follows:

The littoral zone is strictly limited to those portions of the shore lying between the average highest flood-tide and the average lowest ebb-tide of the month. Above this all deposits belong to the land surface, even though they may be in the form of low-lying deltas which perhaps once a year are flooded by the sea. Below the littoral zone all deposits belong to the general class of marine sediments, which may in turn be subdivided into estuarine, shallow open sea, and true deep sea.

It is pointed out that the sediments of the continental, littoral, and marine zones are accumulated under distinctive conditions which should frequently allow them, upon sufficient study, to be sharply separated. It is, moreover, concluded that, in comparison with continental and marine deposits, those of the littoral zone should form but a small fraction of the stratigraphic series, and that therefore, in the case of certain formations bearing marks of shallow-water origin and occasional exposure to the air, their frequent reference to an origin between tidal limits over the mud-flats of a shallow sea is inherently improbable, and should only be accepted where indubitably proven.

On the other hand, it is argued on inductive and deductive lines that an appreciable portion of the mechanical sediments incorporated into the geological record should have been made as subaërial delta deposits and therefore continental in nature, laid down in close association with the sea, and more or less interbedded with marine formations.

Besides these delta deposits, it appears that, taking the world as a whole, interior basin deposits, both of desert and pluvial climates, are now widely forming, frequently under favorable chances for preservation, and that such deposits should also occur to an appreciable extent in the geological record.[1]

Finally, it is concluded that the ratio of continental to marine sediments should have fluctuated widely through geological time. Following an epoch of continental uplift with mountain-making, the deposits formed in interior basins should attain a maximum, especially the deposits made under desert conditions. Accompanying this stage, piedmont alluvial deposits would be formed, largely temporary in character, since, upon the topography passing into the stages of maturity, they tend to be removed by the rivers which laid them down.

As the erosion verges toward maturity, subaërial delta-building, encroaching upon the shallow seas, would attain greater importance, since the amount of stream-dissection over the region of the headwaters increases; the streams, now being graded, carry the sediment through to the shores, and submerged continental platforms have had time to form. The greatest proportion of subaërial alluvial deposition should take place after epochs of mountain-making which have taken place without notable uplift of the continental platforms, as seems to have occurred several times during the Paleozoic. Since in that case a large portion of the river sediment is poured into more or less protected epicontinental seas, none of this portion reaches the deep ocean, and much of it forms a subaërial delta, since the seas are shallow and the wave-action weak.

Eventually, as the continent becomes topographically old, the mountain slopes become subdued, the burden of the rivers lessens and becomes more largely rock matter in solution. The rivers can no longer build out extensive deltas against the seas, and marine planation, aided by a slight elevation of the ocean surface, may cause

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[1] While this article was being written, in December, 1905, a paper on "Torrential Deposits and the Origin of Sandstones and Conglomerates" was read by title to the Geological Society of America by Professor W. H. Hobbs, in which he argues for a much larger proportion of subaërial arenaceous deposits in ancient strata than has been recognized. This article the writer has not yet had the pleasure of reading. The recent volumes of Chamberlin and Salisbury, 1906, also place emphasis upon the importance of subaërial river deposits, especially in Cenozoic times.

the latter to widely transgress the base-leveled land. Therefore, in the topographic old age of a continent shallow-water marine deposits should attain a maximum.

This cycle of relations between continental and marine sedimentation is then applied to geological history, especially to the late Proterozoic and Paleozoic, and it is concluded from the general geographic relations of certain epochs, as understood at the present time, that notable subaërial deposits of river waste might be expected to occur within those particular epochs.

The preceding discussion prepares the ground for a second portion, concerned with the detailed consideration of the significance of mud-cracks in association with other features, as indicating the continental and alluvial nature of certain deposits. Since mud-cracks also occur in littoral deposits, the necessity for the preceding quantitative study is seen. It is concluded that, next to coal-beds formed *in situ* or an abundance of land fossils belonging to the animal kingdom; in association with certain other easily recognized features mud-cracks form one of the surest indications of the continental origin of argillaceous deposits. The structure is also seen to most commonly originate under climatic conditions where the other tests are apt to fail. It is not contended that mud-cracked littoral deposits may not also form, but it would appear that they should be relatively rare.

This conclusion stands in opposition to the interpretation given to mud-cracks in the standard textbooks, where they are ascribed to the drying of tidal flats and regarded as evidences of shallow seas; the flood-plain origin, if noticed at all, being given second place.

On account of this divergence from the prevailing interpretation, attention is called to the desirability of confirming or modifying the present conclusion.

Finally, the criteria developed as to the significance of mud-cracks are applied in detail to the Belt terrane of Montana and the Unkar and Chuar terranes of the Grand Canyon, both of late Proterozoic age. This furnishes an example of the use of the criteria, and at the same time draws conclusions in regard to the origin of these formations, which in general are barren of both animal and plant fossils, and therefore lack the usual guides for arriving at their origin.

It is concluded that the Belt gives an illustration of two sedimentary cycles, each of which contains a strongly marked formation of mud-cracked red shales, the shales alternating with sandy strata, and both judged to have been deposited on the flood-plains of rivers whose deltas had gained over the subsidence, finally filling up and displacing the shallow epicontinental sea. The cycle is thus seen, not only to pass from arenaceous and argillaceous to calcareous formations and back again, but to pass from land to sea, and back again to land, the latter transition being marked, not by a plane of unconformity, but by subaërial river aggradation. Ancient land surfaces are not to be recognized alone by the work of erosion, but may be surfaces of sedimentation, and resemble in this respect the work more usually done within the domain of the sea.

In the Grand Canyon region it is concluded that at least a large part of the Unkar terrane, with its 6,830 feet of strata, was built up by subaërial aggradation as the delta plain of a large river exposed to a climate characterized by frequent seasons of desiccation alternating with seasons of flood. Thus the detailed examination of these late Proterozoic terranes confirms by largely independent reasoning the general expectation arrived at in the earlier part: notable amounts of continental deposits being here found collected in geosynclinal basins formed within the continental platforms during this area of wide land extension. The agreement of conclusions from the geographic and stratigraphic lines of approach is felt to strengthen the degree of probability that in these instances the indications as to origin have been correctly interpreted.

INTRODUCTION

As pointed out by Walther in 1893,[1] although all geologists are familiar with the occasional extensive deposition of land-waste upon the land as among the results of geological activities at the present time, yet the prevalence of erosion on the land and of sedimentation beneath the sea has governed the interpretation of nearly all ancient sedimentary deposits. It has ordinarily been accepted as a geological principle that ancient continental surfaces are only determined by unconformities, while, on the other hand, all sediments, unless obviously deposited by fresh waters as proved by their organic contents, are

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[1] *Einleitung in die Geologie*, pp. 719, 720.

taken as indications of the presence of ancient seas. Numerous instances illustrating this tendency could be cited from the writings of the leaders of the science, but a single illustration will suffice. In 1893 Bailey Willis contributed a most valuable article to the *Journal of Geology*, entitled "Studies for Students: Conditions of Sedimentary Deposition." It is because of the originality and value of this writer's numerous geological articles in general, and of this one in particular, that it is chosen for illustration. In this article sedimentation is defined as follows: "Sedimentation consists of three sub-processes—sorting, distribution, and deposition. These are effected by waves and undertow, tides, winds, and oceanic currents."[2]

While lacustrine deposits could be included under this definition, it leaves no place for fluviatile sedimentation, and of course does not pretend to include sorting, distribution, and deposition by the wind. While it would hardly have been within the limits of this one article to have treated fully of these land deposits, yet it is noticeable that in the introductory pages no mention is made of them, and sedimentation is repeatedly referred to as pertaining to the sea, rock disintegration and decomposition to the land, while the streams are mentioned as the carrying agents which sweep the sediment to the sea.[3]

In the above-mentioned article the subject of marine sedimentation is ably treated, especially noteworthy being the dependence indicated between the relation of the sediments upon both the activities of the ocean and the topographic character of the land. The present article aims to treat of some of the general relations of marine and continental sedimentation, and to partially indicate how these relations may be expected to fluctuate with the extent, topography, and climate of the continental masses. It may be considered, therefore, as supplementary to the above-mentioned article on the conditions of marine sedimentary deposition.

As showing exceptions to this tendency to neglect the deposits formed upon the land must be noted the work of the geologists of the Indian survey for the past thirty years, and that of other geologists who have been most familiar with the Tertiary and Recent deposits within the interiors of Asia and America.

While the importance of land deposits has, during the past decade,

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[1] Vol. I, pp. 476–520. [2] *Loc. cit.*, p. 480. [3] *Ibid.*, p. 480.

become more fully appreciated, it is nevertheless true that the greater part of the sediments comes to rest beneath the sea. Yet the fact that in the past the possibility of other modes of origin has not been sufficiently held in mind, throws doubt, in the opinion of some geologists, upon the interpretation of certain ancient formations consisting of unfossiliferous sandstones and shales.

Further, in regard to those deposits which are universally conceded to be of fresh-water origin, it has formerly been unconsciously assumed, without adequate proof, that the deposits were laid down in permanent bodies of standing water, and hence were lacustrine rather than fluviatile or æolian. To illustrate the important consequences flowing from such an interpretation, it may be mentioned that in all of the older American literature it was always confidently stated, without discussion of other possibilities, that the Tertiary was characterized in the Rocky Mountain region and over the Great Plains by enormous fresh-water lakes, larger than any in existence in the world today. Within a few years this view has been vigorously combated, and Matthew, W. D. Johnson, Haworth, Davis, and Hatcher have shown that the greater number of the Tertiary formations are better interpreted as the deposits of aggrading rivers wandering over broad flood-plains.

In view of the several modes of origin which are possible for shales, sandstones, and conglomerates, and the variable interpretations which have been sometimes given for a single formation, the writer, in that part of a lecture course upon advanced structural and dynamical geology which deals with sedimentary structures and their origins, has been accustomed for the past two years *first, to discuss the conditions of formation of sedimentary deposits,* as they are observed to occur at the present day in various continents and under various climatic conditions; *second, to compare the relative areal and volumetric importance* of the several kinds of deposits forming at the present time; *third, to discuss the probable changes in the relative importance* which may be expected to have occurred in the earlier ages, owing to such general movements of continental uplift and subsidence, mountain making, climatic change, etc., as are generally recognized to have characterized and individualized the preceding ages; *fourth, to give the detailed distinctions in composition, texture, and structure* by which the several kinds of deposits may be distinguished according to their mode of origin; and, *lastly, to apply the foregoing principles to a few examples,* in order to illustrate their use, and to interpret the geography and climate of preceding ages.

In order to bring together the facts for such a discussion, it is only necessary to search the abundant literature of the past fifty years; but the writer has found no single article which presents the subject in quite this way, or arrives by this method at the conclusions to which he has come in regard to the relative importance of certain classes of deposits and their distinctive features. It has seemed worth while, therefore, to arrange portions of this in form for publication, omitting much which is necessary for class work, but which can be found ably developed in various books and articles, and enlarging on other portions which are not so fully discussed elsewhere.

For this presentation it seems best to give, first, an inductive discussion of the relative importance of continental, littoral, and marine deposits, as observed under process of present or recent formation, and to follow this by an abstract and deductive discussion as to the chances for the preserval in general of these several classes of deposits; and, finally, to close with another deductive argument as to the varying relative importance through geological time. This latter discussion should, however, be kept free from positive statements of opinion upon individual formations, in regard to which there may be doubt or difference of opinion; the purpose of the article being accomplished in merely opening the question as to what kinds of deposits should be expected to predominate, from the premises of our present ideas in regard to the geography and climate of past geological times. It would be suitable for a later article, however, to discuss in detail certain distinctive chemical, textural, and structural features characteristic of the several kinds of deposits, and to apply these to individual formations, thus confirming or disproving by an inductive process the preceding general conclusions arrived at by deductive reasoning. Only by a combination and confirmation of these two methods can safe conclusions be arrived at in interpreting the fragmentary remains of the results of unseen and now vanished processes.

Either inductive or deductive methods used by themselves are always liable to error, since we can seldom be sure that man has apprehended all of the essential factors which lead to a result. This is especially true of geological science, where the field of the unknown is so great, and where, for example, the past few years have brought forth facts in regard to Cambrian and Permian glaciation which have overthrown previous confident deductions in regard to the nature of Paleozoic climates. Deductive conclusions, especially, therefore, until confirmed by detailed study, should be offered as suggestive, rather than conclusive; to be tested by investigation before being finally accepted; but on that account they are none the less valuable.

The following article must therefore, as previously stated, be divided into two portions: first, an inductive study from observed facts as to the general relations of land, seashore, and marine sedimentation; and, second, the deductive application of the relation of these to the topographic cycle and to previous time. The last is to be taken as true only in a broad way, and with many possible exceptions; as suggestive rather than final.

THE IMPORTANCE OF CORRECT INTERPRETATION

Stratified deposits may be laid down either upon the land, beneath the sea, or in that transition zone known as the littoral, which by the ebb and flow of tides belongs alternately to the sea and the land. It is of fundamental importance in stratigraphic geology that land and sea deposits should be sharply distinguished from each other, as may be seen from the consequences which follow in attempting to outline the ancient geographies. On the one hand, if the formation is considered marine, it implies a submerged attitude to the land, a spread of ocean waters, a home suitable for the development of marine faunas, a barrier between lands—separating into distinct provinces the neighboring terrestrial faunas. On the other hand, if the formation is considered to be of terrestrial origin, precisely the opposite conditions are implied, the region now excluding the life of the ocean and serving for the support of land-dwelling types, and possibly offering means of communication between otherwise separated lands. The third alternative is to consider the deposits as transitional and belonging to the littoral zone, in which case the life is predominantly related to the sea, though invaded between tides by life from the land.

As oceanic, transitional, or continental, the region must be represented upon maps of the period; and thus in any restoration of the relation of land and sea of past times the paleogeographer is called upon to commit himself as to the origin of the deposit, with all of its far-reaching implications.

Even if the formation is considered as originating upon a continental surface, the problem of interpretation is not ended; for several alternatives remain to be considered: whether the deposit has accumulated within the confines of lakes, or has been laid down under humid climates upon aggrading river plains, or washed upon arid plains by intermittent floods, or, finally, accumulated by the action of the desert wind as loess or dune sand. To extend the illustration previously mentioned: Under the view that the Tertiary accumulations of the Great Plains and Rocky Mountain region in general were made in enormous fresh-water lakes, the Great Plains must have acquired later their tilted character, implying a more recent westward uplift of some thousands of feet. The mountainous plateau has consequently often been regarded as at that time low-lying and the climate moist. Under the contrary view, that the deposits are largely fluviatile or Æolian, the region may, however, be regarded as having been as greatly elevated and tilted then as now, and the climate on the whole as always semi-arid.

THE CLASSIFICATION OF CONTINENTAL, LITTORAL, AND MARINE DEPOSITS

The term "continental," as used by Penck and Walther, applies to all deposits upon the land, whether made by talus, creepage, by rivers, by lakes, or by the wind. The fact that they are made upon the visible surface of the continents and can show no relation to the sea is the only bond of union among these otherwise unrelated deposits. Each is marked by a certain assemblage of characteristics, which cannot be given in detail here, the most certain being the presence of fossils of an abundant fresh-water or land life, and an absence of marine. Where the deposit is unfossiliferous, there may frequently be doubt as to its continental or marine origin.

To marine or estuarine deposits belong all formations deposited in the ocean, or its outlying portions, below the level of the average of the lowest tides. Within this area, covering about three-fourths of the earth's surface are laid down a great variety of deposits, varying from the oozes of the oceanic depths to the muds of protected bays or of epicontinental seas, and the sands and gravels which front the beaches facing the more or less open seas. It is only in regard to the detrital shallow-water deposits that serious doubt as to their origin is liable to arise, and it is only these, therefore, which need to be considered in the present connection.

Where salt or brackish water fossils occur in abundance, a possible continental origin is eliminated, and there will be expected also species which do not live within the zone of the littoral, thus proving the absence of a littoral origin. Where fossils are absent, the more uniform and widespread character of the deposit, the color, and other features, summed up by Walther,[1] may settle definitely the marine origin of an ancient deposit. The marine deposits are, however, as thoroughly characterized by the absence of most of those features which mark continental and littoral deposits, as by their own distinguishing features. Chief among these may be mentioned the absolute absence of mud-cracks, rain-prints, and the foot-prints of terrestrial animals.

To the littoral division belong, strictly speaking, only those deposits which are laid down between the limits of high and low tide. The term is frequently, however, rather broadly used as relating to the neighborhood of the shore. Thus one may encounter expressions in regard to dune sands of the littoral belt or conglomerate deposits as indicative of the littoral; yet dunes are entirely beyond the limits of the tides, and gravels may be laid down at some distance from the actual beach. The littoral zone, with its deposits, is regarded by Walther as related most closely to the land; but this is a view upon which a difference of opinion may be justly held, and the majority of geologists would doubtless decide that its affinities were rather with the sea.

For present purposes it will be necessary to define the littoral zone more exactly, and to sharply restrict its limits. It may, consequently, be considered as the zone embraced between the *average* of the *highest* flood and the *average* of the *lowest* ebb tides of the month. This means that, on the average, the highest portions of the littoral

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[1] *Einleitung in die Geologie,* III. Theil, "Lithogenesis der Gegenwart."

zone will normally be flooded by sea water once every two weeks, while storms and extra high tides may flood still higher portions at longer intervals. The mechanical deposits of the littoral zone are apt to be extremely variable in nature, and the individual beds more limited in area than is the case either upon the land or under the sea. Muds rich in organic matter, and of irregular distribution and thickness, are the common deposits of lagoons; sands and gravels will be deposited in tidal channels and as off-shore bars, the strata showing current marks and cross-bedding. Cleanly sorted sands, gravel, shingle, and sometimes bowlders will mark the face of the outer beach.

The littoral zone is characterized, in common with land deposits, by ripple-marks, mud-cracks, rain-prints, foot-prints, and fossils of land animals and plants; in common with neighboring marine or estuarine deposits, by ripple-marks and brackish or salt-water fossils. As distinctive shore marks held in common by the littoral zone and the margins of lakes are wave-marks, rill-marks, and the shelving nature of the beach.

ORIGIN OF TENDENCY TO CLASSIFY LITTORAL AND FLOOD-PLAIN DEPOSITS AS MARINE

Although the littoral zone is seen to have a number of distinctive marks which separate at least the upper half of its limits from the marine area, it is regarded in the great bulk of geological literature as merely a border portion of the sea, and its deposits, except where beach structure is shown, are commonly thought of as marine deposits made in shallow water, and ordinarily at no great distance from the land. Mud-cracks, rain-prints, and foot-prints are frequently cited as evidence of mud-flats exposed at low tide and bordering the sea.

This close alliance of the littoral zone with the marine might be unimportant, were it not that the majority of the criteria which are relied upon as determining the presence of the littoral zone apply equally well to flood-plain deposits made upon the land at any distance from the sea. Furthermore, in periods of vigorous erosion river deltas may completely fill up shallow seas and receive large amounts of river sediments upon their upper surfaces; then by a slackening of erosion or an increase in subsidence, may frequently become submerged. In such a way river deposits bearing these features common to the littoral zone may occur between truly marine formations. Thus, *first*, the perception of the principle that erosion dominates the land and sedimentation is largely restricted to the sea; *second*, the fact that in Europe and eastern America river aggradation is much less important that in many other regions; *third*, the confusion of littoral and flood-plain deposits ; and, *fourth*, the grouping of littoral with marine formations, render it probable that in the past certain unfossiliferous river deposits have been misinterpreted as marine or estuarine.

It is intended to show that the area of the zone of true littoral deposits is always a small fraction of the area of shallow-water marine deposits, and usually but a small fraction of the area of various forms of land deposition; that, furthermore, the chances for the preserval of littoral deposits is slight in comparison with those of either marine or continental origin, and consequently that, unless an ancient formation is clearly of littoral origin, it is more likely to be either marine or continental. For that reason it will be necessary to discuss the relative areas of deposition of the three classes of deposits, the characteristics which they hold in common, some of their distinctive features, and especially their relative chances for preserval.

THE REGIONS OF CONTINENTAL SEDIMENTATION

Formations made upon the land may be classified under several divisions, as follows:

Desert deposits.—Typically where the evaporation exceeds the precipitation and no outflowing drainage results.

Piedmont river deposits.—Built up by rivers or shallow lakes upon the foreland plains or piedmont belt fronting high mountain ranges.

Basin deposits of pluvial climates.—The deposits laid down by rivers or in lakes in down-warped basins, such as these of the Great Lakes, situated in continental interiors, but not necessarily associated with mountains. If a large river, laden with sediment, flows across such a region, a lake condition can hardly arise, but, on the contrary, a broad river plain is more likely to be found, constantly built up as subsidence takes place.

Subaërial delta deposits.—Where powerful and sediment-laden rivers meet the sea, especially if the latter is shallow and protected from tides and storms, a delta is rapidly developed, a considerable portion of which is a land surface reclaimed by the river from the sea.

GEOLOGICAL IMPORTANCE OF DESERT DEPOSITS

To consider the areas occupied by each of the above divisions, it is to be noted that the arid regions at present cover about 11,500,000 square miles; that is to say, at the present time over one-fifth of the land of the world has no outlet for drainage to the sea.[1] Within these regions extensive sedimentation goes forward, the waste of the mountains filling interior basins, either by wash from the mountain slopes, by streams which sink within their subaërial deltas, or which may flow into shallow interior seas. By far the greater portion of the waste is laid down by rivers, owing to the vanishing of the water into the dry air and the porous soil. At such places the streams flow in channels, but not in valleys, and in time of flood spread in a thin sheet of water for miles over the desert plains. Instances of this nature has been noted by Davis in Turkestan,[2] and by McGee in the Sonoran desert.[3] In Australia large temporary lakes are formed during the wet season, which during the seasons of drought become arid and burning deserts.[4] At irregular intervals, sometimes extending over several years, the most arid portions of the interior will for a few days assume the appearance of a boundless, though shallow, inland sea.[5] The conditions are thus of rather widespread occurrence in desert regions for the formation of stream deposits, current-marks, and mud-cracks associated with river flood-plains and broad, level, sandy tracts and playas—features possessed in common with deltas of arid climates and the mud-flats of the littoral.

In topographic youth torrential deposits near the mountains, and finer alluvium in the central portions, may accumulate to great depths in the interior basins. In maturity the waste is more widespread, though over much of the region more shallow in depth, while in old

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[1] Dr. John Murray, "Origin and Character of the Sahara," *Science*, Vol. XVI (1890), p. 106.

[2] *Explorations in Turkestan*, p. 54 (Monograph, Carnegie Institution, 1905).

[3] "Sheet Flood Erosion," *Bulletin of the Geological Society of America*, Vol. VIII (1897), p. 87.

[4] E. A. Petherick, Mill's *International Geography*, p. 615.

[5] C. H. Barton, Mill's *International Geography*, p. 580.

age, as Passarge has shown, a thin layer of sandy or gravelly waste[1] is almost universal.

Besides these features, chiefly made or modified by the work of water, it is well known that wind transportation plays an important part in desert erosion and deposition. Immense stony wastes, as the belt of the Sierran Hamada, may in this way have all soil removed, the finer dust being carried to great distances and ultimately out of the desert region, the sand being swept in the form of dunes over great areas of country; the dunes themselves, frequently hundreds of feet in height, being but the upper, wind-tossed portion of a deep deposit of sand. From the study of the surface of arid regions it would seem that a conservative estimate would arrive at the conclusion that at least one-half of the desert areas, and consequently one-tenth of the land surface of the world, is covered with more or less important deposits of recent desert accumulations, only a small portion of which are characterized by salt and gypsum. In interpreting desert conditions from the sedimentary record of previous ages, redness of formations, indicating subaërial oxidation, and roundness of sand grains, as indicating æolian action, and other features, are sometimes used; the presence of salt and gypsum is, however, the only characteristic which is determined at a glance and considered as a positive indication of an arid climate, and the only feature which is commonly used. But from the small proportion of present desert areas which are characterized by these deposits, and the great amount of land surface which is now desert, it would seem that the problem of ancient desert deposits should enter much more largely into geological history than is usually appreciated.

PIEDMONT RIVER DEPOSITS

Piedmont river deposits are built up in front of young and lofty mountain regions removed from the sea, by torrential rivers, which on escaping from the mountains are loaded with waste which they are unable to carry across the gentler slopes of the plains. As a region where such work is actively in progress at the present time may be cited the Pampas of northern Argentina. An early and excellent account of this region is given by John Miers, writing in 1825, who,

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[1] Review by W. M. Davis in *Science*, N. S., Vol. XXI (1905), pp. 825–28.

although not a professional geologist or geographer, made many acute observations. His most significant statements in regard to the present topic may be quoted as follows:

> The rivers which flow from the Cordillera proceed only from the melting of the winter's snow, and bring down with them an amazing quantity of fine alluvial mud. In their long passage through the mountains, and for some distance after leaving them, the descent is so rapid that the great quantity of matter held in suspension cannot subside. The Tunuyan, for instance, even as far as Coro Corto, has as much mud in it as can be suspended in agitated water. This is the case with the water supplying Mendoza, which none of the people can drink without either filtering, or placing it for a long time in a state of quiescence; so surcharged is it that they are obliged every day or two to clean out their irrigating channels, which would otherwise be filled with fine sand. If we take into consideration the nature of the country to the southward, its long and almost imperceptible descent towards the ocean, the immense bulk of alluvial matter that must yearly be brought from the Cordillera, and which must somewhere deposit itself,—we cannot but conclude that the rivers which may once have flowed in deep and uninterrupted channels to the ocean, must, from such causes, have had their beds raised in progress of time to the level of the surrounding country: the continual shifting of their courses over level plains; the constant accumulation of muddy detritus, must have effected the gradual disappearance of navigable or continuous streams, and produced that series of swamps, and the kind of country, which, according to the most credible accounts, exists throughout the vast Pampa territory.[1]

In the case of rivers which run through to the sea this process of deposition comes to an end when they have built up this portion of their courses to the necessary grade, unless a geosynclinal warping takes place in front of, and in line with, the neighboring geanticline; in which case the rivers may still continue to build up an extensive plain with a slope of from 1 to 10, or even 30, feet per mile. This process will be favored when the area of the plain is deficient in rainfall, as is the case with the high plains of the United States and Argentina; since under such climatic conditions there is no added volume of river water to assist in carrying through to the sea the detritus obtained from the mountains. The same effect may take place, however, where the climate of the plains is humid, provided that the lessening of the grade is not fully compensated for by the added volume of waters.

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[1] *Travels in Chile and La Plata*, by John Miers, in two volumes (London, 1826; C. Baldwin, printer), Vol. I, p. 113.

This is illustrated by the recent or subrecent alluvial deposits of the Ganges, fronting the Himalayas for nearly 1,000 miles, and maintaining a breadth of from 100 to 200 miles. The most western portion of this plain, as well as the confluent plain of the Indus, receives near the Himalayas between 10 and 30 inches of rain per year, and is relatively dry; but the greater portion of the piedmont Gangetic plain receives between 30 and 50 inches per year. In some ways, however, this plain is not a good illustration, since it graduates insensibly into the delta and is restrained by the plateau area to the south. In no place does it reach 1,000 feet above the sea, the highest elevation recorded being 924 feet above the sea on the low alluvial divide between the Ganges and the Indus.[1]

The Ganges system at the present time is probably eroding more than depositing, but must have built up the river-plain in the past. Nearly the whole area, however, of the Brahmaputra valley, in Assam, a region of heavy rainfall, is occupied by the newer alluvial deposits, and hence must be in the process of piedmont valley-building.[2] Similar important deposits of river conglomerates, sands, and clays of Oligocene, Miocene, and Pliocene age are found on the northern slopes of the Pyrenees and Alps, where the climate was presumably as humid as at present, but the intercalation of marine strata among these indicate a low-lying condition and a proximity to the sea, so that the sediments are probably as much of the nature of delta deposits as of piedmont slopes of waste.

In estimating the areal extent and importance of such piedmont waste slopes of continental interiors, it is to be noted that their extent in the western United States, in Argentina, and in India may be taken as roughly equal in area to that portion of the lofty mountain region from which they come. Such deposits would, of course, be ultimately eroded in a later stage of the same topographic cycle which witnessed their production, were it not that downward warping in front of a mountain axis is a not uncommon incident, allowing a progressive accumulation of waste, and protecting the lower portions from ultimate erosion until some reversal of the geological activities occurs. Owing to such downward warping before the later upturn-

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[1] Medlicott and Blanford, *Geology of India* (1897), p. 391.

[2] *Ibid.*, p. 396; Mill's *International Geography*, p. 475.

ing, some 14,000 feet of river deposits were laid down in the Siwalik formation of the Upper Tertiary in the northwest Punjab.[1] In searching the past for similar deposits, from the nature of their origin they need be looked for only upon the ancient mountain forelands, and only after periods of orogenic revolution.

BASIN DEPOSITS OF PLUVIAL CLIMATES

The basins of the Great Lakes may be taken as good examples of down-warping in continental interiors. Formerly regarded by many as largely owing their origin to ice-erosion, they are rather looked upon at the present time as chiefly due to crustal warping, somewhat accentuated and scoured clean by the Pleistocene glaciation. Their recency, and the fact that no rivers laden with detritus from mountain regions flow into them, cause them to be still unfilled and their basin nature to be clearly apparent. It would seem that such basins are not unique, but are rather constant features of the continental platforms. In times of diminished land surfaces and lessened erosion these may be connected with the oceans and exist as epicontinental seas. In times of wider continental extension and increased erosion they are likely, if shallow, to soon become completely filled with sediment, after which rivers will flow through them on their way to the sea. In this event only a geological study of the region may demonstrate the basin-like structure of the underlying basement.

Perhaps the most conspicuous examples of interior continental basins receiving large quantities of river sediments at the present time are to be found in South America. The Brazilian plateau, like an island, is surrounded on all sides by a wide lowland, at no place more than 650 feet above the level of the sea. The headwaters of the Paraguay and the Guapore, the latter one of the southernmost tributaries of the Amazon, with hardly 4 miles between them, are often covered by the same floods.[2] The greater portions of the great river valleys of South America are underlaid by Tertiary deposits, and the superficial formations are of recent origin.[3] This is indicated by any good map, where it is seen that the central basin of the Amazon possesses braided rivers, lagoons, and unexplored distributaries connecting

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[1] Geikie, *Text Book of Geology*, 4th Ed., p. 1297.

[2] J. Batalha-Reis, Mill's *International Geography*, pp. 865, 866.

[3] *Ibid.*, p. 867.

them, the whole, from the geographic descriptions, constituting a more or less perpetually flooded and impenetrable tropical forest jungle. This great basin is largely shut in on the east by the uplands of Guiana and Brazil.

A similar physiographic condition is graphically described by Mr. H. H. Smith as characterizing the headwaters of both the Madeira and the Paraguay.[1] These streams in their upper portions flow through more or less separate and inclosed basins. The upper Paraguay rises 30 feet annually. All the flat lands above the Fecho dos Morros to Villa Maria—over 400 miles in a direct line—are subject to river floods, and these are deepest toward the north. The width of the flood-plain at the mouth of the Sao Lourenço can hardly be less than 150 miles from the rocky lands on the east to the base of the Serra dos Dourados. The whole region is a labyrinth of lakes, ponds, swamps, channels, and islands in a grassy plain, the only forest being near the river. Even at low water one-fourth of it is flooded; when the river is at its highest, the whole plain is a vast lake, covered with floating grass and weeds.

The South American instances illustrate most fully the manner in which large interior basins may be filled with river sediments. Usually the process of aggradation is not so striking and rapid. Where the down-warping is of minor importance, as in the central plain of Hungary, fertile and habitable plains may occur. Where the down-sinking of the crust has been deep and far more rapid than the infilling by the rivers, large interior seas may result.

Europe is largely surrounded, and separated from the other continents, by a series of such interior basins, but the dividing bridges are so low that they let in the ocean waters, and on the southern side all but the Caspian and Black Seas are united into the Mediterranean. Of these basins the upper Adriatic, the Ægean, and the Black Seas have witnessed great changes since the Tertiary, and Suess[2] regards the formation of the Ægean and Black Seas as even post-glacial. Previously to this recent down-sinking, fresh-water deposits were formed over the site of the Ægean, and still remain on certain islands in the

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[1] J. B. Hatcher, "Origin of the Oligocene and Miocene Deposits of the Great Plains," *Proceedings of the American Philosophical Society*, Vol. XLI (1902), No. 169.

[2] *Das Antlitz der Erde*, Eng. trans., Vol. I, pp. 344, 345; also Plate V, opp. p. 463.

sea. The ability of large rivers to maintain land surfaces over sinking areas may be illustrated by taking a hypothetical case. Choosing Lake Superior, since it is the largest body of fresh water in the world, and the Mississippi-Missouri river system as a type of the greater rivers of the globe flowing from regions of rapid erosion, it may be computed how long it would take the Mississippi to fill the Lake Superior basin with sediment. Taking the annual discharge of the Mississippi, according to Humphrey and Abbot, as a mass of sediment sufficient to cover one square mile 268 feet deep, and again taking the area of Lake Superior as 32,000 square miles, and the average depth, derived from the contours of the bottom, as 550 feet, it may be readily computed that the Mississippi would fill up the basin in approximately 66,000 years. Therefore, if such a basin should originate in the path of a great river bearing a quantity of sediment equal to that of the Mississippi, it would only show at the surface during its subsidence as a somewhat swampy alluvial plain, without a distinct lacustrine stage, unless the movement of subsidence was irregular or the entire depression originated in less than 66,000 years. It is not probable that the majority of epicontinental basins originate as rapidly as this, indicating the conclusion that in periods of high land relief and rapid erosion river deposits, rather than those of lacustrine or marine origin, may be expected to fill the down-warpings within continental areas, and to a lesser extent those which are marginal. On the other hand, Forshey has computed that it would take the Mississippi 11,000,000 years to fill the Gulf of Mexico with sediment, providing that the bottom did not sink under the load; and this points the contrast between the relatively small and shallow epicontinental basins and the true oceanic gulfs or mediterranean seas.

In conclusion, it is seen, then, that interior basins may be divided into two classes, the shallow and the deep. The former, if within the reach of important rivers, may be maintained as a continual land surface, the basin nature being not conspicuous; the latter will more usually form true mediterranean seas. Basins of these two classes occupy appreciable portions of the present continental surfaces, and doubtless have frequently been as important in the past. The shallow warpings still belong to the continental platforms, and their deposits, either fluviatile, lacustrine, or marine, are frequently exposed by erosion; but it is doubtful to what extent such deep downbreakings as those of the mediterranean basins are ever restored to the surface of the land, and their deeper deposits consequently opened to observation, the most favorable chance being where the region becomes involved in a later mountain revolution. Whether or not the deposits of the shallow basins are continental or marine will depend upon the vigor of stream-erosion, the rapidity of subsidence, the breadth and height of the surrounding lands, and nearness or distance from the sea. As epeirogenic and orogenic movements have been intermittent and variable in nature, the continental or marine infillings of such basins will thus have varied largely through geological time.

DELTA DEPOSITS

A delta may be divided into two chief portions, one of which, above the water, forms a low land surface, usually fertile and densely inhabited; another portion being deposited beneath the sea, and building forward the front of the delta. As is well known, borings in the Mississippi, Ganges, and Po deltas have revealed fresh-water fossils and beds of vegetable matter at some hundreds of feet beneath the present level of the sea. Such facts have led to the view that large delta surfaces are frequently regions of subsidence, and that they may be maintained above the sea-level by the continual deposit of river material. Thus it is seen that delta formations are divided into portions which are continental, littoral, and marine.

The possibly subaërial delta origin of certain ancient formations has been long since suggested; to cite a single instance, as far back as 1886, Bonney, in his presidential address before the British Association, concludes that the English Bunter is probably a subaërial delta formation, analogous to the Siwalik deposits of India.[1] Notwithstanding such instances, however, it will probably be admitted by most that, in interpreting the mechanical deposits of previous ages, especially where these are thick, barren, and suggestive of discharge at the mouths of large rivers, usually no adequate discussion has been given as to the possible intermingling of subaërial and submarine portions. The section at one place may represent wholly the land-surface deposits; at another, the wholly off-shore zone; and at still

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[1] *Report of the British Association for the Advancement of Science*, 1886, p. 618.

another, an intercalation of subaërial and submarine strata. As an illustration may be cited discussions regarding the Neopaleozoic deposits of the eastern United States. The interpretation has usually been that of river sediments distributed over the bottom of a shallow interior sea, in which subsidence took place *pari passu* with sedimentation, so that occasionally mud-flats or marshes became exposed; but subaërial delta surfaces are hardly considered, and the region is held to have been essentially a permanent sea, so long as sediments of the time were formed.

Of course, where marine fossils occur, there is no question of the presence of ocean waters, and, on the other hand, at times of coal-formation there is no question as to the presence of a delta swamp; but in regard to the great volume of more or less completely unfossiliferous detrital deposits the interpretation has usually been one of marine origin, without an adequate consideration of a possibly subaërial delta nature; and this sometimes in spite of the fact that mollusca are found whose habitat seems indicative of non-marine waters, as, for instance, Amnigenia of the Upper Devonian.

The deposits of the present, as Walther has noted, are studied in horizontal plan; the deposits of the past are studied in section. It is to indicate from present delta-building the vertical relations which are to be expected in ancient deposits between the continental, littoral, and marine portions of the delta, that a considerable discussion seems necessary.

RELATION OF DELTAS TO REGIONS OF SUBSIDENCE

The ratio of these three portions to be anticipated in the stratigraphic record will depend largely upon the conception of the part which subsidence of delta regions plays, as a usual, or merely an occasional, accompaniment of the process of delta-building. As facts bearing upon the question, may be cited the presence of fresh-water deposits within a number of the present larger delta regions at levels beneath the surface of the sea. Again, periodical flooding of the delta surface is evidence of land deposition going forward at the present time, while rivers intrenched, and never overflowing the plains formerly built up by their agency, are evidence that aggradation has ceased, or even that degradation has begun. Taking a general view of river characteristics, it is seen that at least in North America piedmont slopes of alluvial waste are now frequently undergoing dissection, but that the great delta regions, such as those of the Mississippi and the Colorado, are receiving annual accessions of fresh-water deposits. In many cases, especially on the eastern coast, subsidence has been so recent that the rivers have only begun the work of filling their embayed valleys, and notable deltas have not yet been constructed. On the whole, however, the work at the river mouths stands in contrast to that of their middle and upper courses. Extending the view to the greater rivers of the world, it would seem to be a safe conclusion that, as a rule, they are building up their flood-plains, even if not encroaching upon the sea.

The problem next following is whether this is due to a local stationary attitude, or even subsidence of the delta regions, or to an average general stationary attitude or subsidence of the lands as a whole. In answer to this general problem there appears to be no unanimity of opinion. The continental margins frequently show drowned coastal shelves cut across by river gorges, but this is no indication as to the character of present movements. In Andrée's *Hand-Atlas*, p. 4 (Leipzig, 1904), movements of elevation are indicated as taking place at the present time at many places along the shores of all continents, while movements of depression are indicated only along the eastern coast of North America, the coasts of France and the Netherlands, the eastern shore of the Adriatic, the delta regions of the Nile and Amazon, and more than half of the oceanic islands. While there are undoubted errors of detail in this map, it may be assumed as a first hypothesis that the general result is true, and that the continents at the present time are in a general stage of upward movement; or, perhaps speaking more correctly, the oceans, by the subsidence of their basins, are receding from the lands.

If this conclusion be true, the subsidence of regions of sedimentation at the present time is probably less conspicuous than in the average of past time, since it is only where the local downward movement is more pronounced than the general regional upward movement of the lands that actual subsidence would result.

Turning from induction to deduction, subsidence of deltas as distinct from the surrounding regions is to be anticipated only where the load of sediment is sufficient to lead to isostatic readjustment, or where the river debouches into a natural geosyncline. That such subsidence was common in ancient geosynclines is accepted on the evidence of shallow-water formations accumulated to a thickness of many thousand feet, and whether the formation was made slightly below or above the water surface would apparently have but little influence upon the movement of subsidence. Again, in periods of quiet the erosion of the lands, as Chamberlin has shown, would tend to lift the level of the sea and lead to an apparent subsidence of all delta regions to the extent of some hundreds of feet from this cause alone. Further, the drainage of the continents is, in general, away from the geanticlinal regions and toward the geosynclinal areas. The land-waste is carried in both directions from the geanticline across the stationary tracts, with the exception of those receiving piedmont deposits, and is thrown down by the river in crossing some region of subsidence, or upon meeting the ocean upon the continental shelf or at the margin of the continental platforms. Usually the waste from at least one side of the geanticline must be carried a considerable distance before passing beyond the limits of the continental platform, and the chances are frequently good for deposition before reaching that limit.

Where a geosyncline or epicontinental sea is encountered, the sediment will accordingly be concentrated; and even if the load of waste should not have any influence in leading to isostatic down-sinking, these areas would still be characterized as the great catchment basins of sediment deposited upon the continental platforms; the most favorable situation being that illustrated by the Great Valley of California, where a trough exists between mountain ranges, and the waste naturally gravitates into it; the least favorable being found in such isolated basins as those of the Great Lakes, far removed from any considerable mountain range. There is therefore frequently, but not necessarily a sympathetic relation between regions of subsidence and the discharge of great rivers, with their load of sediment.

From these lines of reasoning it may be accepted that the portions of the continental platforms occupied by the mouths of the larger rivers have frequently been through past time regions of subsidence, with consequent river aggradation; but the strongest evidence for this conclusion is not obtained so much from the nature of present movements as from the evidence of the upturned and eroded strata themselves, deposited as the geosynclinal axes sank.

Where there is no subsidence, as is to be expected in the case of the smaller deltas, the subaërial character is readily maintained and extended as a result of delta-building, but the subaërial deposits cannot extend below the water level. Where subsidence accompanies sedimentation, however, the subaërial character of the delta tends to be destroyed; but if the river is able to build its plain upward as fast as the downward movement takes place, the subaërial deposits may reach to any depth. In the larger deltas which have been tapped by boreholes this appears to be the case.

FACTORS GOVERNING DELTA LAND SURFACES

The strata of a delta have been classified into the bottom-set, foreset, and topset beds;[1] the first consisting of fine material deposited from suspension on the bottom of the sea beyond the main portion of the delta, the foreset beds comprising the steeply inclined portion consisting of slightly coarser detritus, and the flat topset beds being the result of the aggradation work of the river, building up its stream to grade as the front of the delta advances farther outward, or as the whole slowly subsides. The topset beds are largely of subaërial origin, though the delta is fronted for a short distance by a shallow submerged platform, across which the detritus is carried to deeper water. Of these three portions, the foreset beds usually comprise the greater *volume* of the deposits, but the thinner bottomset and topset spread over the greater area.

The ratio of the submerged to the emerged portions of the topset beds depends upon a number of factors. A rapid subsidence may carry the whole beneath the sea, but *where subsidence is slower than upbuilding*, the proportion of the topset surface which is submerged will depend upon the balance of power between the waves, tides, and currents on the one hand, and the constructive work of the river on the other.

The depth of water over the submerged portion of the delta also depends upon the strength of the waves. Thus, an inspection of maps

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[1] Chamberlin and Salisbury, *Geology*, Vol. I, p. 191.

possessing bathymetric contours shows that the Amazon, facing the open ocean, and subject both to wave-erosion and tidal scour, has a submerged delta which for 200 kilometers is less than 20 meters beneath the surface of the sea, while the aërial portions belong rather to the flood-plain, since they do not extend eastward beyond the adjacent margins of the continent. On the contrary, in the case of the Nile, the Danube, the Po, and the Mississippi, flowing into relatively quiet and tideless seas, practically all the foreset beds are above water, and thus the greater part of the *area* of the river delta, neglecting the attenuated bottomset beds, is a region of subaërial—that is, of continental—sedimentation.

According to Forshey

> more than two-thirds of the Mississippi delta in the ordinary state of the river are above water. . . . . But if the river were unrestrained by levees, the highest floods would fill the alluvial basin and make a sea 600 miles long, 60 miles in mean width, and 12½ feet in mean depth.[1]

As another illustration,

> the delta of the Hoang Ho (Yellow River) extends along the coast from near Peking, on the north beyond the Pei Ho, to Hung-tse Lake on the south, where it joins the plains of the Yang-tse-Kiang. The distance is 400 miles, but the mountainous province of Shan-Tung is to be excluded. From the coast the delta extends westward for 300 miles. The river is here useless for navigation. The whole delta region would be under water during flood seasons except for drainage by artificial canals and dikes of great length.[2]

Under natural conditions every flood would, by the settling of mud or sand from the broad flood-waters, contribute to the upbuilding of the delta plain; as, for example, the statute of Rameses II at Memphis has been buried in about 9 feet of river deposit in somewhat over 3,000 years. The interference of man has, however, doubtless here changed the natural rate.

The geological importance of this aggradational work of rivers over their deltas is obvious. During periods of rapid subaërial denudation an appreciable volume of the sediments removed from the interior of the land should be laid down, not beneath the sea, but as a land surface facing and encroaching upon the salt waters. Such a character of river deposition would be at a maximum in a shallow

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[1] J D. Dana, *Manual of Geology*, p. 197; quoted from C. G. Forshey, 1873.

[2] *Ibid.*, p. 198.

epicontinental sea, protected more or less effectually from ocean currents and possibly from tides; a sea which for that reason would be unable to cut away the rapidly forming deposits of the encroaching delta. Such a sea existed over much of the northeastern portion of the United States during much of the Neopaleozoic times. Within this basin of sedimentation former shallow-water conditions are indicated in certain formations by mud-cracks and supplemented by ripple-marks, cross-bedding, and inconstancy of arenaceous strata. This must signify that the upbuilding power of the ancient rivers was, on the whole, equal to or in excess of the progressive subsidence of the basin. There is not likely to be long maintained an exact balance between the two, and hence in general it may be said that such structural feeatures indicate a capacity in river-building to more than compensate for the progressive subsidence of the geosyncline. But, having granted this excess of sedimentary power, it is seen that, especially in the protected bays, the surface of deposition should be very largely a land surface; occasionally flooded, as a result of the rainy seasons, by the fresh waters from the land; occasionally flooded over the seaward portions during combinations of storms and high tides by the waters of the sea.

Diagrams illustrating the relations of foreset and topset beds under ideal conditions are given in Figs. 1 and 2. In Fig. 1 a delta is supposed to be built out into a quiet lake with constant water-level. The thicknesses perpendicular to the planes of stratification of the foreset and topset beds will vary approximately with the angle of dip of each. The ratio of volumes will depend upon the area multiplied by the thickness, and although the topset beds under these conditions may not be more than one-tenth as thick as the foreset beds, their area in a large delta, especially in a shallow sea, may be ten times that of the latter, so that the volumes of sediments deposited above and below the sea may be of the same order of magnitude. In Fig. 2 a *subsiding* delta is supposed to be built upward and outward, with just such speed that the front of the delta is maintained at a constant line. In this hypothetical case the gradient of the delta would be less than in the first case, the currents more sluggish, the delta more frequently flooded, and a greater proportion of the waste would be dropped upon the topset surface. Under such conditions the topset beds might equal or exceed in thickness the foreset beds. Where the area of the delta becomes as great as was the case of the Carboniferous coal swamps of the eastern United States, the resulting volume of land deposits may far outweigh the volume of the foreset beds building the delta front.

At first thought it might be supposed that over a subsiding delta region the only effect would be an encroachment of the sea, without changing the slope of the delta surface, diminishing the subaërial portion without increasing the rate of river deposition upon it. When a dam is thrown across a stream, however, and the water-level artificially raised, the gradient is flattened, and the stream made more sluggish for some distance upstream at levels higher than the upper edge of the dam. Where similar elevations of the water-level occur through natural causes, it is presumed, therefore, that the effect would result in an enlargement of the zone of fresh-water morass and increased river deposit, as well as a tendency to restrict the margin of the delta.

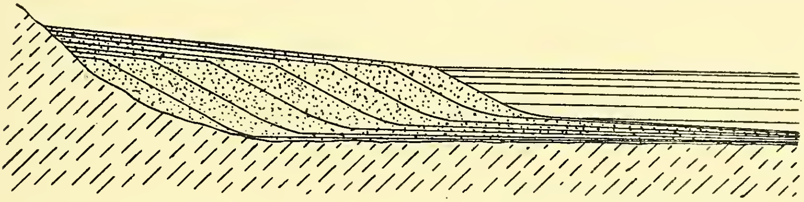

Fig. 1.—Ideal section of delta built out into quiet water of constant level.

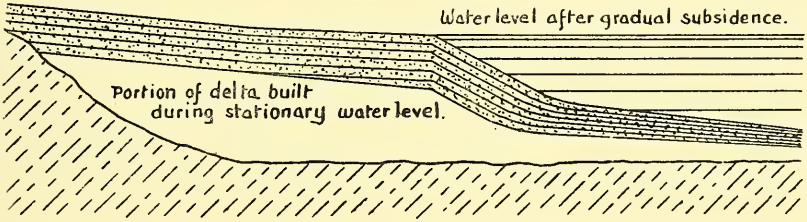

Fig. 2.—Ideal section of delta built out into quiet water when subsidence just balances deposition, resulting in a stationary shore-line.

It is probable that many deltas reach a point beyond which they advance but slowly. This occurs in those fronting large bodies of water, and exposed to heavy tides and storms. For example, Tremenheere has shown that detritus from the Indus is swept northwestward along the coast beyond the limits of the delta by the winds of the southwest monsoon.[1] The monsoon winds of the Arabian Sea are reversed during the year, with a resulting reversal of ocean currents; and this exposure of the delta front to the alternating and powerful waves, tides, and currents is doubtless the cause of the fact, made known by Murray, that terrigenous deposits extend 800 miles from the mouth of of the Indus and cover an area of more than 700,000 square miles.[2]

Under such circumstances the materials which in a quiet sea would contribute to make the foreset beds and advance the delta must be largely swept along shore and out to sea, contributing to widespread bottomset beds.

Excluding these widespread portions from the delta proper, it is seen that under these conditions the topset beds of subaërial origin, while not contributing a larger volume than before, may form a larger ratio of the entire delta deposit. On the other hand, as the delta advances into deeper and open water, a larger amount of material is deposited beneath the surface on the delta front, in order to build it out; and this also would cause the delta to advance more slowly, but diminish the ratio of the land-formed deposits. When a delta has reached a stationary limit, it is only possible for superficial deposits to be deposited through subsidence; but as this appears to be not unusual to such areas at the present time, it is also to be expected in the past.

The diagrams, furthermore, indicate that the ratio of subaërial to marine deposits in an advancing, but not subsiding, delta depends for one factor upon the relative gradient of the topset to the foreset beds. The gradient depends upon a number of factors which cannot be fully discussed here, but it may be mentioned that a river carries the greater amount of its burden in times of flood, and that those are the times when it also overspreads its flood-plain. From the broad and shallow flood waters much material is thrown down, more being

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[1] "On the Lower Portion of the River Indus," *Journal of the Geographical Society*, Vol. XXXVII (1867), p. 77.

[2] "Marine Deposits in the Indian, Southern, and Antarctic Oceans," *Scottish Geographical Magazine*, Vol. V, No. 8 (August, 1889), p. 420.

deposited the shallower the waters, since the bottom velocity becomes less for the same surface gradient.[1] A broad delta, unrestrained by valley walls, unless these valley walls themselves furnish sediment, is therefore advantageous for surface deposition. The same may be said of deltas covered with vegetation, since Lyell long since pointed out from observations on the Mississippi delta the effectiveness with which vegetation entangles the sediment of flood waters. Coarseness and abundance of material, signifying rapid erosion at the headwaters of a river, are likewise favorable for subaërial deposition on a steeper gradient.

Summing up the foregoing discussion, it may be said that moderate subsidence, originally shallow and quiet seas, broad and long delta areas, and the presence of not far-distant mountain uplifts are all favorable to a large proportion of subaërial delta deposition. In addition, periodical floods over an arid delta region, and dense vegetation over a humid one, work to the same end.

While there is probably not sufficient data at hand to give quantitative expression to these statements, and indeed they must vary for every example, it may still give definiteness to thought to attempt to express in figures the ratios for the several classes of delta deposits. James Ferguson, quoting F. Prestage, states that in 1861 careful simultaneous experiments were made as to the quantity of solid particles held in suspension in the waters of the Matabangah (one of the distributaries of the Ganges): first on leaving the Ganges, where it was found to be 1 in 294 parts; while nearly at its junction with the Hoogly the quantity was 1 in 884, proving that two-thirds had been deposited *en route* in that short distance of not much over 50 miles in a straight line, though much longer by the meandering river.

In answer to the question as to how much of the entire Ganges alluvium is deposited upon the delta, and how much is carried to sea, Ferguson points out that during the cold weather, when the rivers are low, almost all of their silt will be carried to sea; but then the quantity of water is small, and that little comparatively clear. At the height of the inundation, when the river is overflowing its banks, at least one-half is deposited inland.[2] It is also pointed out that up to

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[1] J. J. Rèvy, *Hydraulics of Great Rivers* (London, 1874), p. 147.

[2] "On Recent Changes on the Delta of the Ganges," *Quarterly Journal of the Geological Society*, Vol. XIX (1863), pp. 350, 351.

early in the eighteenth century the Brahmapootra joined the Ganges some 60 miles above the present junction, and that for a century later the Brahmapootra probably deposited nearly all its load of sediment in filling up the shallow back-water lakes across which its new course was taken. These lakes and swamps, having been bridged over by the date of writing, Ferguson was of the opinion that the delta face would be built outward with comparative rapidity in the place where it was then deficient.[1]

Thus the ratio of land and marine deposition is variable even on the same delta, with the season and in longer cycles. From various descriptions, however, the present writer would, as his impression, estimate that possibly in the case of large rivers from 30 to 50 per cent. of the material reaching the sea is sufficiently fine to be borne beyond the steep delta front, deposited as widespread blue muds, and forming the bottomset beds. These are largely spread at the present time beyond the limits of the continental platforms, and, where deposited at equal depths during preceding periods, have not entered to that proportion into the structure of the present continental surfaces, but still largely lie beneath the sea. Of the remaining 70 to 50 per cent., possibly from two-thirds to three-fourths has been deposited beneath the water, and from one-third to one-fourth as topset beds laid down upon the land. It is unnecessary to repeat that no value must be attached to these estimates. At any one time, however, the *area* of the land-formed portion is a much greater ratio the discrepancy between area and volume being due to the fact that the subaërial beds are thinner, and a given thickness requires a longer time to form.

In closing the topic, the problem of the unfossiliferous nature of many ancient deposits apparently well suited for the preservation of fossils may be mentioned.

It may be questioned as to why, if certain formations were deposited largely upon land surfaces, those surfaces were not overgrown by vegetation, preserved as carbonaceous deposits. To this it may be answered that other factors, such as climate, enter into such a problem, and that it may equally well be asked: How is it, if these strata belong to the littoral or the shallow sea, that fossils common to those zones

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[1] *Loc. cit.*, pp. 332, 333.

of life are not present throughout? Here again various factors enter external to the present subject, which cannot be discussed without too much digression. It may be said in closing, that the absence of fossils leaves the origin of the formation in doubt, and that an unfossiliferous formation may have originated either on the land or beneath the sea. Certain structural criteria which may frequently throw light upon this question will be discussed in a following part.

SUBMARINE TOPSET DELTA DEPOSITS

In connection with the discussion upon the subaërial part of the delta, some mention has necessarily been made of the submerged part of the same, but more especially the steeply inclined foreset beds. Under the present head it is intended to discuss particularly the shallow, submerged portion of the delta in some detail, in order to show what relations it holds under various conditions throughout the world to the emerged portions of the same.

Relation of Waves and Nature of Deposit.—The proportion of the topset delta surface above and below water will depend upon several factors. Two of the more prominent are the rapidity of the deposit and its coarseness on the one hand, and the power of the waves on the other. The maximum of land topset beds may therefore be seen in such instances as Lakes Geneva and Constance, but especially the former, where the gritty sediment of rapid and loaded streams is confined closely between valley walls and discharged into the relatively quiet waters of a lake. The fact that practically all the upper surface of the delta is a land surface in the case of Lake Geneva

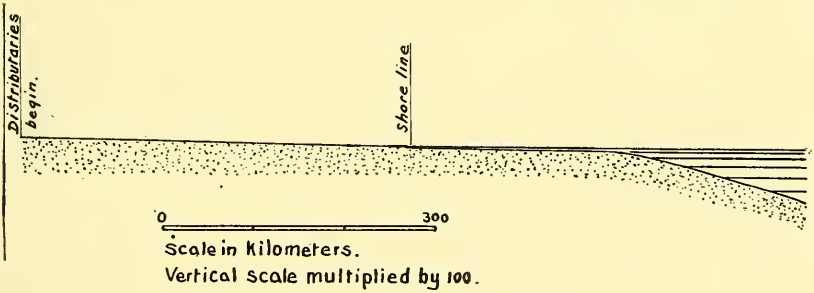

FIG. 3.—Profile. Delta of the Rhone in Lake Geneva.

is shown by the section (Fig. 1) plotted from the bathymetric contours shown in Andrée's *Hand atlas.*

Turning to deltas which show a greater or less frontal submergence, the submerged portions are observed to lie either within or without the outer limit of the general coast-line, as determined by the off-shore reefs. Such important shallow submarine delta platforms lie in front of and completely beyond the limits of the land in the case of the great Chinese rivers and the Amazon. In these instances the development of the submerged delta surface may be due in part to the fineness of the river deposit, allowing the sediment to be largely flooded out to sea in the fresh river water, as it spreads over the salt water below. On the other hand, the waves, tides, and currents are important and aid in cutting back the land surface by marine planation, the land material being swept by the undertow to seaward into the gradually deepening water. Thus in any particular case a certain equilibrium tends to be maintained between the continental and marine portions of the delta surface—an equilibrium which is especially liable, however, to be temporarily destroyed by irregular movements of subsidence or upheaval, since a small vertical movement will transfer the beach-line a long horizontal distance across the almost level surface.

Effect of Variable Point of Discharge.—In the above instances the delta surface is sharply divided into a land and water portion, and the littoral zone is at a minimum.

In another class of cases, illustrated by the Mississippi delta and the combined deltas forming the Netherlands, the deltas inclose within their outer land limits considerable bodies of shallow water or brackish lagoons, as the Mississippi and Chandeleur Sounds, and the Zuider Zee. In these cases it is observed that a large amount of sediment is discharged at one or two separated points over an extended delta coast-line, building out the delta at those places. The waves, drifting the material laterally, throw up barrier beaches, and shut off more or less completely large bodies of water, which thus lie within the front limits of the land delta. Usually it is only a matter of a few centuries at the most until the river abandons its built-out mouths and turns into the intermediate lagoons, as the Mississippi has been known to do near New Orleans, breaking through its levees in times of flood and pouring into Lake Pontchartrain. Such a course would possibly before this have become permanent, had the river not been restrained by artificial means. Even in these cases, however, of land-protected sounds and lagoons, it is to be noted that the area of mud-flats exposed between tides is much less than the areas permanently covered by lagoon waters.

A river possessing a broad land delta, and shifting across it periodically, will thus build up a delta formation whose seaward portions will embrace an alternation of marine or lacustrine and fluviatile deposits. Farther inland the deposits will be entirely fluviatile.

Effect of Variable Water-Level.—Another condition which must normally modify the relations of land and sea in delta-building is that of changing level, resulting either from those variations in the water-level to which inland seas are peculiarly liable, or from irregular vertical movements, usually of subsidence, such as are known to be characteristic of regions undergoing sedimentation.

Interior seas.—The case of inland seas is illustrated by the delta of the Volga, shown in cross-section in Fig. 4, and which may be contrasted with Fig. 3. A good map shows that the entire northern portion of the Caspian Sea, lying chiefly east of the line of the section, is but from 1 to 11 meters deep. Such an extended shelf to an inland sea facing two large rivers cannot reasonably be ascribed to wave planation of the river deltas, nor, on comparing this shelf with other deltas, can it be supposed that waves in the absence of tides and currents could have transported the land-waste to such a distance from the river mouths.

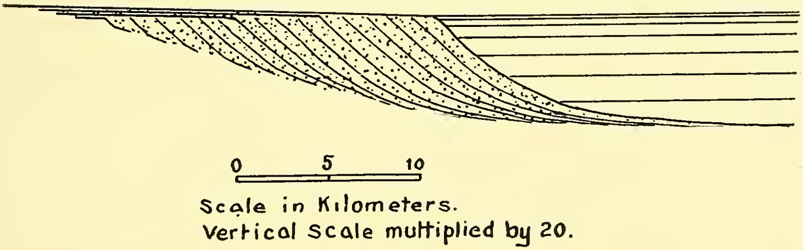

FIG. 4.—Profile. Delta of the Volga in the Caspian Sea.

It seems certain, then, that the present submerged shelf was developed as a land surface, and presumably by river-building rather than by river erosion. In confirmation of a former lower level of the Caspian Sea, Walther quotes the record of a boring on the shore of the Caspian southeast of Krasnovodsk, in which dune sands were found to a depth of 35 meters;[1] and more recently Davis has noted the evidence of a low-water epoch between the Tertiary and Quaternary periods of Caspian expansion, as indicated by the stream-eroded character of the present shores at Baku, which must have endured for a much longer measure of time than that of the Quaternary high-water stage and the present mid-water stage taken together.[2] Davis does not correlate the low-water stage with the development of the present submerged shelf, but unless crustal warping has materially disturbed the relations, it would seem a not unnatural correlation.

Not only are interior seas thus liable to long periods of expansion and diminution, resulting in an alternation of fluvial and lacustrine deposits, but cycles of shorter period, though enduring for centuries, may be superimposed. Thus Huntington has recently presented the evidence for a working hypothesis that the Lake of Sistan has passed through at least ten fluvial epochs during the Quarternary era;[3] the fluvial epochs being marked by widespreading floods over temporary playas, leaving pink beds of clays and very fine silts, often passing into layers of fine brown sand. The lake stages are marked, on the contrary, by white or, more exactly, greenish clays, and form but a small portion of the thickness in the exposed sections. In this alternation of fluvial and lacustrine deposits the former comprise the bulk of the mechanical sediments, the latter the bulk of the fossils.

By seasonal changes in the water-level of interior seas there is an especial liability to the development of a broad intermediate zone, corresponding to that of the littoral bordering the open sea, and characterized by variegated shales showing mud-cracks, rain-prints, and ripple-marks. Thus in ancient interior basin deposits there may be shore relations indicated by the nature of the strata which might

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[1] "Das Oxusproblem in historischer und geologischer Beleuchtung," *Petrographische Mitteilungen,* Vol. XLIV (1898), p. 211.

[2] *Explorations in Turkestan,* Carnegie Institution (1905), p. 25.

[3] *The Basin of Eastern Persia and Sistan,* Carnegie Institution (1905), Plate X, and p. 291.

readily be mistaken for those of an epicontinental sea in tidal connection with the ocean. As distinguishing features it may be noted that in the former case the subaqueous shore deposits take place continuously for months. The periods of exposure likewise endure for months, and the prolonged desiccation gives a maximum opportunity for the formation of mud-cracks and the hardening of rain-prints or foot-prints. This hardening is favorable to their preservation, as Lyell has shown, since the record is not readily washed out by the returning waters, which bring with them another layer of sediment, by which the record is buried and indefinitely preserved.[1]

The shores of the epicontinental sea, on the contrary, if open to the tides, are subject to two daily inundations, and the chances for the formation and preserval of mud-cracks is at a minimum, except at the highest limits of tidal flooding.

Variable water-level—marine deltas.—To consider the effects of irregular vertical movements upon deltas facing the ocean waters, it is to be noted that the change is due to movements of the land rather than of the sea. Of land movements the nature of subsidences is more difficult to observe than that of elevations. In the latter, successive beach-lines carved along coasts, successive development of partial peneplains, and the actual observations of uplifts, as those noted during the nineteenth century along the coast of Chili, all give testimony to the largely intermittent character of upheaval. But in regard to subsidences also, observations have been made. These are sometimes slow, and for a time at least equable, as that affecting the present eastern coast of the United States, at other times subsiding at unequal rates, as indicated by the halt during the past century of the subsidence of the deltas of the Rhine and the Meuse, compared with the occasionally disastrous inroads made during the previous millennium.[2] Again at times districts suddenly subside during earthquakes. Such movements must tend to occasionally flood considerable portions of the delta surfaces of large rivers with sea water, which will stand over the regions perhaps for centuries or millenniums before it is again reclaimed by delta-rebuilding.

Perhaps the most striking instance is to be found in the Runn of

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[1] *Quarterly Journal of the Geological Society of London*, Vol. VII (1851), p. 239.

[2] A. de Lapparant, *Traité de géologie*, 4th ed., pp. 570, 572.

Cutch on the southern portion of the delta of the Indus, a brief account of which is given by Suess[1] after Cunningham, Wynne, and Burnes.

The Indus, at least since 680 A.D., has delivered the most of its water along the western side of its delta. On the extreme eastern side walled off from the sea by the hilly island of Cutch, is found the Runn of Cutch, a salt desert, estimated to comprise about 10,000 square miles in area. The great Chinese traveler Hwen Tsang, who visited it in the year 641 A. D., describes the district even at that time as low-lying and damp, and the ground as filled with salt. This immense plain of the Runn is covered, during a southwest monsoon from Lakhpat, with salt water; during the floods of the Indus with fresh water, conveyed by the channels of the Banas or the Luni; at other times it is dry, and is then strewn with great patches of salt of dazzling whiteness.

This region was visited in 1819 by a violent earthquake and a low mound called the Allah Bund, or "mound of God," was raised across the northern side. Wynne and Suess, however, in contradistinction to Burnes and Lyell, consider that the real movement was one of subsidence of the Runn, as indicated by the fact that eight years after the earthquake the Indus burst its banks in upper Sind, flowed across the Allah Bund, which thus offered no obstacle to its progress, and spread over the Runn of Cutch.

Without attempting to sharply discriminate between variable delta-building and variable subsidence in this disputed case, it remains as the most striking instance of how, for more than a thousand years, portions of a delta surface the major part of which is land may be covered by the sea. Here the alternation of fresh- and salt-water floods with seasons of aridity is not representative of pluvial climates, but depends upon, *first*, the small rainfall of the region; *second*, the southwest monsoon which raises the sea-level slightly during one season; and, *third*, the river floods produced by a period of rains in distant mountains.

Under more usual circumstances the reach of the ocean waters, which now spread periodically over the Runn, would doubtless be greatly diminished, since in the course of the six hours between high

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[1] *Das Antlitz der Erde*, Eng. trans., Vol. I, pp 40–47.

and low tide the water could flow but a limited distance over tidal flats, and in a more pluvial climate much of the region would doubtless be covered with fresh-water lakes and lagoons. Both salt and fresh water, by wave- and current-action, would tend to differentiate the water from the land. This conclusion is in conformity with what is observed upon deltas facing the sea, the delta being normally divided into a land surface occasionally covered by river floods and a subaqueous portion perennially covered by the sea water, the two being separated by a relatively subordinate littoral zone.

CONCLUSIONS ON GENERAL NATURE OF DELTA DEPOSITS

A review of the deltas of the world at the present time shows that, as a rule, the shallow basins marginal to the continents are filled with alluvial deposits, except in regions where the submergence or warping is very recent, as in the case of the Baltic Sea and Hudson's Bay, or where tidal scour tends to maintain an open estuary.

The deltas of the larger rivers, where they have had a reasonable geological time to form, customarily end in deep water beyond the general limits of the coast-line.

But the present is a time of continental extension and mountain-building, though the late Tertiary was still more striking in this respect. Therefore it may be reasonably concluded that at times of similar topographic character in past geological history such epicontinental seas as remained became, as a rule, largely filled, and usually rather rapidly, by delta deposits, and shallow seas would thus give way to alluvial plains. Even in times of partial continental submergence, however, as in the upper Devonian and the Carboniferous, the mountain-building then present would be expected by the accompanying erosion to have given rise to extensive subaërial delta deposits, which could, however, have only occupied the landward portions of the broad epicontinental seas. Under such circumstances the preceding discussion has indicated that the beach might be a shifting line, usually fluctuating about a certain limit, but sometimes transgressing the alluvial delta plain, or again moving a shorter distance seaward. The strata, as seen in vertical section, would be, under these assumed conditions, to a considerable extent land deposits in the region of thick sedimentation, largely marine where they thinned out on the seaward side. The two kinds of formation would be intimately interfingered at the contact—an interfingering which might extend for tens, or occasionally for hundreds, of miles.

The distinction, however, which it is wished to emphasize here is that these deposits would be chiefly either land or marine, and only subordinately littoral. The broad exposure of the land surface is not a matter of between tides. Limited districts, as the Runn of Cutch, might be regularly inundated by sea water during a certain portion of the year, and other districts might be occasionally covered by great storms; but more usually changes over considerable border districts from land to sea would be a matter of centuries at least. In interpreting such deposits, mud-cracks, rain-prints, foot-prints need not necessarily, nor even usually, indicate exposures of tidal mud-flats, as is usually assumed,[1] but may equally well be interpreted as records of a subaërial delta surface, regularly flooded by river inundations or occasionally by the sea. Again, an occasional intercalation of strata holding marine or estuarine fossils in a great series of mechanical sediments is not evidence in itself that the entire formation is marine or estuarine. On the other hand, an occasional occurrence of fresh-water strata in an unfossiliferous formation is not evidence in itself that the entire series is of continental origin.

In times when the lands are topographically old, it is to be anticipated that land surfaces upon delta deposits will be at a minimum since marine planation will not have been lessened in power; while, on the other hand, the ability of the rivers to build out against the seas, or to build up whenever subsidences occur, will have greatly diminished.

CONCLUSION ON PRESENT CONTINENTAL SEDIMENTATION

It has been shown in the preceding pages that important continental deposits either now in process of formation, or so recently made as still to exist as superficial formations, cover an appreciable portion of the continents.

Of these the interior formations of arid climates have been roughly estimated to cover a tenth of the land surface of the globe, the pied-

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[1] The question of the origin and preserval of mud-cracks made on tidal flats is considered later.

mont waste slopes of several continents to cover an area of the same order of magnitude as that of the great mountains from which they come. Interior basins of pluvial climates are seen to be largely filled by fluviatile deposits; again, where the land meets the sea sediment is deposited as deltas, forming fluviatile deposits with bottoms far below the level of the sea. These have been observed to be of varying importance in different continents, and no estimate of their aggregate areal extent has been given. Still, it would seem to be in the neighborhood of the truth to place the subaërial deposits of piedmont waste, of continental basins, and of deltas as covering a tenth of the emerged continental surfaces. Adding this to the estimate of the deposits of arid climates would give a fifth of the land surface as mantled by continental formations. From the generalized profile showing the relative areas of the earth's crust at different heights given by Penck,[1] and also by Gilbert,[2] from Murray's figures it is seen that one-fifth of the land surface is elevated more than 1,200 meters above the sea. The more elevated portions of the crust suffer, *on the whole*, the most severe and rapid erosion. Consequently, a general idea of the localization and rapidity of erosion upon the land may be gained by stating that at present one-fifth is subject to extremely rapid erosion, one-fifth to rapid erosion, one-fifth to moderate erosion, one-fifth to slight erosion, and one-fifth, either now or in recent geological times, to sedimentation. Not all of the latter would be permanently preserved by the continued action of the forces which have led to their accumulation. Such superficial formations as those deposited upon slightly warped slopes previously graded, as the Lafayette formation of the eastern United States is presumed to be, or the thin deposits of ancient deserts, are especially liable to be destroyed, so that the geological record of former ages should show a far less proportion of thin and superficial land deposits. Basin deposits of either desert or pluvial climates and delta deposits possess, however, indefinite thickness, and the chances of indefinitely long preservation of at least the lower portions is nearly as good as in the case of the deposits upon the floors of epicontinental seas. As, however, changes in geological activities

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[1] *Morphologie der Erdoberfläche*, Vol. I (1894), p. 136.

[2] "Continental Problems," *Bulletin of the Geological Society of America*, Vol. IV (1892), p. 180.

frequently take place by subsidence of land areas, even the highest of such land deposits stand a chance of preserval. Therefore others of a similar nature should be expected to occur buried in older portions of the geological record, but not so abundantly as those originally formed at lower levels. Continental deposits depend, however, so largely upon the climate and geography that their areal extent and importance must have varied largely through geological time.

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ON A POSSIBLE REVERSAL OF DEEP-SEA CIRCULATION AND ITS INFLUENCE ON GEOLOGIC CLIMATES[1]

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The control of secular climates is obviously a condition prerequisite to biologic continuity. The preservation of a narrow range of temperature and a limited variation of atmospheric constituents throughout the millions of years of the biologic past was absolutely essential to organic evolution. Continued preservation for millions of years to come seems equally a condition precedent to an intellectual and spiritual evolution commensurate with the physical and biological evolutions that have preceded it. Only such a prolonged evolution of the intellectuality now just dawning gives full moral satisfaction to our conception of the sum-total of terrestrial history.

The narrowness of the range to which temperatures must be confined to permit progressive organic and intellectual evolution takes on its true meaning only when we recall that the natural temperature range on the earth's surface is sixteen times as great as this, while that affecting the solar family is at least sixty times as great. For a hundred million years, more or less, this narrow range of temperature has been maintained quite without break of continuity, unless geologists and biologists are altogether in error in their inductions. On the further maintenance of this continuity hang future interests of transcendent moment.

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[1] Published by permission of the President of the Carnegie Institution, under whose auspices these studies have been prosecuted. Read, with unimportant alterations, before the American Philosophical Society at the Franklin Bicentennial Celebration.

So, too, the maintenance of a narrow range of atmospheric constitution, notably in the critical element carbon dioxide, has been equally indispensable. These two critical limitations of temperature and of constitution seem also to have been interdependently correlated with one another.

The climatic problem is as difficult as it is important. The factors are so many, so elusive, so imperfectly determined, perhaps even so imperfectly determinable, that the utmost patience and assiduity are a duty of the investigator, and the utmost charity of judgment an obligation of fellow-scientists. I am persuaded, however, that tentative analyses of the tangle of factors are an indispensable aid to the future solution of the problem. One of the gravest difficulties confronting us today is the imperfection of observations and the inconclusiveness of experimentation; and this arises in no small degree from the lack of such patient preliminary analyses of the problem as shall bring into sharp recognition the occult things that are to be observed and the precise experimental determinations which alone can really aid in the solution. If the little contribution of this paper shall have any value at all, it will lie in its suggestive relations to the larger problem of secular climates, past and prospective.

As this larger problem has recently assumed, with some of us, a phase much at variance with its more familiar aspects, it may need to be briefly sketched. It has been customary to assign to the primitive earth a climate quite beyond the Miltonian conception of Gehenna in its fiery intensity, and to predict an impending refrigeration scarcely inferior in antithetic severity. The familiar conception of the sum-total of atmospheric history as a decline from one excess to another as the sequence of thermal wastage, is a logical deduction from the hypothetical derivation of the earth from a gaseous or quasi-gaseous nebula through gravitative condensation. To some of us, however, such a derivation seems inconsistent with the dynamics of the present solar system, and an alternative hypothesis has been formulated to meet the supposed requirements of existing phenomena. The acceptance of this requires a reconstruction of the whole conception of geologic climates. The new view discards the primitive molten state as a necessary condition, and presents the alternative of a slow growth of the earth by planetesimal accessions. This alternative involves a slow growth of the atmosphere also, until it reached a volume similar to the present, when its growth is assumed to have been arrested and thereafter limited by the interplay of opposing agencies. These agencies are thought to have held it ever since within so narrow a range of oscillation as to foster organic evolution. A continuance of the same control offers ground for hope of a perpetuation of conditions congenial to organic and intellectual life, through a period to which no definite limits can now be set beyond the presumption that there must ultimately be a limit. The inevitable cooling of a once white-hot earth plays no part in this prognosis. The agencies of atmospheric maintenance and control thus force themselves upon consideration as factors of supreme importance.

The assigned agencies of atmospheric *restraint* are molecular velocities, chemical combination, and condensation. By virtue of the first, the lighter constituents are reduced to a minimum and all constituents are restricted within certain large limits. By virtue of the second, the chemically active factors are kept down to states of dilution compatible with organic evolution, while the inert elements have probably been permitted to increase steadily. By the third, the excess of water-vapor has been condensed into the ocean, which has probably increased rather than diminished through the ages.

The postulated agencies of atmospheric *supply* are accessions from without and emanations from within, of which Vesuvius has just been giving us an impressive illustration.

To the interplay of these opposing agencies of loss and gain is assigned the maintenance of the requisite narrow range of atmospheric constitution, of temperature, and of associated conditions. Under this general resetting of fundamental conceptions, the question of climatic regulation takes on very concrete aspects and presents specific lines of study.

Subsidiary to these narrow limitations, recognition of pronounced variations is forced upon us by a growing mass of geologic evidence. Throughout most of the well-known geologic periods, the poleward distribution of life implies warm climates, even as high as 70° and 80° of latitude. How life of subtropical types could have survived the long polar nights is one of the most obdurate puzzles of the earth's climatology. It becomes all the more strenuous if we cast aside all resort to an early fervid state and a molten interior. Quite irrespective of primitive conceptions, however, the edge of the problem has sharpened as we have been forced to recognize that *between* the warm polar stages there were episodes of glaciation in strangely low latitudes. It appears necessary now to accept as demonstrative the evidences of extensive glaciation in India, Australia, and South Africa in the midst of the later coal-forming stages of the Paleozoic era. The glacial beds lie even between coal beds of Permian or Permo-Carboniferous age; while, strangely enough, the areas of glaciation approach, and even overlap, the tropics of Cancer and Capricorn. And yet, figs and magnolias have grown in Greenland since, and mild polar climates are as well authenticated after as before this climacteric glaciation. Less complete evidences from China[1] and Norway imply a very much earlier glaciation, falling in the oldest Cambrian, or perhaps even pre-Cambrian, times. Still more recently, similar evidences of early Paleozoic glaciation in South Africa have been announced.

The climatic student seems therefore compelled to face oscillations within the known geologic periods, ranging from sub-tropical congeniality within the polar circles, on the one hand, to glacial conditions in low latitudes, on the other, and these *in alternating succession;* while neither of these oscillations was permitted to swing across the narrow limital lines of organic endurance. There is little doubt that the ocean, the daughter of the atmosphere, is one of the most potential agencies in controlling these oscillations. It is one of its possible functions in such regulation that invites our present attention.

Some of the regulating functions of the ocean have long been recognized. Certain less familiar ones have been brought under study in recent years by a few students independently. Schlœsing was perhaps the first to clearly recognize that the carbon dioxide of the ocean is an important agency in the regulation of the atmospheric content of this critical factor. As early as 1880[2] he advanced the

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[1] Willis, *Third Year-Book*, Carnegie Institution (1904), p. 282.

[2] "Sur la constance de la proportion d'acide carbonique dans l'air," *Comptes Rendus*, Vol. XC (1880), p. 1410.

view that the carbon dioxide of the atmosphere is in equilibrium, not only with the free carbon dioxide absorbed in the sea water, but, through dissociation, with the second equivalent of carbon dioxide in the oceanic bicarbonates. The sum-total of such free and loosely combined carbon dioxide available at present as a possible supply for the atmosphere may be some twenty-five times the present atmospheric content. Schlœsing held that any depletion of the atmospheric content would be followed by emanation from the ocean, and any excess acquired by the atmosphere would be followed by oceanic absorption, and hence great changes in the atmospheric content would only be brought about by reducing or increasing the large sum-total of atmospheric and oceanic supply. This was a contribution of the first order to the problem of atmospheric regulation. It is necessary for a geologist, however, to recognize that the exchange, and even the equilibrium itself, are dependent on geological and physical conditions. At periods in which the oceanic bicarbonates were most abundant, the amount of free and loose carbon dioxide in the ocean may perhaps have reached 30 or 40 times the present atmospheric content, while, on the other hand, it may have fallen to a very low figure when the ocean was depleted of carbonates. It is necessary also to recognize that the diffusion of gases in water, so far as it is covered by experiment, is a slow process, and computation seems to show that the supply of carbon dioxide to the atmosphere might be much too slow to offset its consumption under certain geologic conditions, unless effectively aided by oceanic circulation. The active superficial circulation immediately assignable to the winds would aid somewhat, but its competency is limited. It was in an attempt to determine the functions of the deep-sea circulation in this interchange that the conceptions of this paper arose.

In an endeavor to find some measure of the rate of the abysmal circulation, it became clear that the agencies which influenced the deep-sea movements in opposite phases were very nearly balanced. From this sprang the suggestion that, if their relative values were changed to the extent implied by geological evidence, there might be a reversal of the direction of the deep-sea circulation, and that this might throw light on some of the strange climatic phenomena of the past and give us a new means of forecast of climatic states in the future.

That the deep-sea circulation is now actuated dominantly by polar agencies is clear from the low temperatures of the abysmal waters, even beneath the tropics. It is a firm inference that cold waters creep slowly along the depths from the polar seas equatorward, where they gradually rise to the surface and return on more superficial routes. This is not, however, yet a matter of observation, and the courses pursued are unknown. It is perhaps more probable that they are gyratory or spiral and complex than that they are simple and direct.

The agencies that affect oceanic circulation include at least (1) wind, (2) atmospheric transfer, (3) differences of salinity, and (4) differences of temperature, including freezing and thawing. The earth's rotation, of course, modifies the currents, but does not actuate them.

1. The effect of the wind is superficial and familiar, and need only be considered here in so far as it affects the deep-sea circulation. Its currents constitute horizontal circuits, and their frictional effect upon the deep currents is probably slight and of a gyratory phase in the main. In so far as they are strictly horizontal, they doubtless favor equally poleward and equatorward movement in the abysmal waters. If there is a component of their sum-total that favors the piling up of waters in the polar regions, it must favor the present deep circulation. If the opposite is true, it must antagonize it. There seems no way at present to measure the relative amounts of these opposing tendencies. It is plausible enough to reason that the cold air from the polar regions would flow more largely at the base of the atmosphere than would the warmer air from the equatorial regions, and that the polar winds would thus antagonize the present abysmal circulation. But theoretical deductions are rarely sure-footed in these complex subjects. The balance of influence whatever it may be, is probably so slight as to be negligible.

2. We cannot here attempt to follow empirically the transfers of water by evaporation and precipitation, but general inspection seems to indicate the nature of the average effect. The saturation point of the atmosphere falls progressively from the equator to the poles, and

the actual humidity runs roughly parallel to it on the grand average. Poleward movement of the atmosphere leads therefore to a lower content of moisture; equatorward movement, to a higher. As the acquisition of moisture lags behind the capacity to hold it, it is a rather firm inference that precipitation exceeds evaporation in the high latitudes, and that evaporation exceeds precipitation in the low latitudes, on the grand average. The bearing of observational data is of the same import. The result of these ratios of precipitation and evaporation is a raising of the ocean surface by fresh waters in the polar regions and a lowering of it in the low latitudes accompanied there by concentration of saline constituents. Considered alone and ideally, this should give a slight equatorward gradient and a flow of fresh surface waters in that direction. These waters, however, mingle with the superficial sea waters, and involve a movement of these also toward the equator. So far as these affect abysmal movement, they antagonize the present circulation.

3. In so far as evaporation exceeds precipitation in the low latitudes, it results in an increased salinity of the superficial waters, and a tendency of these to sink and flow poleward to replace the salt waters carried equatorward by the fresh waters as just observed. If these were the only factors, it seems clear that the deep circulation would be poleward.

4. On the other hand, the lower temperatures of the high latitudes increase the density of the water, and tend to cause it to sink and flow equatorward. But the low temperatures affect primarily the superficial stratum which is freshened by the superior precipitation of the high latitudes, and both computation and observation show that cold fresher waters may float upon warmer saline waters. A large part of this cold superficial water flows away in surface currents to lower latitudes. The actual mode by which polar agencies control the deep circulation is therefore by no means so simple as it might seem.

There is ground to suspect that the formation and melting of ice is an important factor. In freezing, the salt and gases of the surface layer are largely forced out into the underlying layer. If the surface layer has an average degree of salinity, the underlayer is supercharged and, being also cold, must tend to sink. On the borders of the ice-covered tracts, where the precipitation and melting are considerable, and where adjacent polar lands pour in much fresh water, the surface layers are so much fresher than the average sea water that the concentration of salinity by freezing does not overbalance the original freshness. But in those polar regions where there is little inflowage from the land, and where precipitation is slight and almost wholly snow, which accumulates on a previously frozen surface and absorbs most of its own summer melting, it is believed that a sufficient degree of saline concentration combined with depression of temperature takes place to cause an effective downward movement. This is believed to co-operate with diffusion and conduction in giving the lower body of polar waters the superior gravity which actuates the abysmal circulation. The sea immediately bordering Antarctica and that lying northwest of Greenland seem to furnish these conditions. Moss[1] and Krogh[2] have found that at times of northwesterly winds the air west of Greenland contains about double the usual content of carbon dioxide. This, I have suggested, may come from waters overcharged with it by the freezing of the overlying layer.

To a large extent the polar ice is carried to lower latitudes, and the waters arising from its melting do not redilute the concentrated waters, which are thus left free to pursue an independent course.

It is not to be inferred, however, that the deep-sea waters derived from the polar regions are superior in salinity to the waters of the evaporating tracts of low latitudes, but merely that by this concentration, conjoined with low temperature and modified by diffusion and mechanical mixture, water of superior gravity is derived, and that this controls the abysmal circulation.

Dr. Otto Pettersson, in an elaborate article, supports by experiment and observation the theory of Bjerknes, that the melting of the polar ice also promotes circulation, both superficial and deep-seated; but I can only make reference to this here.[3]

A survey of the existing temperatures and salinities of the ocean

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[1] Moss, "Notes on Arctic Air," *Proceedings of the Royal Dublin Society*, Vol. II (1880).

[2] Krogh, "Abnormal CO_2 Percentage in the Air of Greenland, etc.," *Meddelelser om Grönland*, Vol. XXVI (1804), pp. 409–11.

[3] "On the Influence of Ice-Melting on Oceanic Circulation," *Geographical Journal*, Vol. XXIV (1906), pp. 285–333.

makes it clear that the battle between temperature and salinity is a close one, and that no profound change is necessary to turn the balance. The combined results of the many polar expeditions have shown that in the high latitudes of both hemispheres there is a superficial sheet of water 200–300 meters deep that is colder, but lighter, than that below, because it is fresher. It floats upon a warmer, more saline body of water below. This has been specially demonstrated by the investigations of Nansen.[1] This layer of coldest water moves to lower latitudes superficially in the main, showing that coldness alone is not determinative.

In the open Pacific and Indian Oceans hydrostatic equilibrium must be very closely maintained, because of the slight resistance to adjustment. It is shown by the charts of Dr. Alexander Buchan[2] that the concentrated warm saline waters form inverted cone-like masses that reach downward 4,000 feet or more. It thus appears that they lie in the same horizons as great masses of colder waters which their salinity must counterbalance. Less striking phenomena of similar import mark the evaporating areas of the north and south Atlantic. The equatorial tracts of freshened waters arising from high precipitation are scarcely traceable to half the depth. This seems to imply that in the low latitudes increased density due to evaporation is more potent than freshening precipitation, in harmony with theory, as already set forth, and that the density due to salinity is not greatly overmatched by the low temperature density of the Antarctic regions, from which the Pacific and Indian Oceans are not separated by appreciable barriers.

An interesting illustration of the close balance between salinity-density and temperature-density is presented by the saline waters that issue from the Mediterranean, in which evaporation is in excess of combined precipitation and inflow from adjacent lands. As a result, the concentrated waters that form the deeper body of the Mediterranean creep out through the bottom section of the Straits of Gibraltar, while the upper section is occupied by a compensating

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[1] Fridtjof Nansen, *The Norwegian North Polar Expedition*, 1893–1896, *Scientific Results;* Vol. II, "Oceanography of the North Polar Basin."

[2] Challenger Reports, *Summary of Results*, Part II, Appendix, "Report on Oceanic Circulation."

inflow from the Atlantic. Although the Straits are shallow, the outcreeping current does not appear in the upper horizons of the adjacent Atlantic waters, according to Buchan's charts, but descends to depths of 3,000 to 5,000 feet before it finds a horizon of density-equilibrium. It then spreads westerly in a great spatulate wedge across the North Atlantic, and occupies the larger part of its area between the depths of 4,000 and 5,000 feet. It is warmer and more saline than the normal oceanic waters at its horizon, and lies on colder but less saline waters below.

These and similar phenomena point to a notable closeness of the balance between the density-effects of salinity and of temperature respectively. More saline but warmer waters both overlie and underlie less saline but colder waters. On the whole, however, at present, the temperature effects are dominant and cold waters occupy the abysmal depths of all the great oceans.

A comparative computation of salinity-effects and of temperature-effects on density, from such data as are now available, leads to a similar conclusion relative to the closeness of balance between the opposing agencies; but this cannot be entered upon here.

Now, as previously remarked, the geological record gives good evidence that in the majority of known periods the temperatures in the polar regions were sub-tropical or warm temperate. Freezing must apparently have been a trivial factor, if not quite absent, and low temperature was robbed of its chief densifying effects. Evaporation in the zones of descending air-currents in low latitudes must apparently have been operative, in some degree at least, to furnish the geological agencies which the record implies. Deposits of salt and gypsum in not a few periods testify directly to regional aridity. The most marked of these are, to be sure, referable to the periods of glaciation, but many of them have no such assignable association.

In these periods of warm polar temperatures there is reason to believe that the polar temperature-effects fell below the low-latitude concentration-effects, and that therefore the deep oceanic circulation was actuated by the dense waters of the evaporating tracts. These may then be supposed to have slowly descended and crept poleward, acquiring a trivial amount of heat from the earth's interior, and losing some to the waters above, but substantially maintaining their temperatures until they rose to the surface in the polar regions and gave their warmth to the atmosphere. Aided by the enshrouding mantle of vapors that must have arisen from such a body of water, it is conceived that the mild temperatures requisite for the maintenance of the recorded life through the polar night may have been thus maintained.

If this be granted, however, it is wise to note that this is not a radical solution of the climatic problem, for a fundamental cause for the conditions that brought on freezing at one period and prevented it at others is prerequisite to the postulated influence of these in the reversal of the abysmal circulation. At the best, our suggestion offers only an auxiliary agency in the control of secular climates. Some more fundamental agency or agencies must be sought.

THE SERRA DO ESPINHAÇO, BRAZIL

ORVILLE A. DERBY
São Paulo, Brazil

The name Serra do Espinhaço ("Backbone Range") was introduced into geographical literature in 1822 (1) by the founder of Brazilian geology, Wilhelm von Eschwege, as a comprehensive term for the various orographic units that form a great watershed between the rivers flowing directly to the Atlantic and those that discharge first into the Uruguay, Paraná, and São Francisco. By modern usage, and in fact by the subsequent usage of Eschwege himself, the name has, however, been practically limited to the section of this watershed corresponding to the São Francisco basin, the greater part of that corresponding to the Paraná basin being known as the Serra da Mantiqueira, while the remainder of this section and the one corresponding to the Uruguay basin are considered as forming parts of the Serra do Mar range. As thus limited, the name, though robbed of much of its pristine importance and appropriateness, is applied to a well-marked orographic feature distinguished by special topographic, geologic, and tectonic characteristics.

Some of the most distinctive topographic and geologic features of the range are well set forth by Eschwege in his detailed descriptions of his various journeys in the gold and diamond districts (2) comprised in the section extending from Ouro Preto to Diamantina, the occurrence of these minerals being of itself one of the leading characteristics of the range. Thus he contrasts the greater mean elevation (1,000^{m}± with peaks rising to 1,500–1,800^{m}), the general plateau character with abrupt margins, the bald and rugged aspect of the peaks and minor ridges, and their general north-south trend, and the predominance of schistose rocks (especially quartz and ferruginous schists), with the lower altitude, gentler and apparently systemless topography ("like a storm-tossed forest sea") and predominance of crystalline rocks (principally gneiss and granite)[1] that characterize

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[1] Eschwege had a special crystalline-chemical hypothesis of his own (set forth in detail on pp. 11 ff. of his *Gebirgskunde*) regarding the mode of formation of what

the adjacent zones, particularly the one lying to the eastward. The tectonic features of the range have, on the contrary, scarcely been touched upon by him or his successors.

Owing to its wealth of gold and diamonds, the southern section of the range, from Ouro Preto to Diamantina, has been frequently visited and described, with attempts to give an idea of its geological characteristics; but, with the exception of the writings of Eschwege, Spix and Martius (3), Helmreichen (4), Henwood (5), and Hussak (19), but little is to be found in the somewhat voluminous (as compared with other parts of Brazil) literature relating to this region that, from a geological point of view, is comprehensible, or, being so, is of permanent value. The remaining sections and the regions on either side are almost a *terra incognita* from both a topographic and a geologic point of view, and, as in all other parts of Brazil, the lack of reliable maps is an almost insuperable obstacle to detailed geologic studies. The present sketch is based on a few flying trips to the above-mentioned gold and diamond regions, a hurried and partial examination of the diamond-bearing section in the state of Bahia, a boat trip on the river São Francisco and its tributary, the Rio das Velhas, and an excursion into the region of the middle Jequitinhonha, which, however, did not extend as far as the eastern margin of the Serra do Espinhaço region. The observations that could be made on these hurried trips, supplemented by the meager gleanings to be found in the literature relating to the region, are manifestly inadequate for more than the most general treatment of the subject.

The Serra do Espinhaço, as now understood, constitutes a zone with a width of about 50 to 100 kilometers, and a mean elevation of over 1,000^{m}, characterized by rugged topographic features, and rising with abrupt margins a few hundred meters above the lower regions of more uniform topography on either side. It extends in

in his time were known as the primitive rocks, among which he included, as a second division, the bedded arenaceous and argillaceous rocks of the Serra do Espinhaço. He did not admit a succession of sediments among them; he did not attempt to subdivide them into series. The most unfortunate result of this point of view was the lumping-together of all the quartzose rocks of the region under the general name of "itacolumite," which has been an incubus on Brazilian geological studies. Being an acute geological observer, he did not fail to note evidences of the existence of two unconformable series of beds among the rocks so classed, but, withheld by his theory, he did not give these observations their due importance.

almost perfect parallelism with the coast-line and with the river São Francisco (above the great bend at Cabrobó), with a general northerly trend from about latitude 20° 30″ to about latitude 9°, where the river São Francisco, after making a sharp bend to the southeast, cuts through the range or, more probably, flows past its northern end. Throughout this extension of over 1,000 kilometers, this zone forms the eastern rim of the São Francisco basin, which receives the drainage of its western portion, while its eastern drainage goes directly to the Atlantic through the rivers Doce, Jequitinhonha, Pardo, Rio de Contas, Paraguassú, Itapicurú, and Vasabarris. In the upper part of the basins of the Rio das Velhas, Jequetinhonha, and Paraguassú, and to a less extent in that of the Rio de Contas also, the drainage courses correspond approximately with the north-south trend of the serra, while, after escaping from it, the Rio das Velhas and the Jequitinhonha flow for a considerable distance in general parallelism to its margins. As certain structural features are more apparent in the northern than in the southern section of the range, our examination can best be made from north to south.

The São Francisco, at some 80 kilometers below the great bend at Cabrobó, where it changes from a northeast to a southeast course, enters a zone of sandstone country which lies in the line of prolongation of the Serra do Espinhaço, though it is somewhat doubtful if it should actually be included in that range. This zone extends from near the mouth of the small river Pajahú to near the great cataract of Paulo Affonso, with a width, along an east-west line, of at least 50 kilometers, while away from the river the width appears to be much greater. The river, which above this zone flows over a bed of gneiss and granite, enters the sandstone belt at an elevation of about 330^{m} and leaves it at an elevation of about 300^{m}, to again flow over gneiss, granite, and syenite, in which it has excavated a deep canyon that contains one of the most notable of Brazilian cataracts. The sandstone therefore rests on a nearly horizontal base of truncated crystalline rocks (a peneplain ?) with a mean elevation of about 300^{m}, and rises in table-topped hills and ridges on each side to about an equal elevation, or approximately 600^{m} above the level of the sea.

The sandstone is moderately hard, usually coarse-grained, with frequent inclosed pebbles, which in some layers become sufficiently

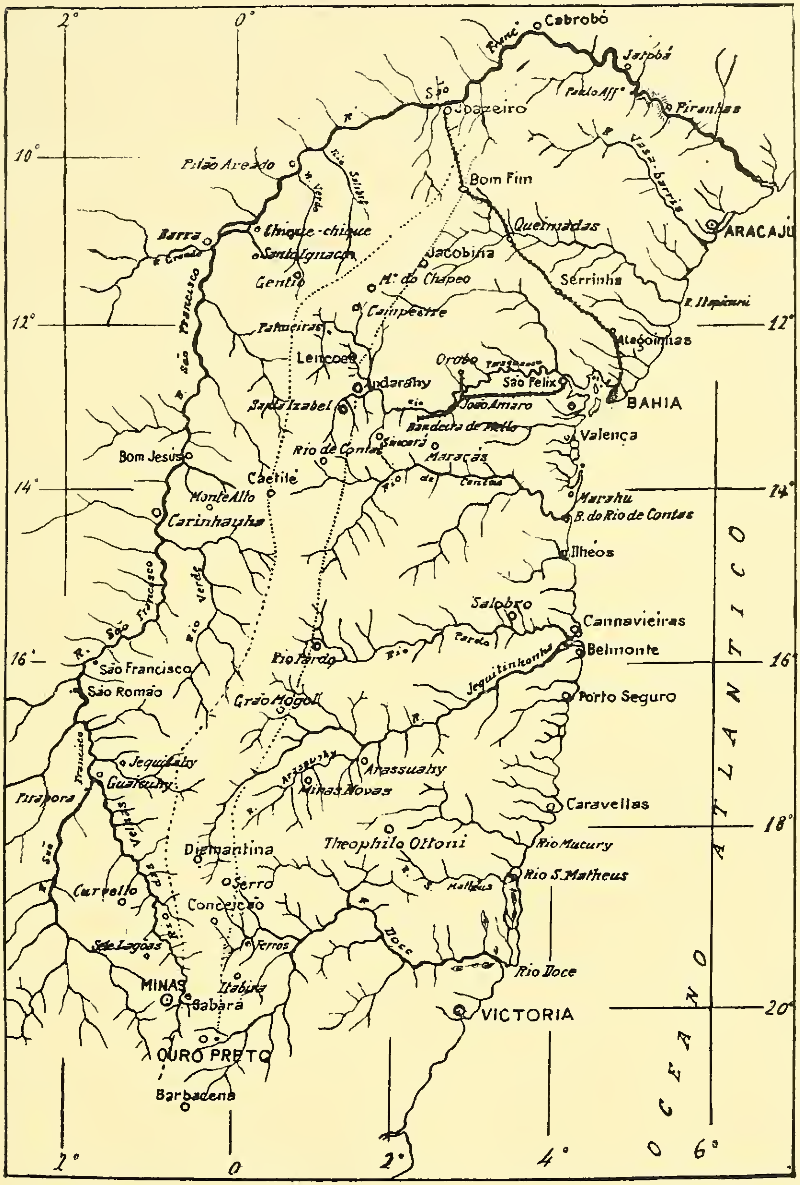

FIG. 1.—Sketch map of the region to the east of the river São Francisco. (The dotted lines show the approximate limits of the Serra do Espinhaço belt.)

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abundant to constitute a conglomerate. The rock is frequently argillaceous, and thin layers of marly shale appear in which at two points (Atalho and Angico, about 6 kilometers apart) I found fossil woods, cyprids, and bones, teeth, and scales of fishes and reptiles (8, 9, 10). The small collection made here was unfortunately lost, but on the occasion of making it I had the strong impression of a close relationship with the fresh-water Cretaceous fauna of the neighborhood of Bahia, based on the general aspect of the fossils, and especially on scales that I identified as *Lepidotus*. In this connection it is to be noted that the famous fossil fishes (including a *Lepidotus*) of the vicinity of Jardim, in the state of Ceará, occur at a distance of about 200 kilometers to the northeast, in front of the base of a sandstone table-land which may readily be presumed to be connected with that of the margins of the São Francisco. The sandstone beds appear at first sight to lie horizontally, but at a number of points moderate northerly dips (seldom more than 10°) were observed, but no distinct evidence of folding could be detected.

The railroad from Bahia to Joazeiro on the river São Francisco affords an undoubted section across the Serra do Espinhaço belt which is crossed near the town of Bom Fim (formerly Villa Nova da Rainha). The road, starting from sea-level at Bahia, runs for 122 kilometers in a general northerly direction to Alagoinhas (alt. 137^{m}) through a country composed of soft Cretaceous and Tertiary strata that have been quite fully described by Hartt, Rathbun, and myself (6, 7). From this point the narrow-gauge prolongation runs in a general northeasterly direction for 452 kilometers, crossing the Serra do Espinhaço belt between kilometers 320 and 370, with a summit level of 683^{m}, and ending at Joazeiro at an elevation of 372^{m}, the terminal station being only slightly above the high-water level of the São Francisco at this point. In a trip over this line the following car-window observations could be made.

From Alagoinhas the road ascends for 60 kilometers over horizontal beds of soft sandstone to an elevation of 406^{m}. Up to the 200^{m} level the beds are quite argillaceous and gritty, and a water-bearing horizon occurs here which probably marks a break in the stratification, since the beds above this level are more sandy and porous, generally deeply stained by oxide of iron, and in general of quite different aspect from those below. At kilometer 29 (elevation 281^{m}), near the station of Uruçanguinhas, a soft ochrous shale, containing beautifully preserved fossil leaves, appears in a cutting. Collections of these fossils were remitted some years ago to Sapota and Ettenhausen, but both unfortunately died before reporting upon them. It is understood, however, that they were considered to be of late Tertiary, probably Pliocene, age. The western face of this Tertiary plateau presents a thickness of about 80^{m} of strata, as gneiss appears in a stream-bed at kilometer 85 at an elevation of 322^{m}. From this point to Jacuricy station (kil. 245) the road crosses a plateau of a general elevation of about 400^{m}, dotted with detached

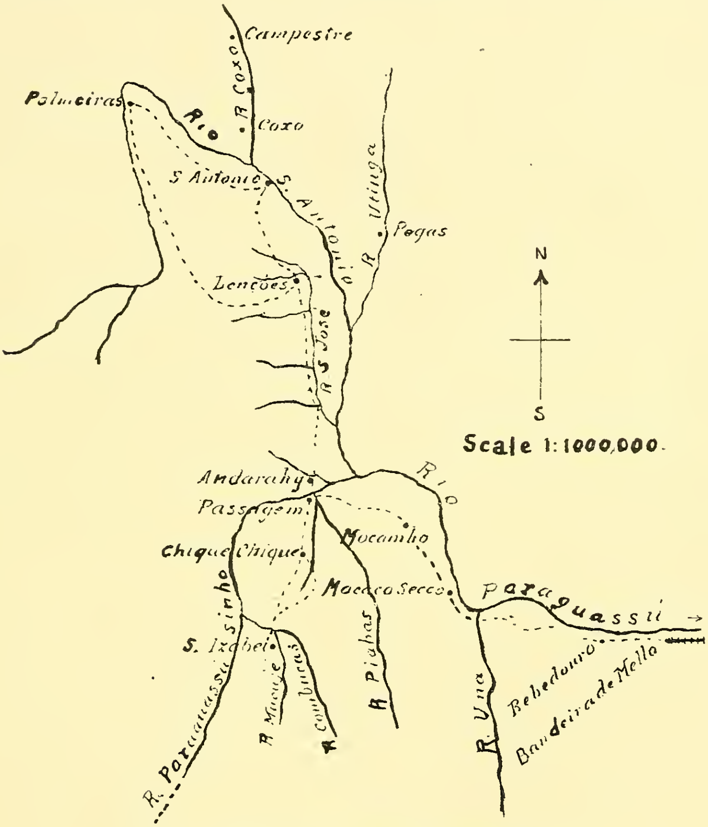

FIG. 2.—Sketch map of upper Paraguassú basin.

knobs and ridges. The soil cap is generally thin, gneiss and granite rocks appearing underneath it. With these occur considerable stretches of a black schistose rock, which is presumed to be mica or hornblende schist. A considerable part of this section of the road is along the watershed between the Paraguassú and Itapicurú, descending afterward to the valley of the latter. To the westward of this comparatively level section rises (kil. 257; alt. 343^m) the Serra de Itiuba, a bold ridge of red granite estimated to be about 800^m high. The road crosses it in a gap at an elevation of 437^m, and descends to the river Itapicurú (kil. 280) at 354^m, and then ascends over gneiss and granite to the city of Bom Fim (kil. 320), on the flank of the Serra do Espinhaço, at an elevation of 548^m. On the ascent to the summit (kil. 355; alt. 683^m) the cuttings are in granite to kil. 333, where flaggy quartzites begin to appear and continue, with occasional interruptions of granite, to Angicos station (kil. 383; alt. 487^m), which is a little beyond the western base of the serra. From Angicos to the end of the line at Joazeiro (kil. 450; alt. 372^m) the country is a gradually sloping plain, so slightly accidented that for 60 kilometers the road has been laid out on a perfectly straight line. Scattered knobs and ridges of granite, gneiss, and quartzite rise abruptly above the general uniform level. The rocks seen from the foot of the Serra do Espinhaço to kil. 391 (alt. 490^m) are gneiss and granite, with occasional outcrops of quartzite. From this point to kil. 430 (alt. 416^m) the surface rock is a whitish limestone in horizontal beds, and of only a few meters' thickness. The aspect of the rock is that of a fresh-water deposit, and though no fossils could be found, it is presumed to be of Tertiary, or possibly Quaternary, age. A similar limestone is known to occur higher up the river in the neighborhood of Chique-Chique, where it appears to cover a considerable area. Along the last 20 kilometers of the road gneiss and granite reappear.

A recent excursion to the diamond region of the upper Paraguassú basin gave me an opportunity to examine the section characteristic of the valley of that river. The trip was made by the Bahia Central Railroad to its terminal station, Bandeira de Mello, situated about 100 kilometers, by the river, to the east of the point where it escapes from the serra at Passagem (see annexed sketch map), the remainder being made on mule-back. The railroad, starting from São Felix near the mouth of the river, rises at once with a heavy grade to the top of a gneiss plateau with a general elevation of 200 to 300^{m}, over which it runs in a line parallel to the river and about 20 kilometers to the southward of it to kil. 165, where it again meets the river and follows its margin to the terminal station at kil. 259. The gneiss plateau away from the river is remarkably level, but dotted with isolated knobs and ridges that for the most part seem to be composed of granite, which also appears in numerous bare ledges that do not rise perceptibly above the general level of the plain. Except in the eastern part, about the headwaters of a small river draining directly to the sea, and apparently in a zone of abundant rainfall, the soil-cap is very thin, often lacking. In this respect, and in the general evenness of the surface, the western part of this plain, like those above described along the São Francisco road, seems to offer a good example of the formation, under arid conditions, of plains by the truncation of strata that normally would present a strong relief.[1] The section accompanying the river is bordered by gneiss

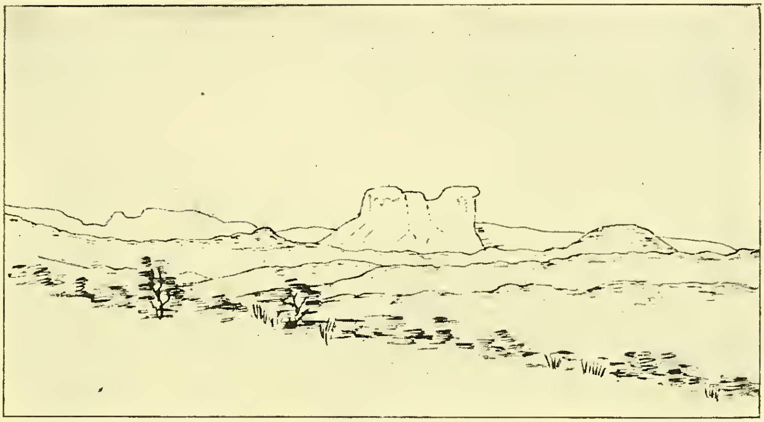

FIG. 3.—Profile near Lençoes.

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[1] See discussion of subaërial denudation in an arid climate, by Professor W. M. Davis, in *Journal of Geology*, No. 5, 1905. No reliable data regarding the mean annual rainfall in the districts here considered could be obtained, but it is tolerably certain that it is less than a meter, and that the minimum is often less than half a meter. With the exception of the Paraguassú and the streams of the Serra do Espinhaço belt, all streams dry up, or become reduced to strings of pools during several months of each year.

and granite rising a few hundred meters above the level of the river, and here the traveler cannot form an adequate idea of the general topographic features of the region, which, however, appears to be considerably higher than that along the first section of the line. The terminal station, Bandeira de Mello, is at an elevation of about 300^{m} above the level of the sea, in the midst of gneiss and granite hills that rise about as much higher.

About 20 kilometers to the westward of the end of the railroad begins a region of sedimentary rocks that includes the whole of the upper part of the Paraguassú basin. Near the river this region begins at Bebedouro with an escarpment of sandstone and limestone rising some 250^{m} above the level of the stream to a plateau of a mean elevation of about 600^{m}. Behind this rises a second plateau of sandstone to a mean elevation of $1{,}000^{m}$ or more, and constituting the Serra do Espinhaço proper, or, as it is here known, the Chapada Diamantina ("Diamond Table-Land"). To the northward of the Paraguassú the margin of the serra is marked by the river São José, which escapes from it near Lençoes and flows along its base. On the south side of the Paraguassú this margin makes an offset to the eastward as far as Mocambo, thus causing a great bend in the river,

FIG. 4.—View of Santa Isabel do Paraguassú.

and from there extends southward in a high ridge between the small rivers Piabas and Una. This upper sedimentary part of the Paraguassú basin is of rectangular shape, with its longest axis lying in a north-south direction, and thus perpendicular to the general west-east course of the middle and lower portions. It is characterized topographically by secondary valleys extending from south to north and from north to south, which unite their waters below Passagem, and where the main valley assumes a general easterly direction.

The geological structure of the first and lower plateau is fairly well seen along the road from Bebedouro to Mocambo. At the first locality a fine escarpment, that extends southward as far as the eye can reach, rises abruptly from the right bank of the river to an estimated height of 250^{m}. The base is composed of a horizontally bedded, coarse, reddish sandstone. On a trail leading back among the hills the sandstone is seen to rise to about 20^{m} above the river, intercallations of micaceous sandy shale appearing near the top. The section is then interrupted for a further rise of 40^{m}, and then comes a magnificent bluff of light-blue flaggy limestone about 40^{m} high. Some of the layers are full of cherty nodules, which on weathering out of the rock afford a means of tracing it where concealed by a soil-cap. At the Cachoeira do Funil, 6 kilometers above Bebedouro, a similar escarpment, that stretches away to the northward, appears

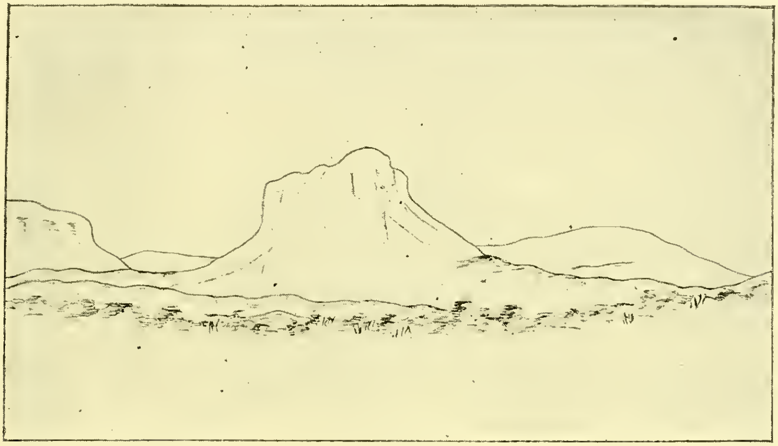

FIG. 5.—Profile near Santa Isabel.

on the northern side of the river, and the base of the sandstone is seen to consist, for a thickness of a few meters, of a coarse conglomerate containing pebbles and bowlders of gneiss and granite. At one point the conglomerate is seen to rest on granite. The road then ascends, over a chert-strewn trail, a table-topped ridge known as the Serra das Araras, which is said to abut on the river in a fine limestone bluff. On the top of this ridge the aneroid indicated an elevation of 575^{m}. Small outcrops of limestone occur on the western descent to the river Una, where just below the bridge is another limestone bluff 35^{m} high. The beds here, as at Bebedouro, have a slight westerly dip of 5–10°. On the ascent from the river Una the road passes over about 100^{m} of strata above the limestone, but no rock *in situ* appears. Cherty nodules appear in three distinct zones, and the underlying rocks are presumed to be shales and sandstones with intercallations of limestone.

A diligent search for fossils both at Bebedouro and Rio Una was fruitless, although the limestone seems very favorable for preserving them. Limestone is reported to occur near the head of the Rio Una, and the valley of this small river is presumed to be almost exclusively occupied by this series, which also appears to the northward of the Paraguassú in the valley of the lower Santo Antonio, and Utinga in the neighborhood of Pegas. So far as could be made out, this series is from 200 to 250^{m} thick, and is practically undisturbed, or at all events much less so than the strata in the adjacent Serra do Espinhaço zone. About a quarter of the thickness, and perhaps much more, is composed of limestone which is characteristically cherty, at least in many of its layers.

From Mocambo to Passagem the road passes, at an elevation of 600^{m}, over a ridge that rises considerably higher to the southward. The rather unsatisfactory rock exposures consist of sandstone, in places lying horizontally, in others with a moderate dip to the eastward or to the westward. The section along the road seems to be across the expiring end of a fold which to the southward forms a high ridge known as the Serra do Sincorá, on the eastern margin of the Serra do Espinhaço plateau. An appearance, as seen from a distance, of synclinal structure in the valley of the Piabas, on the western flank of the supposed fold, confirms this interpretation.

The serra front between Chique-Chique and Lençoes is constituted by a heavy series of sandstone beds dipping eastward at an angle of about 30°, and rising from a minimum elevation of 330^{m}, in the bottom of the valley at Passagem, to a crest line of 1,100–1,200^{m}. Passing over the crest on the road from Chique-Chique to Santa Isabel, flat-lying portions and westerly dips were observed. Westerly dips also occur on the road leading northward from Lençoes to Palmeiras, and about the latter place. The details of the structure could not be worked out, but it is evident that a great sandstone sheet is here bent into broad anticlinal folds. Apparently the main fold of the district begins with a narrow end to the northward of Lençoes, broadens out southward, and narrows down again near Santa Isabel, where it becomes confused with other folds. The combined valleys of the São José and Chique-Chique are excavated along the strike of the softer upper beds of the eastern wing of this fold, laying bare a group of harder quartzitic and conglomeratic beds that occur near the middle of the series. The most prominent member of this group is a thick bed of coarse conglomerate that is diamond-bearing, and in consequence of the topographic disposition of the strata, the entire serra front from Lençoes to Chique-Chique is marked by an almost continuous line of active or abandoned diamond-washings.

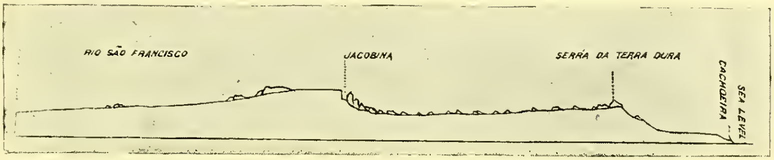

FIG. 6.—Profile of the route from the São Francisco to Bahia, by Mr. J. A. Allen.

Over the top of the plateau, which, as already stated, has a mean elevation of 1,000^{m} or more, the sandstone sheet is much broken up into detached blocks, as shown in the annexed outlines traced from photographs, and in the view of the town of Santa Isabel which I owe to Dr. Henry Furniss, United States consul at Bahia. The escarped margins of these blocks, and other phenomena in the district, are at times suggestive of faulting, but, however important this may have been in determining minor features, it is evident that the main tectonic features of the region have been produced by folding and denudation.

The sandstone sheet, estimated to be from 400 to 500^m thick, consists of a lower flaggy, reddish portion, well seen in the blocklike hills about Santa Isabel, succeeded by a coarse conglomerate that passes to a whitish sandstone with scattered pebbles and patches, and layers of conglomerate, and finally to argillaceous sandstones and sandy shales. The conglomerate, where seen in contact with the lower red sandstone, contains large fragments of this rock that indicate a time-break and unconformability, at least of overlap, between the two. Some of the sandstone layers next to the conglomerate are very hard and quartzitic, but in general both members of the series are unmetamorphosed. The lower member may take the name of the Paraguassú group, as it is especially well developed in the vicinity of Santa Isabel (or São João) do Paraguassú. The upper member may appropriately be denominated the Lavras group, as its conglomerate member is undoubtedly the principal, if not the only, repository of the diamonds that have given the popular name of Lavras ("Washings") to the whole district. The thickness of the Paraguassú group can be estimated with approximate accuracy at about 250^m; that of the Lavras group cannot be so closely calculated, but it is probably about the same.

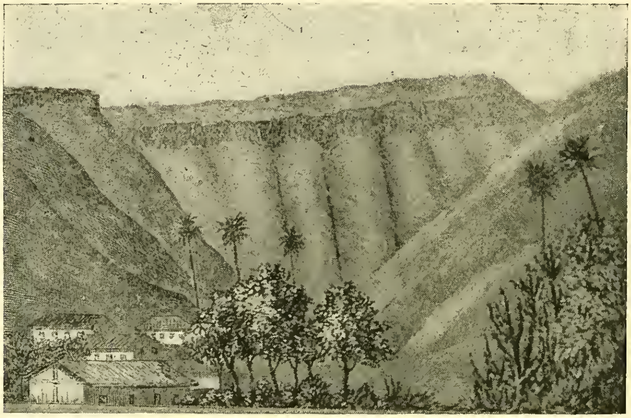

Fig. 7.—The Tombador (Tumble Down) near Jacobina, by Mr. J. A. Allen.

With the exception of the sandstone blocks above mentioned, the pebbles of the conglomerate, seen by the thousands in hundreds of square meters of clean-cut fractures passing through them, are exclusively of quartzite. These represent an older formation, to be mentioned farther on, which is known to occur in other sections of the Serra do Espinhaço and which may be presumed to occur also in the Paraguassú section to the westward of the region here described. The central portion of the range in this section and the country to the westward are very imperfectly known, but the recurrence of diamond camps justifies the presumption that the Lavras conglomerate recurs frequently, through folding, over a great part of it. The westernmost of these camps is in the Serra de Assuruá, a detached mountain ridge near the river São Francisco. Burton (20), who visited it, mentions the occurrence of a coarse conglomerate, which he compared to the Old Red Sandstone of Scotland.

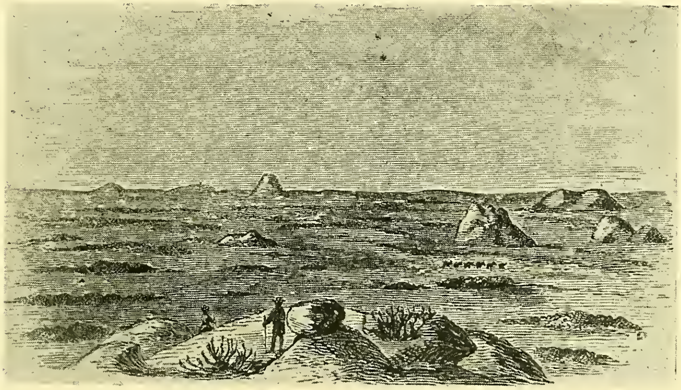

FIG. 8.—View on the gneiss plain of Bahia, by Mr. J. A. Allen.

Another section, intermediate between the two above described, across the range and the adjacent country on each side, is given in an interesting note by Mr. J. A. Allen, published in Hartt's *Geology and Physical Geography of Brazil.* Mr. Allen's route was from Chique-Chique on the São Francisco to Bahia, passing by Jacobina, and thus about 100 kilometers to the southward of the first railroad line above described. His profile of the route and sketches of characteristic line of travel as being essentially over three distinct plateau regions, a limestone plateau to the westward, a sandstone one in the central or Serra do Espinhaço region, and a gneiss one to the eastward. The last presents a remarkably level aspect, being apparently everywhere of nearly uniform altitude, but is dotted with isolated, abruptly rising points and knobs, as shown in the annexed sketch. The soil-cap is thin, and often entirely absent, over areas of several acres in extent.[1] In the serra zone a horizontal sandstone gives rise to a beautiful level, grassy plain occupying the summit of the watershed. To the eastward this table-land breaks down abruptly in precipitous cliffs, to the lower gneiss country, but to the westward the slope is more gradual to the limestone plain, and across this to the São Francisco. Above the generally level surface of the latter rise irregular pinnacled hummucks and low serras. The limestone is highly inclined, and in one place was seen lying unconformably under horizontal beds of sandstone that stretched away southward like a vast level floor. Near the western base of the serra two large hills of hornstone or chert were crossed.

From the general topographic features of the Serra do Espinhaço zone it would be natural to assume that the sandstone sheet of the Jacobina region should be considered as the northern prolongation of that of the upper Paraguassú district, which, with its characteristic diamond contents, certainly extends northward as far as Morro do Chapeo, or about two-thirds of the intervening distance between Lençoes and Jacobina. In this case it has remained unfolded in the northern end of the zone—a seemingly improbable hypothesis; or the evidences of folding escaped Mr. Allen's observation, which also seems unlikely, as his sketch confirms his description. Moreover, unfolded sandstones occur in the region at no greater distance away than those of Lençoes, as shown in the annexed sketch by Dr. Theodoro Sampaio of a table-topped ridge, $750\pm^{m}$ high, above

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[1] Mr Allen describes singular holes in the rocks of this region, which are usually filled with water and known as *caldeirôes* ("pot-holes"), and states that nearly all of a considerable number examined prove to be genuine pot-holes, some of which were of great size. These are probably of the same nature as the caverns, looking like gigantic swallows' nests in a clay bank, seen on the granite knobs along the Bahia Central Railroad. So far as could be judged from distance, these are due to a peculiarly localized action of disintegration. Those seen, however, were on the sides of hills and would not hold water.

Joazeiro and close to the São Francisco, and which he informs me is composed of horizontal beds of sandstone and conglomerate overlying inclined quartzite. The topographical features and the elevation of this ridge, as of others in the vicinity, are suggestive of the Cretaceous plateaus of the lower São Francisco and of the states of Ceará and Piauhy, and there is nothing improbable in the hypothesis that these (coming from Piauhy) extend into this region. This hypothesis would become a certainty if one could accept unreservedly the statement of M. Liais (21) that at a place called Engenho, somewhere near the western base of the Jacobina serra, he found nodules of argillaceous limestone containing scales of *Lepidotus*, a ganoid tooth, and gasteropod shells which he identified as *Paludina* and *Planorbis*. These fossils, with the exception of the shells, are very suggestive of those of the fish-bed of Ceará, which have been carried far and wide over the country, and in part probably over this very road. On the other hand, experience elsewhere has shown that the statement of this author must be taken with caution. Still there is no inherent improbability in the hypothesis that the fossils may have been found *in situ* as stated.

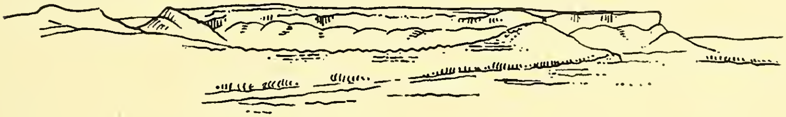

FIG. 9.—Serra do Encaibro (Ridge Pole), seen from the river São Francisco.

In the region to the west of the serra Mr. Allen seems to have generalized his observations on inclined limestones to all of those seen along the road. It is certain that horizontal beds of limestone like that above mentioned in the vicinity of Joazeiro occurs at and about Chique-Chique, and, as in other parts of the São Francisco basin, it is probable that both horizontal and inclined limestones occur among the older rocks. The chert-strewn hills are suggestive of the series to the east of the serra in the Paraguassú basin.

Another line of travel across the Serra do Espinhaço region in the state of Bahia lies to the southward of the Paraguassú route above described, and passes by Maracás, Sincorá, Villa do Rio de Contas, Caetité, and Monte Alto, to Caranhanha on the river São Francisco.

Some interesting information regarding the topographic and geologic features of this route can be gathered from the narrative of Spix and Martius (3), and from the report of Dr. Theodoro Sampaio (22). The road, starting from São Felix, is for some distance nearly coincident with the railroad line above described, and over a gneiss plain of moderate elevation. It then rises to the top of a higher gneiss and granite plateau at Maracás, at an elevation of about 1,000^m, that occupies the watershed between the rivers Paraguassú and Rio de Contas. This plateau, according to Dr. Sampaio, breaks down to the westward in a wall-like face about 350^m high which overlooks an undulating region with detached hills that intervenes between it and the Serra do Sincorá, the eastern front of the Serra do Espinhaço plateau. This region is also composed mainly of gneiss and granite, but about the headwaters of the Rio Una a zone of reddish shale and ash-colored limestone intervenes between the crystalline rocks and the sandstone and conglomerate of the Serra do Sincorá. The Serra do Espinhaço section of the road, extending from the south end of the Serra do Sincorá to beyond Caetité, is mainly over a highly inclined series of quartzites and argillaceous schists, which Spix and Martius identified with those of the gold districts in Minas Geraes (this region is also auriferous), with occasional exposures of gneiss, micaschist, and granite. To the right of the road, and forming the highest points of the region, these older rocks are overlain by a conglomeritic sandstone, which Spix and Martius referred to the Rothtodtliegende, and which evidently represent spurs and outliers of the sandstone sheet of the adjacent upper Paraguassú basin. The western face of the plateau, known by the local name of "Serra Geral," is abrupt, but of no great altitude (850^m) at the watershed near Caetité, where it is composed of gneiss. To the west of the mountain front the road is over a nearly level plain of truncated granite, gneiss, quartzite, and limestone rocks, but with isolated knobs and ridges rising above the general level.

To the south of the Rio de Contas road to Grão Mogol, in the state of Minas Geraes, a distance of about 300 kilometers, but little is known of the Serra do Espinhaço plateau beyond the fact that diamonds occur in several localities. For the section about the northern headwaters of the Jequetinhonha in the neighborhood of the diamond-mining town of Grão Mogol, Helmreichen (4) has given an excellent description, accompanied by a geological section of his route from the middle Jequetinhonha across the serra to the Rio Verde.[1] According to this description and section, the Serra do Espinhaço is here a broad mountain plateau, which rises abruptly above lower plateaus on either side. The eastern plateau consists of truncated strata of micaceous gneiss and micaschist with, near the foot of the serra, intercallations (outlyers?) of quartzite; the western one, of truncated inclined beds of grauwacke and limestone. The central, or Serra do Espinhaço, plateau consists of an undulating central portion of various schists, including gneiss and quartzite, with patches of granite and hornblende rock, above which rise ridges of quartzite which is frequently conglomeritic,[2] and in which diamonds occur—a circumstance that has given great importance and interest to the locality of Grão Mogol. From specimens that have come to hand, and from information given by two excellent geological observers, Drs. Francisco de Paula Oliveira and L. F. Gonzaga de Campos, it is clear that (as in 1882 I predicted would eventually prove to be the case), (12), the section at Grão Mogol is essentially identical with the one at Diamantina, which will now be considered.

In the neighborhood of Diamantina the range also consists of a broad mountain plateau, with a mean elevation of 1,200 to 1,300^{m}, rising abruptly above lower plateaus on either side. In the one to the eastward truncated strata of gneiss and micaschist, full of quartz veins that are frequently auriferous, have been leveled up to about the 900^{m} line by horizontal beds of soft sandstone which cover an extensive area in the valleys of the Jequetinhonha and its tributary, the Arassuahy, forming table-topped hills and ridges between the valleys which have been cut from 200 to 300^{m} below the level of the plain. Hartt, who visited this region in 1865 (6), correlated these

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[1] This section is along a zigzag line which in part accompanies the strike of the strata. Thus, while it gives a transverse section of the range, it fails to give an accurate idea of the relative width of the different zones.

[2] Helmreichen, following Eschwege, lumped all the quartzites of the region together under the name of "itacolumite," and interpreted the pebbles in the conglomerate as concretions or segregations. For this reason, although he clearly described and figured evidences of unconformability between two distinct series of quartzites, he did not interpret them as such, and thus his otherwise excellent description of the region loses much of its value from a geological point of view.

beds with the Tertiary series of the coast, and cited them as evidence of a general uplift to the amount of about 1,000^{m}. There is, however, no evidence that they are of marine origin, and it seems much more probable that they were deposited in a closed inland basin, which extends for a long distance down the Jequetinhonha valley, but is probably cut off from the lower-lying coast Tertiary series by a high zone of older rocks. In this case the evidence of uplift is given by the depth to which the valleys have been excavated below the surface of these beds, rather than by their elevation above the level of the sea, and its amount (250±^{m}) accords fairly well with that indicated by the coast Tertiary beds themselves.[1] The sandstone beds are often quite thin, and probably nowhere more than 100^{m} thick.

The plateau to the west of the Serra do Espinhaço, with a general elevation of 800 to 900^{m}, also shows truncated folds, but the strata here consist of shales, sandstone, and limestone thickly threaded with quartz veins. Farther west, and near the São Francisco, appear table-lands of horizontal sandstones and shales of about 800^{m} elevation. Silicified dicotyledinous wood occurs in some of these beds, which are presumed to be of Cretaceous age.

The central plateau, or Serra do Espinhaço proper, shows along both flanks of the Diamantina section heavy beds of quartzitic sandstone, which dip sharply to the east on the eastern flank and to the west on the western (11, 12). Over the central part the dips are gentler and more variable, the beds in places being nearly horizontal. Over large areas the sandstone has been completely denuded away, revealing an underlying series of quartzites and argillaceous schists, with in one place a considerable patch of granite. As in the Paraguassú and Grão Mogol sections, there is here abundant evidence

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[1] See Branner (18), who traced the coast Tertiary beds to the summit level of the Bahia and Minas Railroad in the Serra dos Aymores. The altitude is not given, as the railroad levelings were not obtainable, but by my aneroid readings it cannot be much over 200^{m}. Along the Bahia and São Francisco Railroad, as noted above, the Tertiary beds rise to 400^{m}, or a little more; but here the upper portion is of fresh-water origin, and perhaps much later than the lower beds, which correspond better in character with those along the Bahia and Minas line. In the basins of the upper Rio Doce in Minas Geraes, Tieté and Parahyba in São Paulo there are high-lying fresh-water Tertiary basins, with fossils, that seem to correspond with the one above considered.

that the sandstone is the source of the diamonds that characterize the region. A number of the workings are in decomposed conglomeritic portions of the sandstone sheet, and at Grão Mogol diamonds have been found in the sound rock as well.

The southern section of the range, forming the head of the Rio Doce basin, being in a region of very abundant rainfall, is much more deeply eroded than those above described, and along the usual lines of travel, which are parallel to its trend or cross it in deep gaps, its tectonic features are not clearly apparent. The central zone is occupied by great ridges, or blocks, of quartzites, or quartzitic sandstone, rising to an elevation of 1,500 to 1,900^{m}, and which, being comparatively barren of gold and of difficult access, are almost completely unexplored. These seem to represent a great sheet like that of the Jequetinhonha and Paraguassú sections, which on the lower grounds has been completely swept away, or so denuded as to be difficultly recognizable, especially as a very similar rock occurs as a member of the underlying formation. The latter consists of a great series of essentially argillaceous and micaceous schists, with intercallations of flaggy micaceous quartzites, ferruginous quartzites (itabirites), and limestones, which is frequently gold-bearing. In the bottom of some of the valleys gneiss, micaschist, and granite appear, and these are the predominant rocks in the region to the eastward of the serra, which is, however, so imperfectly known that the eastern margin of the Serra do Espinhaço zone cannot be satisfactorily traced. The western margin, as in the Jequetinhanha section, is abrupt and overlooks a similar region of truncated sedimentary rocks, which, however, throughout a considerable part of the section is separated from the base of the serra by a zone of granite and gneiss.

From the above sketch it appears that the Serra do Espinhaço consists of a basement complex of metamorphic and eruptive rocks overlain unconformably by one or more series of sandstone strata that have been disturbed by a system of northward-trending folds, whereas in the mountainous region of southeastern Brazil, of which it is an offset, the dominant trend is northeastward. In the southern sections (Jequetinhonha and Doce) the orographic movement producing the folds has also produced a certain amount of metamorphism in the form of shearing and granulation, accompanied by the development of mica, giving the rock an appearance so similar to that of the quartzite members of the underlying metamorphic series that the two have been very generally confounded under the name of "itacolumite." In these sections, however, outcrops occur, as in the neighborhood of Diamantina, in which the rock is a typical unmetamorphosed sandstone or conglomerate; and it is now clear that metamorphism, when it exists, is a local, not a general, characteristic.

Regarding the age of the Espinhaço uplift, and of the beds affected by it, no satisfactory evidence is at hand, as thus far no fossils have been found in these beds, or in others whose relations to them have been clearly established. Up to the present all writers who have treated of the region, myself included, have considered it to be very ancient, Archean or early Palæozoic. This opinion was based largely on the metamorphism of the rocks in the Diamantina and Ouro Preto districts, and, in my own case, partly on the fact that in other parts of Brazil the epoch of folding and metamorphism on a large scale could be proven by fossil evidence to be pre-Devonian. Both of these arguments are evidently weak, and must now be put aside in view of the unmetamorphosed and comparatively modern aspect of the folded rocks of the Bahia section of the Serra do Espinhaço, and of the possibility of local disturbances affecting rock of Devonian or later age. In the coast regions of the states of Bahia, Sergipe, and Alagoas there are evidences of such disturbances which have some bearing on the question here considered.

On the lower Rio Pardo, Hartt (6) found a series of inclined conglomerates, sandstones, and shales, with obscure plant remains which he referred to the Devonian, and noted indications of the presence of the same series on the lower Jequetinhonha as well. In a recent excursion in this region I found that this series occupies a zone several kilometers wide, and was informed that to the westward there is a considerable zone of limestone (marble). Owing to the high state of the river, I missed seeing the fossil locality. The conglomerate also occurs at Salobro, about a league distant from the margin of the Rio Pardo, and here it is diamond-bearing (the so-called Cannavieiras diamond district), presenting considerable resemblance to the diamantiferous conglomerate of the upper Paraguassú region. The occurrence of this series on the Jequetinhonha was confirmed by Dr. Joaquim Bahiana, a competent geological observer, and it evidently occupies a considerable belt along the eastern margin of the gneiss plateau. Branner (17) has described a similar fringe of presumably Palæozoic strata in the states of Sergipe and Alagoas, and I have seen traces of it to the northward of the city of Bahia in the neighborhood of Inhambupe. The fossils reported by Hartt were fragmentary and unsatisfactory, and his reference of them to the Devonian can only be considered as provisional. It is highly probable, however, that the series is Palæozoic, and certainly not older than the Devonian. On the other hand, the uplifted strata (consisting of conglomerates, sandstones, shales, and limestones) of Sergipe and Alagoas are certainly pre-Cretaceous.

The limestones of the upper São Francisco basin appear to represent, as Eschwege (2) has already indicated, two distinct geological formations which have not yet been discriminated. A part of them is certainly included in a disturbed series of sandstones and shales which is almost certain early Palæozoic and presumably older than the Espinhaço uplift; another part lies horizontally, at least in places, and is presumably newer. At Bom Jesus da Lapa, on the right bank of the São Francisco and almost due west from Rio de Contas, I found, in 1880 (8, 9, 10), badly preserved fossil corals of the genera *Favosites* and *Chaetetes* (?), which indicate middle or upper Palæozoic age (Upper Silurian to Permian). Possibly this limestone can be correlated with that above described to the east of the serra, but nothing definite can be said on this head. If, as above suggested as possible, the sandstone of the Jacobina region proves to be folded and of Cretaceous age, the question of the age of the uplift would be decided as Cretaceous or post-Cretaceous; but it hardly seems probable that this will prove to be the case.

The rocks entering into the composition of the Serra do Espinhaço fall naturally into three groups, each of which will probably eventually have to be subdivided into two or more. These are: (1) the gneisses and micaschists; (2) the schists, quartzites, and limestones of the auriferous regions; and (3) the quartzites and sandstones of the diamantiferous regions. With these are associated granites and other eruptives which apparently have not penetrated into the upper series and presumably antedate it.

As Eschwege has already remarked, gneiss and micaschist only appear in the lower levels of the Serra do Espinhaço zone, while, with their associated eruptives, they form the main mass of the mountains to the eastward and southward belonging to the Serra do Mar and Serra da Mantiqueira systems. These rocks have been but little studied in the region here discussed, but, so far as known, they correspond with those of the other parts of Brazil, and can safely be considered as of Archean age. It also seems tolerably safe to consider the great majority of the Brazilian gneisses (at least those that from their resistance to decay are most in evidence) as sheared eruptives, the original types being granites, norites, diorites, etc. A part of the micaschists are also of eruptive origin, but presumably the larger part will prove to be metamorphosed sedimentaries. In the part of Brazil here considered these rocks form a great shield-shaped area in eastern Minas Geraes and Bahia (with the adjacent states of Espirito Santo and Rio de Janeiro), which for the most part has been dry land since Archean times. About its borders, particularly on the west, and over its lower-lying portions the later sedimentary deposits have been laid down.

The schistose series of the Serra do Espinhaço and adjacent regions, which may conveniently be denominated the *Minas series*, consists of a great complex of predominantly argillaceous schists, with subordinate masses of ordinary quartzites, ferruginous quartzites (itabirites passing to pure iron ores), and limestones. All of these rocks are greatly sheared, and characterized by a greater or less development of a mica-like mineral (biotite, sericite, micaceous hemetite, chlorite, talc, etc.); and as in general they are much decomposed, there is great difficulty in distinguishing the different members (except the quartzose and ferruginous ones), and thus far no successful attempt to work out the order of succession in them has been made. It is tolerably certain that the quartzose, ferruginose, and calcareous members are repeated at various horizons, and eventually they will serve as reference lines for establishing the subdivisions of the series; but before this can be done the repetition due to folding and faulting must be determined and taken into account. Apparently the whole series has been bent into closely appressed overturned folds, and doubtless it has been much faulted. Until the region, or at least a typical portion of it, has been accurately mapped, any attempt to determine its detailed structure is hopeless.

The argillaceous members of the Minas series include micaceous (mainly, if not exclusively, sericitic) schists, calc schists, graphitic schists, chloritic schists, and talc schists. A considerable part, if not the whole, of the last two types consists of undoubtedly sheared and metamorphosed eruptives, and I have elsewhere attempted to show (13, 14) that a part of the sericitic schists are of the same origin.[1] There can be no doubt, however, that the greater part of the series is of sedimentary origin. Its age can only be guessed at, but it seems tolerably certain that it cannot be younger than Cambrian, and that it may be older.

The Minas series has always been regarded as the characteristic formation of the Serra do Espinhaço, and it is certain that it, or another series very like it, appears throughout the entire length of the range. To the northward of the Rio Doce section the characteristic ferruginous and calcareous members seem to disappear in the zone of the serra, though they occur again on the banks of the São Francisco between Urubú and Joazeiro. It seems probable, therefore, that more than one geological series is here included. It is also certain that these characteristic members occur on both sides of the Rio Dòce section at considerable distances from the reputed margins of the Serra do Espinhaço zone, and with indications of folds with a northeasterly trend, and thus parallel with the neighboring Archean ranges. It seems probable, therefore, that their first and strongest folding was due to a movement producing northeast-trending folds, and presumably involving the shale, sandstone, and limestone series of the São Francisco basin as well. The occurrence farther southward in the Paraná basin of a series very similar to this last, and which has been involved in the northeast folds of the adjacent Archean region, confirms this point of view. These rocks of the Paraná basin, like those of the São Francisco, are in general but slightly metamorphosed and are overlain, in the state of Paraná, by horizontal strata containing Devonian fossils (15). Though they

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[1] Since the above-cited papers were written, a specimen has come to hand showing one of the types there discussed (the monazite-bearing schist of Sao João da Chapada), with a well-defined eruptive contact with quartzite.

have afforded no fossils, they are presumed to be of Cambrian or Silurian age.

This sedimentary series of the Paraná basin is abundantly injected with granite, which, for this region at least, fixes the age of the granitic eruptions as pre-Devonian. The granites are of various types (hornblendic, biotitic, and muscovitic), and doubtless several periods of eruption are represented among them, but presumably these were contemporaneous with, or posterior to, the orogenetic movements that produced the folding. The granites that occur quite abundantly in the areas occupied by the Minas series have not been studied, but it may be presumed that the above conclusions regarding age and periods of eruption will apply to them as well. Aside from the granites, these areas present frequent outcrops of basic eruptives of gabbroitic, diabasic, and peridotitic types, which, so far as observed, show signs of metamorphism (a certain amount of shearing and an uralitic alteration of the pyroxene), which may plausibly be attributed to the later movement of upheaval that involved the overlying sandstone as well. So far as observed, this last has not been affected by eruptive injections, nor do the auriferous veins so characteristic of the Minas series extend into it.

The sandstone capping of the Serra do Espinhaço zone presents, everywhere that it has been examined, great uniformity of aspect, except that the division into two series noted in the Paraguassú section has not been observed elsewhere. The conglomeritic character of the upper beds of this section is general throughout the range, and although in the Jequetinhonha and Doce sections the rock is in places somewhat metamorphosed, this apparently is not a sufficient reason for considering it as distinct. Another very general characteristic is the occurrence of diamonds, but these appear to be lacking, at least in workable quantities, in the extreme southern portion of the range in the vicinity of Ouro Preto, and also in the northern portion in the Jacobina region and beyond.[1] As already stated, there are reasons for suspecting that the Jacobina sandstone is more recent than that of the more southern portions of the range, but on this head nothing definite can be said. As to whether, with this

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[1] The question of the mode of occurrence of the diamond in this range and other parts of Brazil will be discussed elsewhere.

exception and that of the lower beds of the Paraguassú region, the sandstones of the range are to be considered as constituting a geological unit, or not, must also remain in doubt, though I am personally inclined to an affirmative opinion.

The geological age of the characteristic rocks of the Serra do Espinhaço zone, and of the orogenetic movement that has given them their present attitude, must also remain in doubt. The most that can be said is that neither is as ancient as has hitherto been supposed, and apparently the Devonian can be taken as the extreme limit of age. This, however, includes the hypothesis, not in itself improbable, of a localization of the orogenetic movement, since the definitely known Devonian deposits of other parts of Brazil (in the states of Paraná, Matto Grosso, and Pará) were not affected by it. The other extreme age limit is the Cretaceous, but until the Jacobina section is examined, and the reputed find of fossils verified or disproved, this hypothesis can neither be accepted nor completely put aside. The hypothesis of a Mesozoic age (Cretaceous or pre-Cretaceous) is a seductive one, as this would bring into line, at least as regards age, the occurrences of the diamond in various parts of Brazil and in South Africa (17); but against this we have the assumed, though not definitely proven, relation of the horizontal limestones of the São Francisco valley and of the Rio Una, which, for the present at least, must be regarded as Palæozoic and newer than the Espinhaço uplift. All things considered, it seems to me most probable that the age, both of the rocks and of the uplift, will eventually prove to be the middle or late Palæozoic (Devonian to Permian).

The escarped margins of the Serra do Espinhaço zone is in many places very suggestive of faulting, and I was until recently inclined to admit the existence of fault lines of gigantic proportions. With a better knowledge of the adjacent regions, it seems probable that this feature may be due in great part to denudation under conditions of drainage and elevation different from the present ones. The range throughout a considerable portion of its length is bordered by well-defined denudation plains, some of which, as that of Joazeiro, are but slightly sculptured, while others are dissected by valleys excavated from 200 to 300^{m} below the general level. In the region of the middle Jequetinhonha the conditions at one time, probably during a part of the Tertiary age, were such that an inland basin was filled up with horizontal deposits nearly to the level of the surrounding denudation plain, and later, through a rise in the land, both were dissected to a depth of 200 to 300^{m}. About the same amount of elevation is indicated by the coast Tertiary beds, by the Cretaceous strata near the Paulo Affonso cataract, and by the dissection of the denudation plain and horizontal Cretaceous (?) strata of the upper São Francisco basin; so that this movement may be taken to have been general and of approximately equal amount throughout the whole region. The Cretaceous strata of the Paulo Affonso region seems to have been laid down on a still older denudation plain, which must have stood at about the level of the sea, since the fauna contains a mixture of fresh-water and marine forms (cyprids and sharks). The denudation of the mountain zone was therefore effected by successive stages, and under different conditions of drainage and elevation; and to this circumstance are doubtless due many of its topographic characteristics.

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THE VARIATIONS OF GLACIERS. XI[1]

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The following is a summary of the *Tenth Annual Report* of the International Committee on Glaciers.[2]

REPORT ON GLACIERS FOR 1904

Swiss Alps.—Of the ninety glaciers under observation in Switzerland, seventy-three were measured in 1904. Five are uncertain, and the others are retreating or are stationary; none are surely advancing. We therefore see that there is a still greater tendency to retreat this year than last. The temperature in 1904 was markedly above the normal, and this undoubtedly had some influence on the retreat of the glaciers.[3]

Eastern Alps.—The tendency to retreat is nearly everywhere noted. Of fifty-one glaciers observed, forty-four are retreating and only four actually advancing. Here also we find an increased tendency of the glaciers to recede. In the Ortler group the Duldenferner has advanced 11 meters since last year, but the others have been retreating at the rate of from 3 to 10 meters a year. The Fürkeleferner has been retreating much faster, namely, 31.7 meters per year since 1899. In the Oetztal the retreat is also general at the rate of from 10 to 20 meters per year. The Mittelbergferner has retreated 119 meters since last year; the year before that its retreat was 83 meters. The Mitterkarferner has advanced 3.3 meters per year since 1901. The Vernagtferner is about stationary, but its rate of motion has diminished, and a retreat will probably be reported soon. The velocity of the Guslarferner has also diminished. On the other hand, the motion of the Hintereisferner has slightly increased, but the end has retreated 20.6 meters since last year. All the glaciers of the Stubaï group are retreating from

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[1] The earlier reports appeared in the *Journal of Geology*, Vols. III–XIII.

[2] *Archives des sciences physiques et naturelles* (Geneva, 1905), Vol. XX, pp. 62–74, 169–90.

[3] Report of Professor Forel and M. Muret.

3 to 10 meters per year. The Gliederferner, in the Zillertal, has advanced 34 meters since 1899 and has formed a moraine in front; its motion is a third less than it was from 1897 to 1899, during which time it advanced 36 meters; the very end is still swollen, but the rest of the glacier is thinner than normal. The other glaciers of this group are retreating or are stationary. The glaciers of the Venediger group are all retreating at rates varying from 0 to 22 meters per year. The Grosselendkees in the Ankogel group has advanced 1.4 meters since 1903. The other glaciers of this group and those of the Glockner are retreating.[1]

Italian Alps.—The snow-fields of the Cavallo, which were reported as having increased considerably in 1903, were found in 1904 to have diminished very much. The glaciers on the south side of Monte Rosa seem to be advancing, but they have not yet reached their limits of 1901. In the Graian Alps there is evidence of a considerable diminution of the glaciers. The glaciers on the south side of Mont Blanc are in general retreating, and in some cases markedly. The glacier des Jorasses, which has been retreating, shows evidence of an approaching advance. The general result regarding the Italian glaciers of Mont Blanc is that the phase of retreat is about finished, and that the thickening which began in the upper reservoirs is now approaching the ends and about to cause an advance. The snowfall in the higher regions has been very heavy.[2]

French Alps.—A careful study of the glacier Noir and the glacier Blanc has been made and maps prepared on the scale of 1/10,000.[3] These two glaciers, which are very near together have shown striking differences in their behavior. The glacier Noir has been retreating steadily since 1860; and the glacier Blanc, on the other hand, retreated from 1865 to 1886, but advanced between 1889 and 1896; since then it has been retreating. It occupies a very high reservoir, 3,000 to 3,300 meters in altitude, and has a very clean surface. The increased precipitation which occurred toward the end of the nineteenth century caused it to advance. The glacier Noir, on the other hand, lies, for its

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[1] Report of Dr. H. Angerer.

[2] Report of Dr. F. Porro.

[3] Charles Jacob and George Flusin, "Étude sur le Glacier Noir et le Glacier Blanc," *Annuaire de la Société des Touristes du Dauphiné*, 1905.

greater part, in a deep valley, and has been much affected by the warm weather, and has consequently retreated.

Professor Kilian[1] has published a short account of the glaciers of the Dauphiné, in which he concludes that there is a general tendency toward the diminution of these glaciers, and he thinks that a number of them will disappear before long; some of the smaller ones have already disappeared.

All the glaciers of Savoy which have been observed are retreating, and some of the small ones have disappeared. The same statement applies to the glaciers of the Pyrenees, with the exception of one, the Pai Bache, which has increased since 1883, but seems now to be retreating.[2]

Norway.—In the Jotunheim region twenty glaciers were found to be retreating and four advancing. In the Jostedal four are retreating and two advancing; whereas in the Folgenfon the three glaciers observed were all advancing. There seems to have been considerable difference in the snowfall in the different regions, but it does not seem to correspond to the changes in the glaciers.[3]

Sweden.—The Mika glacier was found to have advanced from 7 to 10 meters between 1902 and 1904.

Greenland.—The glacier of Jakobshavn has undergone many changes in its water front; sometimes a portion of the front has advanced, and then again, as a result of the calving of the ice, it has been cut back; but, on the whole, since 1902 the central parts of the end retreated nearly 400 meters, and the sides about 210 meters. The glacier has also diminished in thickness about 16 meters near the side. Other small glaciers show a slight retreat.[4]

Russia.—A large number of glaciers have been visited in the Caucasus, and they all seem to be retreating; but some of them show a swelling in their middle courses, which may cause an advance before long. In the Pamir there are many small glaciers, some of which have been advancing in the last few years.[5]

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[1] *Les Glaciers du Dauphiné* (Grenoble, 1904).

[2] Report of M. W. Kilian.

[3] Report of M. P. A. Oyen.

[4] Report of M. K. J. V. Steenstrup.

[5] Report of Colonel J. de Schokalsky.

South America.—Dr. Benrath has collected some observations of the glaciers in the Coast Cordillera of Peru, which show that they have been retreating for the last twenty-five years; and the bare condition of the ground in front of the ice shows that this retreat has existed for a still longer period. The existence of extensive moraines at some distance from the glaciers indicate a former glacial period in this region (12° south latitude).

Captain Crosthwait states that most of the larger glaciers seen by him during a trip through the straits of the southern end of Patagonia showed signs of shrinkage.

Africa.—The crater of Kibo, Mount Kilimandjaro, was visited by Dr. Uhlig in 1901 and 1904. In the former year the crater contained more snow and ice than at the time of Dr. Meyer's visit in 1898, but the snow did not extend to as low a level on the slopes of the mountain; and this was after a very dry season. In 1904, on the contrary, after a season of unusually heavy precipitation, there was less snow and ice in the crater of Kibo than has been reported at any earlier period.

Canada.—A very interesting account of the glaciers of Canada has been given by Miss Ogilvie.[1] She divides them into three groups: First, those of the central and eastern Rockies which, in general, lie in very deep valleys surrounded by nearly vertical cliffs, and are fed by avalanches from the slopes, or from the hanging glaciers above; that is, they are débris glaciers. Their whole course is practically below the snow-line, and they are covered very completely with rubbish, so that for a large part of their surface the ice is entirely invisible. Of this group the Victoria glacier has retreated but little. The glacier of the Ten Peaks valley is advancing. The glacier of the Consolation valley was but slightly shorter than at the time of its recent maximum extension, and the other glaciers of this group are probably in the same general condition. The second group of glaciers, which lie in the western Rockies and Selkirks, are practically like the ordinary valley glaciers of Switzerland, except that they are, as a rule, broader and shorter. The moraines are practically similar to the moraines of the Swiss glaciers. Of this group the Wapta shows a recent rapid retreat. The Illecillewaet, the Asulkan, the Geikie, and the Deville glaciers are all

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[1] The Effect of Super-glacial Débris on the Advance and Retreat of Some Canadian Glaciers," *Journal of Geology*, Vol. XII (1904), pp. 722–43.

in rapid retreat. Of a third class of glaciers, intermediate between the other two, one is advancing and the other retreating.

Messrs. Vaux have continued their observations of some of the Canadian glaciers as follows:

There is evidence of a continued retreat of the Victoria glacier, at about the rate of previous years. The Illecillewaet continues to recede, the tongue being 5 feet behind the location of last year. This recession is much less than that noted for several years past. The glacier continues to decrease in thickness and width. The slight advance of the Asulkan glacier, noted the last three years, appears to have ceased, and in 1904 the tongue was 11 feet below the range line of 1899, showing a recession of 5 feet since 1903. Changes in the form of the glacier appear slight. The Yoho glacier is evidently retreating and decreasing in thickness. It was last visited in 1901; since that date the tongue has receded 89 feet, or on an average of 29⅔ feet per year. A very splendid ice-arch on the right side of the glacier was one of the notable features last summer.

REPORT OF THE GLACIERS OF THE UNITED STATES FOR 1905.[1]

Professor U. S. Grant has visited the glaciers of Prince William Sound, Alaska, and reports various changes in them. The Shoup glacier lies in the neighborhood of Valdez; two large rocks are being exposed by the retreat of the glacier which were not visible four years ago; along the sides there is a broad space of bare ground free of soil and vegetation, and the whole aspect of the glacier indicates that it is retreating. Photographs were obtained from fixed points which will be useful in determining future changes. The western part of Columbia glacier—i. e., the part west of Heather Island—is rapidly discharging, and presents apparently the same appearance as when visited by the Harriman Expedition. At the north end of the small island north of Heather Island, on which the front of the glacier is resting, and where a few years ago the glacier had intruded and overturned the front of a forest, a photograph was obtained from the same position as one taken by Mr. Gilbert in 1899. At this point the front of the ice has retreated 160 feet since 1899. On the ground since vacated by the

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[1] A synopsis of this report will appear in the *Eleventh Annual Report* of the International Committee. A report of the glaciers of the United States for 1904 was given in this *Journal*, Vol. XIII, pp. 316–18.

glacier, there is very little vegetation—practically nothing except fireweed, which has encroached upon this territory only a few feet. Brooks glacier enters the head of Unakwik Bay. It is formed by the junction of two branches, and comes down to tide water; the front is about a mile and a quarter in width and is actively discharging. As viewed from a distance of about a mile, trees and bushes are seen to come down to the ice, and there is no zone, or a very narrow one, between the ice and the vegetation. The extreme front of Barry glacier, Port Wells, has retreated at least a mile since 1899. The long point which projected into Doran Strait for nearly two miles has entirely disappeared, and the front is now nearly straight across. The little tongue of ice which lay along the east side of the glacier has also disappeared. Photographs and sketches of the front of the glacier were obtained to show its exact position in 1905.

Photographs and observations were made of a number of the smaller glaciers and all seem to be in retreat. Several of these have been observed for the first time, and the data obtained will serve as a basis for future changes.

A short account of the glaciers of the Wrangell Mountians, with a map showing their locations, is contained in Mr. W. E. Mendenhall's "Geology of the Central Copper River Region," Alaska.[1] Some of the glaciers are 30 and 40 miles long. Those of the west slope are smaller than those flowing in other directions, which is ascribed to the volcanic heat of the rocks. The glaciers were at one time much larger than they are now, but no information is given regarding recent changes.

The Yakutat Bay glaciers were especially studied last summer by Professor Tarr and Mr. Martin,[2] and the positions of the glaciers compared with their positions as noted by Professor Russell in 1891, and by the Harriman expedition in 1899. The Turner glacier, which reaches the sea in Disenchantment Bay, indicated a general recession between 1891 and 1899, and a slight advance on the sides between 1895 and 1905 with a recession in the center. The northwestern half of Hubbard glacier has also advanced in the last six

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[1] U. S. Geological Survey, *Professional Paper No. 41.*

[2] "Glaciers and Glaciation of Yakutat Bay," *Bulletin of the American Geological Society,* Vol. XXXVIII, pp. 145–67.

years, though the amount could not be determined; there is no definite evidence of advance in the southern side of the glacier. One of the Indians who accompanied the expedition was confident that the Hubbard had been advancing for the last ten or twelve years, but this idea does not seem to be well supported by the maps. The Nunatak glacier ends in tide-water with a short arm resting on the land, separated from the main stream by a rocky knoll, which was completely surrounded by the ice when visited by Professor Russell in 1891. Comparison of Mr. Gilbert's photograph of 1889 with one taken in 1905 shows that the tide-water front has retreated almost a mile. The arm resting on the land has also shortened from 200 to 400 yards, so that the knoll is now not more than half surrounded by the ice. The Hidden glacier ends some distance from tide-water on a gravel deposit which in places is underlain with ice. The photographs show that this glacier has retreated about one-quarter of a mile. The Cascading glacier near the Nunatak is retreating, as are also many other small glaciers which were examined by Messrs. Tarr and Martin. One remarkable glacier on the west side of Disenchantment Bay, whose end is about 1,000 feet above the water, slid out of its bed and was precipitated into the bay on July 4, the day after it had been photographed. The glacial gravels in this region were especially studied, and the late glacial history there corresponds very closely with that made out for Glacier Bay. The great earthquake of September, 1889, which appears to have been central in the neighborhood of Yakutat Bay, and which made a number of faults in that region, has not left any marked changes in the glaciers such as have been observed in Glacier Bay. It is possible that the breaks caused by the earthquake have been made up since.

Not very much information has been received regarding Muir glacier, but no changes have apparently taken place. The same report is made regarding the Taku glacier, which apparently is not undergoing any special changes; but photographs taken in 1905 reveal a marked advance over the position of the glacier in 1890, as shown by a sketch made that year. Davidson glacier is apparently retreating, but no measures have been made (Davidson). A noticeable recession has taken place in the hanging glaciers in the Chilcat

River Valley between 1898 and 1905, although no measures have been made. The summer of 1905 was unusually warm, and the glacier streams were very much larger than usual (Flemer).

Last summer the Mazama Club of Portland, Oregon made its annual excursion to Mount Rainier. General Howard Stevens, who, with Mr. P. V. Van Trump, made the first ascent of Mount Rainier in 1870, was one of the party. He recognized some marked changes since his former visit. The Paradise glacier has retreated about 800 feet. The snow in the western crater on the summit was at least 40 feet lower than in 1870, and the wind-swept ridge separating the two craters, which was bare in 1870, was covered by a mound of snow 30 feet high in 1905. Mr. Longmire, who has been living near Mount Rainier for the last twenty-five years, thinks the Nisqually glacier has retreated a quarter of a mile in that period (*Mazama Magazine*). Professor J. N. LeConte made some measures of the movement of this glacier, and found a velocity of 22.4 inches per day at a distance of 3,000 feet from the end. He also erected a monument near the end as a station for the determination of future changes.[1] The precipitation in Oregon has been below normal for some years. The record at Portland shows a mean annual precipitation of 46.83 inches; whereas the average for the last six years has only been 35.47 inches. It is not surprising, therefore, that the glaciers observed on the southern side of Mount Hood are retreating; the White glacier is retreating less rapidly than the Zig Zag and the small one to the west (Montgomery). There is no new information regarding the recent variations of the Mount Adams glaciers, but a comparison of photographs taken in 1895 and 1901 shows that the ice at the end of Avalanche glacier, on the west side of the mountain, diminished in thickness at least 25 feet in that interval.

The Sperry and Harrison glaciers, and a small unnamed one on Mount Jackson, Montana, give evidence of a very recent retreat by the terminal moraines which they have deposited a short distance from their present ends, and which are so recent that vegetation has not yet taken hold upon them. (Chaney.)

Judge Henderson measured the movement of the Arapahoe

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[1] His complete article will be published in the new *Zeitschrift für Gletscherkunde* and in the Sierra Club *Bulletin*.

glacier, Colorado, and found a velocity of 27.7 feet from August 30, 1904, to the same day one year later. The glacier continues to shrink along the sides, but has not retreated in the center. The snow-line, which was quite low in 1903 and 1904, has receded nearly to the bergschrund, a change which is not explained by the records in the nearest Weather Bureau stations.[1]

Hallet glacier seems to be a trifle larger than it was a year ago. The snow seems more abundant, showing a curious difference from the Arapahoe glacier near by. (Mills.)

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[1] "Arapahoe Glacier in 1905," *Journal of Geology*, Vol. XIII (1905), p. 156.

CORRELATION OF THE RAISED BEACHES ON THE WEST SIDE OF LAKE MICHIGAN[1]

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CONTENTS

INTRODUCTION

The eastern border of Wisconsin, along the western shore of Lake Michigan and around Green Bay, has long been known to bear the marks of a series of stages of the extinct glacial Great Lakes. Terraces, bluffs, and beach ridges at various altitudes above the present lake were briefly described in 1877 by Dr. T. C. Chamberlin, in his report on the *Geology of Wisconsin.*[2] In the summer of 1893 Mr. F. B. Taylor touched at several points on the Wisconsin shore, in a rapid reconnaissance around the Great Lakes.[3] The highest shore-line discovered by him at Kewaunee, Green Bay, Sturgeon Bay, and northward through the Upper Peninsula of Michigan was found to rise toward the north at a rate of more than a foot per mile, as if due to regional deformation of the extinct water-plane. The Door County peninsula (north of Sturgeon Bay) was not visited; but the early measurements of Chamberlin in a general way confirmed this view. The "highest shore-line" was later identified by Taylor as the beach

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[1] Published with the permisssion of the Director of the Wisconsin Geological and Natural History Survey.

[2] *Geology of Wisconsin,* Survey of 1873–77, Vol. II, pp. 219–28.

[3] "A Reconnaissance of the Ancient Shore Lines of Green Bay," *American Geologist,* Vol. XIII (1894), pp. 315-27; and other papers published in the *American Geologist* the same year.

of Lake Algonquin—a great lake which occupied the Huron, the Michigan, and part of the Superior basins, while the ice formed a dam across low passes to the northeast. In the absence of direct observation south of Kewaunee, the plane of this Algonquin beach was extended by inference so as to pass under the present lake near Two Rivers. Still later observations by Taylor and others, however, pointed to the probability that the shore-lines become horizontal above Lake Huron and Lake Michigan, encircling the southern ends of both.

FIG. 1.—Map of part of the Great Lake region.

In the southeastern part of the state and further south, around the head of Lake Michigan, a series of beaches, studied in detail by Mr. Frank Leverett, Dr. W. C. Alden, and others on the United States

Geological Survey,[1] were taken to mark a local ice-front lake, Lake Chicago. Of these beaches, the highest, about 60 feet above the lake, and a lower one about 40 feet, were not known to extend north of Racine County, Wisconsin, until very recently, when Alden found a terrace near Belgium (a few miles north of Port Washington) which corresponds somewhat closely to the 40-foot plane.

According to Taylor's studies, these beaches seemed to lie wholly above the plane of Lake Algonquin. Lower beaches of Lake Chicago, forming a complex group from 10 to 25 feet above Lake Michigan and called the "Toleston" beaches, had not been traced northward beyond Belgium when the present study was undertaken; and the actual relation between these and the inferred Algonquin plane was doubtful. It was suspected by Leverett, Chamberlin, and others that the lower beaches of the Toleston group (those from 10 to 15 feet above the lake) in the Chicago district might be shore-lines of Lake Algonquin.

In the summer of 1905 opportunity was given the writer by the Wisconsin Geological and Natural History Survey to study the old shore-lines of eastern Wisconsin with these problems of exploration and correlation in mind. Sufficient evidence was collected, it is thought, to show that only the beaches above 40 feet in the Chicago-Sheboygan district belong to a separate Lake Chicago; that the 20–25-foot Toleston beach of the Chicago district is the shore-line of Lake Algonquin; and that the strong 14-foot terraces and ridges of southeastern Wisconsin and northeastern Illinois mark the border of a later stage of importance, known as the stage of the Nipissing great lakes. It is the purpose of this paper to show on what grounds these conclusions were reached.

THE FIELD-WORK

The distance around the shores of Green Bay, from Marinette southward to Green Bay City, and thence northeastward to Washington and Rock Islands, is about 100 miles. From Washington Island southward along the shore of Lake Michigan to the Illinois line is approximately 200 miles. This entire stretch of shore, except

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[1] See *Monograph XXXVIII*, U. S. Geological Survey, "The Illinois Glacial Lobe," by Leverett; and the Chicago Folio, No. 81, with discussion of Lake Chicago by Alden.

for about 20 miles near Milwaukee (part of the area recently covered by Alden), was traversed during the field season, chiefly on foot. Gasoline fishing-boats were used to advantage near the end of Door County Peninsula and on the southeastern shores of Green Bay. South of Sturgeon Bay the traverse was a continuous one, the present shore being followed wherever it has cut back a line of high cliffs beyond the earlier shore-lines, as is very common, and the fragments of abandoned shore-lines being followed from their beginnings, at the lake cliffs, to their endings further along. North of Sturgeon Bay, on the less thickly settled peninsula, the beaches were not followed continuously, but were visited at short intervals of from one-half to five or six miles, wherever they are most accessible and best developed. Although the hand level was used in favorable places, to economize time, such measurements were not regarded as critical. With the spirit or "wye" level accurate profiles of the entire series of beaches were measured at about fifty localities, most of them on the Door County peninsula, where the best records were found. By this means it was possible to correlate the fragments with more than usual con-

FIG. 2.—Boyer Bluff, at the northwestern end of Washington Island. Three steps or notches in the headland mark three important stages of Lake Algonquin.

fidence, and thus to reconstruct the water planes of the extinct lakes.

CHARACTER OF THE RECORD

On the rocky and exposed peninsula north of Sturgeon Bay the shore-lines are developed in conspicuous form. Fig. 2 shows a characteristic headland cut by the waves at successive levels so as to look like a great flight of steps. Heavy beach ridges of cobble stones occur across the bay heads or on shelving shores (see Fig. 3). The record of successive stages is singularly complete in this district, because exposure was great enough to allow each successive water-plane to be registered, while the rocky surface was usually too resistant to allow the shore cliffs of a lower lake stage to be cut back beyond higher shore-lines, and thus to destroy them.

FIG. 3.—Beach ridge of the Nipissing shore-line at Graceport, near Sturgeon Bay. It stands 19 feet above the level of Lake Michigan. On the left, between this beach and the shore of Green Bay, are lower ridges.

South of Sturgeon Bay the expression of the beaches undergoes a marked change, corresponding to the change in the character of the ground. In place of bed-rock at the surface, there are thick red-clay deposits, in part ice-laid and in part water-laid, into which the waves can cut with ease. Consequently the present shore south of Algoma commonly consists of high red-clay cliffs, which are rapidly retreating under the attack of the waves, and have long since eaten away the abandoned shore-lines of higher stages. When fragments are preserved, moreover, they commonly show that the lake at the Nipissing plane (the next important one above the plane of the present lake) cut back beyond the earlier shore-lines of Lake Algonquin and Lake Chicago. The record south of Sturgeon Bay, then, is relatively incomplete, and fragments of the lower stages are more common than those of the higher.

FIG. 4.—Terrace and bluff of Lake Algonquin near Sturgeon Bay, 40 feet above Lake Michigan.

The same is true of the southeastern border of Green Bay. Along the low western shore of Green Bay, on the other hand, deposition of beach ridges has been the rule from the first, so that no cliff recession at the lower stages has here destroyed the record of earlier stages. There is an almost complete series of sandy ridges. But the weakness of expression of these beaches, probably in large measure an original weakness, together with the sandy structure which has permitted the wind to spread and otherwise modify them, makes it somewhat difficult to find enough data for accurate measurements. Nevertheless, enough was found to show that the shore-lines on both sides of Green Bay correspond exactly to those on the Lake Michigan border.

THE ALGONQUIN SHORE-LINES

The systematic variation in altitude of the highest shore-line of Lake Algonquin can be seen by reference to the map. Here the figures mark the altitude of the Algonquin beach or terrace at each locality where it was measured with the spirit level. It is found by experimentation that these points lie closely in harmony with a tilted (or more accurately a warped) plane, on which the direction of steepest ascent is about N. 15° E., and that of no differential uplift is about N. 75° W. On Washington Island the highest Algonquin beach is about 90 feet above Lake Michigan. When followed southward, it is found to decline rather steadily until it is only 40 feet above the lake at Sturgeon Bay (Fig. 4). Throughout this distance it is marked either by a strongly cut terrace or by a well-built ridge of gravel or chip stone. Above it there are no signs of submergence. Below it several other shore-lines can be traced with equal distinctness. They have similar warped attitudes, and represent successive later planes of the lake, determined by repeated uplifts in its northern part.

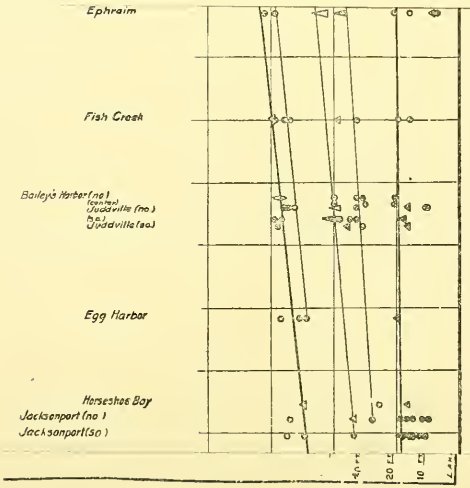
In Fig. 5 the warped planes are drawn in profile in the direction of steepest inclination, N. 15° E. Each ordinate records a spirit-level measurement of the crest of a beach ridge or the base of a cut bluff, according to symbols which are explained in the legend. The vertical scale is 500 times the horizontal, greatly exaggerating the slope of the planes, and proportionately magnifying the discordance of the ordinates. In view of this, and of the chance of discordance due to (*a*) original variation in crest-line of the beaches and terraces, (*b*) the error involved in determining the datum lake-level during days when waves were running high, and (*c*) the error in leveling, which probably amounts to a fraction of a foot, the accordance of ordinates to the inferred planes of the highest Algonquin beach is remarkable. Nearly all the ordinates lie within 3 feet of the plane; and the few which are 5 or 6 feet too high are all of them points which were regarded at the time of their discovery as ridges built up to exceptional height by storm-waves in places of unusual exposure. A great barrier ridge at Egg Harbor, for instance, which was built in 60 feet of water across the head of a bay, has a crest 7 feet higher than the cut terrace from which it tails out. The terrace corresponds closely to the inferred Algonquin plane; and a distant beach ridge lies at the same level just below the top of the barrier embankment. The discordance of this ordinate, like the two or three others, is wholly within expectation.

It is seen that this reconstructed plane slants southward from Washington Island at about 1½ feet per mile to Sturgeon Bay (slightly more in the northern part and less in the southern part), and that it suddenly becomes flatter near Sturgeon Bay and slants southward at the rate of about 8 inches per mile to Two Rivers, where it is nearly, if not quite, horizontal. For long distances south of Sturgeon Bay the Algonquin shore-line has been cut away during later stages; but the extinct flood-plains, now terraces, are found at appropriate heights in most of the stream valleys.

Two lower Algonquin planes, marked on Washington Island and near Death's Door by deeply cut terraces, can be traced southward in a similar way, converging slightly in that direction until at Sturgeon Bay they are so close together as to be difficult to identify separately. Ordinates which lie between the planes and mark weaker beaches suggest short-lived stages of intermediate age. In only one case (plane A′) has an attempt been made to reconstruct these less distinct planes.

THE NIPISSING AND LOWER SHORE-LINES

Below the slanting and diverging Algonquins is a nearly horizontal plane which is marked everywhere, and more strongly than any other (see Fig. 3). From 22 feet above the lake at Washington Island this declines almost imperceptibly to about 16–18 feet at Two Rivers—a drop of only 4 or 6 feet in a distance of about 90 miles. The remarkable strength of this shore-line—usually a high-cut bluff and broad terrace—together with its correspondence in altitude with the Nipissing shore-line traced by Taylor in the northern part of the Great Lake region down to Gladstone and Escanaba (just north of the eastern Wisconsin district), leaves little doubt that it marks the Nipissing plane, a stage of the lakes when both the North Bay outlet and


Ephraim
Fish Creek
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Juddville (so.)
Egg Harbor
Horseshoe Bay
Jacksonport (no.)
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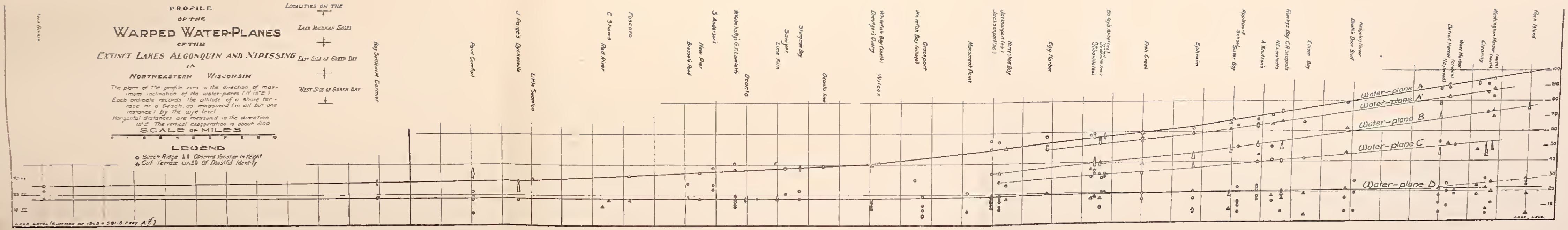

Fig. 5.—Profile of the warped water-planes.

the Port Huron outlet were running. The nearly horizontal position of this plane in eastern Wisconsin indicates clearly that very little deformation has occurred there since Nipissing time.

Below the Nipissing plane are usually several shore-lines which mark more recent stages of the lake, depending upon the deepening and widening of the present outlet. No attempt has been made to reconstruct them; but a 12-foot stage and a 9-foot stage are commonly recorded. These sometimes give rise to confusion regarding the altitude of the real Nipissing plane. Near Algoma, for instance, a very strong red-clay bluff of the Nipissing stage has at its base a terrace which is sometimes 12 and sometimes only 9 feet above Lake Michigan, but usually about 20, showing that the lake, after dropping a few feet below the 20-foot Nipissing level, easily cut back across the broad terrace to the base of the high Nipissing bluff.

EXTENSION OF THE ALGONQUIN AND NIPISSING PLANES SOUTH OF TWO RIVERS

Some difficulty attends the reconstruction of the old water-planes south of Two Rivers, for extensive cliff recession at the Nipissing and the present level has largely obliterated the record. (See Fig. 6.) No trace of a 25-foot beach ridge is seen between Two Rivers and Kenosha. High clay bluffs rise abruptly from the lake to heights above the extinct Algonquin plane, except where for short distances (as at Centerville, between Sheboygan and Port Washington, and at Fox Point) a terrace and bluff of the Nipissing stage has cut farther back into the upland. In most of the stream valleys along this distance there are terraces which mark the adjustment of streams to two and sometimes more high stages of the lake, their heights corresponding closely to the Algonquin and Nipissing planes. At Kenosha there are short remnants of a 25-foot beach ridge, and at Evanston, Ill., a strong beach ridge of the "Toleston" group of beaches of Lake Chicago runs inland at the height of 24 feet, and may be followed with occasional interruption through the Chicago district and around the head of Lake Michigan.

The flattening of the highest Algonquin plane in eastern Wisconsin, going southward toward Two Rivers, strongly suggests that it there becomes essentially horizontal. The presence of a very definite beach ridge at the 25-foot level at those places where no cliff recession has occurred at a lower stage—viz., at Kenosha and in the Chicago district—agrees with this view. The abundance of shells in the "Toleston" beach, noted by Dr. Marcy before 1867,[1] and confirmed by other collectors since that time (including a recent discovery by the present writer in Evanston, Ill.), when contrasted with the absence of life in the 40- and 60-foot beaches, favors the idea that the Toleston or 25-foot beach marks a lake of less frigid water than the glacial Lake Chicago. Similar shells have been found in the Algonquin beaches on the west side of Lake Huron, by those working in Michigan. But of still greater significance is the fact that Mr. F. B. Taylor, Dr. A. C. Lane, and others in Michigan have found the Algonquin beach in a horizontal position in the southern part of the Lake Huron basin, 25 feet above the lake.[2] If there has been no tilting in the Huron basin

FIG. 6.—Terrace and bluff of the Nipissing shore-line north of Algoma, Wis. In the foreground the old shore-line is cut away by the receding cliffs of the present lake. In the distance the Nipissing terrace is covered with a veneer of wind-drifted sand.

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[1] See *Geological Survey of Illinois*, Part III, "Geology and Paleontology," p. 250 (1868).

[2] See *Geological Survey of Michigan, Report on Huron County*, by A. C. Lane, Vol. VII, Part II, p. 75.

south of Port Austin, as is inferred, it is probable that the same is true of the southern half of the Michigan basin, and the Algonquin beach should there be horizontal at the same altitude, 25 feet—the actual position of the highest member of the Toleston group.

The Nipissing plane can be extended in a similar way and on the basis of somewhat stronger evidence. In the region south of Sturgeon Bay the Nipissing bluffs are developed with remarkable strength, usually 30 and sometimes 80 feet high. The terrace shows an approximately horizontal attitude, descending southward at a very small fraction of a foot per mile, so that at Centerville it stands 14 feet above the lake. South of Centerville, measurements on the Nipissing terrace at Oostburg (near Sheboygan) south of Belgium, at the state line, at Zion City and Beach Station, Ill., place it within a foot or two of 14 feet. It forms a conspicuous bluff which lies just west of the tracks of the Chicago & Northwestern Railway between the state line and Waukegan, Ill. In the Chicago district, where no terraces were cut during the lower stages, an extensive series of beach ridges from 10 to 15 feet above Lake Michigan seem to mark the Nipissing and lower planes. Occasionally there is a strong wave-cut bluff, however, in the Chicago district at the 14-foot level, as at Englewood, where the low terrace is the strongest member of the "Toleston" series.

The exceptional strength of the Nipissing shore-line and the prevalence of sharply cut bluffs seem to express the gradual rising of the waters which is known to have led up to this stage in the lake history, according to the studies of Taylor and others. The evidence from Wisconsin and Illinois, therefore, seems to make the Nipissing shore-line horizontal at the altitude of about 14 feet in the southern part of Lake Michigan. Confirming this view is the evidence collected by Lane in Huron County, Mich., where a strong beach that stands 11 to 14 feet above Lake Huron is thought to mark the Nipissing plane.[1] A single observation recently made by Mr. Leverett and the present writer a few miles north of Port Huron places a strong beach, probably the Nipissing, at a height of 12 to 14 feet above the lake. Although previous observations in Michigan have suggested a slightly lower level for the Nipissing plane, it seems likely, all things con-

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[1] *Op. cit.*, p. 76, and personally communicated to the writer.

sidered, that there has been the same confusion of terraces mentioned in connection with the strong bluffs near Algoma, Wis.—the upper few feet of the Nipissing terrace in many places having been stripped away at a slightly lower stage. The Nipissing plane, then, seems to be horizontal, and about 14 feet above the present lake-level in the southern parts of both the Huron and the Michigan basins.

THE LAKE CHICAGO SHORE-LINES

The terrace of the Calumet or 40-foot shore-line of Lake Chicago, traced by Alden near Belgium, Wis., was followed with some difficulty almost to Sheboygan. For most of this distance it is ill-defined, occasionally giving way to low bars; and its height seems in places to reach 49 feet. With a mile of the northern border of the Port Washington sheet, and again east of Oostburg, a gravel ridge was found 63 feet above the lake. If these fragments mark the Glenwood or 60-foot stage of Lake Chicago, they are important in extending that stage northward nearly to Sheboygan, where broad flats of stratified sand stand 60 feet above the lake. The Belgium and Oostburg 63-foot beach fragments are also important in showing that the Glenwood level persisted after a certain re-advance of the Michigan ice-lobe, which seems to have buried Glenwood beach gravels beneath a deposit of red clays near Milwaukee.[1] The fact that both the 60- and 40-foot beaches appear interruptedly nearly as far as Sheboygan, and there seem to end near a belt of rather strong morainic topography, when seen in the light of Taylor and Leverett's studies on the eastern side of the lake, suggests a re-advance of the ice in the vicinity of Manitowoc and Manistee, Mich., at the close of the 40-foot stage, overrunning for an unknown distance the northern part of the 60- and 40-foot beaches and destroying them. Further study of the beaches and moraines on both sides of Lake Michigan should make this point clear. So far as measurements were obtained on these Lake Chicago beaches, they seem to indicate a horizontal attitude, at least as far as Racine. It is possible that they rise a few feet between Racine and Oostburg.

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[1] "The Delavan Lobe of the Lake Michigan Glacier," etc., U. S. Geological Survey, *Professional Paper No. 34*, by W. C. Alden, p. 69 (1904).

CONCLUSIONS

A detailed investigation of the terraces and raised beaches in eastern Wisconsin, with many measurements by spirit level, leads to the following conclusions.

1. There is a series of warped water-planes of Lake Algonquin, which rise at a moderate rate north of Sturgeon Bay, diverging, fan-fashion, until the highest is 90–95 feet above Lake Michigan at Washington Island. The divergence of these planes is interpreted to mean earth-movements contemporaneous with the Lake Algonquin stages. The tiltings seem to have decreased greatly in measure south of Sturgeon Bay, dying out in the vicinity of Two Rivers, where the Algonquin beach stands about 26 feet above the lake. South of that point the Algonquin shore-line is thought to be horizontal above Lake Michigan and represented by the highest beach of the "Toleston" group in the Chicago district, at a height of 20–25 feet, just as in the southern part of Lake Huron basin the Algonquin seems to be horizontal at a 25-foot level.

2. A shore-line of remarkable strength, usually marked by high-cut bluffs and terraces, which lies everywhere below the Algonquin sand in a horizontal position along the whole Wisconsin shore, is regarded as the Nipissing shore-line. At Washington Island this terrace is 20–22 feet above the lake; but it gradually declines to 18–20 feet at Sturgeon Bay and 16–18 feet at Two Rivers, reaching 14 feet at Centerville, at which level it seems to become horizontal and to be represented by strong 14-foot terraces in Sheboygan county, near the Illinois state line, and in the Chicago district.

3. The Glenwood or 60-foot and the Calumet or 40-foot beaches of Lake Chicago are poorly preserved north of Racine, but seem to run to Sheboygan, possibly being obliterated north of Manitowoc by an advance of the ice which formed the Manistee (Mich.) moraine.

4. If this identification and correlation is correct, one of the outlets for Lake Algonquin was the Chicago outlet, the sill of which is 8 feet above Lake Michigan. The depth of water in the Chicago outlet would have been slight after the earliest stages of Lake Algonquin, however; so the outlet at Port Huron probably played a more important part.

5. It is inferred, from the apparently horizontal position of the Algonquin and Nipissing planes in the southern parts of both the Huron and Michigan basins, that no earth-movements have affected this region since the earliest Algonquin stage, and that, if any deformations are now in progress in these two lake basins, they are limited to the more northerly portions.

THE GEOLOGIC DAY

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The fact that geologic formations, whether lithologic or faunal units, given the same name—the Potsdam, for instance—are not in all parts strictly contemporaneous, has been often noted. Terms like "homotaxial" have been applied to them to avoid the assumption of contemporaneity.

A good part of the time of the geological congresses has been devoted to a discussion of problems of a similar nature. Yet it is rarely, if ever, noted that the same problem comes up in connection with the civil day, and, in fact, with any possible measurement of time.

It has just been vigorously impressed (April 19) that 5:13 San Francisco time is not the same as Washington time, but about three hours later. Therefore the day ends and begins later at San Francisco than at Washington. The sidereal day is a little different from the solar day, the astronomical year from the civil year. The reason for this lies near to the heart of things. Time is measured by change, and change, as we know it, must progress from point to point. The progress may be as rapid as an explosion or as the transmission of light, or as slow as the precession of the equinoxes. Nevertheless, there is always a rate of progress which is measurable, and any interval of time must be marked by a certain stage in the change, and so begin differently at different points.

There is no reason to be surprised, therefore, if we find this to be true in dividing up our geological time. We measure it generally by some slow change: the evolution of life, or orogenic movements, or the accumulation of salt in the sea, the changes in sedimentation consequent on elevations of continents, or changes in climate, like the passing away of the glacial epoch.

Take postglacial time for an illustration. It is clear that the ice must have retired from the valley of the Ohio before it retired from the Straits of Mackinac some time, and perhaps a very long time. Therefore the postglacial epoch begins later at Mackinac than at Cincinnati. Yet I do not think that it necessarily should have a different name, any more than April 18 has a different name for Europe and America. Of course, there are difficulties, just as there are difficulties in saying what is the birthday of a child born near midnight, or near the date-line in the Pacific. But they are inherent in the facts, and are not lessened by introducing new terms, which indeed may lead one to overlook the realities of the case. All these difficulties as to exact time, however, real as (for instance, to friends of the Psychical Research Society, discussing apparitions of the dying) they are at times, form but a fraction of the total application of the usual terms, "day," "year," and "hour," which are ordinarily intelligible and unambiguous. Is it not so with the geologic terms, and may we not ordinarily be justified in speaking of our Eastern and Western Niagaran by the same name as belonging to the same geologic year and coeval, even though we know one lithologic unit may have begun to form somewhat sooner than the other?

Difficulties have arisen from the fact that the lithological evidences of contemporaneity do not always agree with that furnished by fossils, and the early assumption (really a relic of the old cataclysmic theory, according to which God made one set of created beings, then wiped off his slate and began over again) was that fossils were the best and surest index of contemporaneity, in comparison with which all other factors or means of determination were of no weight.

No competent paleontologist now holds this extreme view, and many of them, like Williams, have shown clearly that fossils are not absolutely inerrant evidence of contemporaneity. Yet the influence of the old views, and the idea that the lines of a division of geological time must be lines separating different faunas, has so clung on that the tendency has naturally been, where the faunas proved misleading, to give up the idea of time entirely, and refer merely to homotaxis.

This will be a mistake. The idea of time is present in our geological divisions and their names, and though our divisions be imperfect expressions of our ideal, for that reason to throw away the ideal would be to make the same mistake as Hobbes, to whom a straight line was merely the straightest line he could draw, and who accordingly thought he had squared the circle, because he found a construction which was correct so far as he could see. It does not follow, however, that we should give a new name every time we find evidence of real difference in geologic time in the beginning of one of our geologic divisions. It should be carefully noted, and left to be weighed and compared with other evidences, until we are ultimately able to place each division at each place accurately on a true scale of time, which shall be to the common scale as is astronomer's time to the local times and seasons of everyday use.

Of these various evidences, fossils are by no means the best evidence of strict contemporaneity. Other evidences, as good or better, are:

1. A shower of volcanic ash like that which has recently come from Vesuvius, *if* it can be identified, is one of the best evidences of contemporaneity. The same remark applies to a surface lava flow. Individual lava flows of peculiar character, like the foot of the Kearsarge lode, have been traced many miles in the Keweenawan, and great floods out West may, I presume, be equally contemporaneous. In time to come, geologists of the future may use volcanic ash-beds, among the series of shales and muds, which are overlooked now, as horizon-markers of the first importance.

2. The whole nexus of mud-flows, lavas, ash-beds, and the like, which make up an eruptive epoch, would not make so exact an index of contemporaneity, but in many cases are of considerable value. The Keweenawan, and Triassic of the Atlantic coasts are illustrations both of the value and of the danger of such correlations. While indicating real contemporaneity, if the correlation is correctly made, there is likely to be an eruption of indistinguishable rocks (or nearly so) at widely different times.

The error is analogous to that which may be made by confusing colonies among fossils; though, on the whole, with a large enough fauna there is little danger of faunal confusion.

3. A change of climate may extend with great rapidity over a province or over a very large part of the world. The glacial period in Europe and America is one glaring illustration. Another is the change in the Carboniferous from the hot, dry climate of the Mis-

sissippian to that of the Pennsylvanian. The change may, of course, have occupied considerable time in its spread, but probably only a fraction of the duration of each period. Salt beds, whether formed in desert wastes or inlets of the ocean, point to a dry climate.

4. If one could only get samples of water in which the strata were buried which had not changed in the meantime, one might, in the case of open marine strata, be able to date them from the progressive change in the character of the sea water. This may be of more value in the future than in the past, as it probably can be used only on water carefully preserved from deep borings in slightly disturbed synclinals where numerous beds are impervious.

5. Changes in the elevation of the land, and consequently in the shore-line, produce changes in the sedimentation in which climate may co-operate. These changes in the sediment-determining factors may be slow, like the tilting of the basin of the Great Lakes, now going on. But even in such cases they may be nearly simultaneous over long stretches of shore-line. They may also be sudden, like the uplifts of the South American coast described by Darwin and numerous other earthquake disturbances. In general, it may be said to be likely that a sudden change, involving the injection of fine mud in the ocean water, is not likely to be extremely local.

As a result of these changes, the fauna is driven hither and thither, and more or less modified by the stress of circumstance.

If the difference in sedimentation slowly progresses, it is quite possible that the corresponding change of fauna will be equally slow in spreading from point to point. Thus, in determining what is really genuinely coeval, there is often no reason to prefer the evidence of fossils to that of sedimentation, if all the factors of the early geography are duly taken into account.

The great advantage that the fossils have is that they never come back to their original combinations. The course of life has never really gone backward, whereas sandstones, limestones, and shales of recent times may be undistinguishable from those of earlier times. Thus, when it comes to determining the general place in the geological column, to deciding whether the Lake Superior sandstone was "New Red," "Old Red" or coeval with the Cambrian, fossils, if obtainable in sufficient quantity, far outclass other kinds of evidence.

But when it comes to minute comparison, they are by no means exclusively to be trusted. If we find ourselves following along the shore-line of an older, settling land-mass, and there are indications that the land settled as a whole without tilting, or that, if it tilted, we are still following one coeval shore-line, which was the farthest extent of the overlap of the time, we may often be sure of a good degree of contemporaneity, independent of fossils. Of course, if we regard black shales as colored by pollen and spores, it may be said that the black shale is a faunal characteristic. But if we disregard the species and genera of spores, it becomes a mere physical characteristic, dependent on climate, like a bed of salt. Then we may fairly ask if the physical change which leads to the sudden appearance of a bed of black shale above a limestone (like the Marcellus above the Corniferous) is not likely to be closely contemporaneous over a wide area. We may extend such illustrations indefinitely. The point that I would make is that, while the paleontologist can sometimes draw fine lines of time-division, a careful stratigrapher, a paleogeographer, can at times draw equally valuable lines of time-division, as nearly the same in different places, relatively to the lengths of the intervals separated, as the divisions of civil time.

If objection is made to using paleontology for the larger and broader time-determinations, and using various other methods for details, and not always drawing the line at the same place in using terms applied to these divisions in the different regions, we can again fall back on the analogy with the divisions of common time, where the sun rules the year, and the moon long ruled the month, while the finer and more exact divisions depend on other data, and the year does not begin or end exactly at the same time at every place.

STUDIES FOR STUDENTS[1]

RELATIVE GEOLOGICAL IMPORTANCE OF CONTINENTAL, LITTORAL, AND MARINE SEDIMENTATION

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PART II

THE REGIONS OF MARINE SEDIMENTATION

For the present purpose it is unnecessary to consider the deep ocean deposits, or even the massive limestone formations, since the discussion centers on the comparison of the areal extent and importance of the detrital deposits upon the land and beneath the sea.

The investigations of the Challenger expedition[2] showed that the rubble, sand, and silt were practically limited to the upper 100 fathoms of the ocean bed, and that this corresponded rather closely with the limits of the continental shelves. At about this depth the bottom is in general rarely disturbed by the action of currents or waves. Except in bays, fjords, and inclosed seas where mud is met with in shallow water, it may be said that in general, fronting all

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[1] Continued from p. 356.

[2] Murray, *Deep Sea Deposits*, p. 184.

open coasts, 100 fathoms is the average depth at which fine mud or ooze commences to form; but local exceptions may be noted. In general, the cleaner sands are restricted to a belt within 30 miles of shore, and the average limit of the blue muds is about 200 miles, though this varies greatly in different regions. The relation of these terrigenous to the true pelagic deposits is well brought out in Chart I, *Deep Sea Deposits*, Challenger Expedition. This area of marine deposits of land-waste is etimated to cover about one-seventh of the globe and to be equal to half the area of the continents, while the area within the 100-fathom line, which more immediately concerns the present subject, is estimated at 10,000,000 square miles, or about one-fifth of the continental areas.

The deposits of former ages corresponding to the shallower and deeper portions of the terrigenous zone may be distinguished by a number of textural and structural features. For instance, considering the conditions of present deposition, it is seen that the ancient equivalents of the present blue muds will be rather widely extended, uniform, massive, argillaceous deposits, usually slightly carbonaceous and grading into calcareous formations. They will be without cross-bedding and ripple-marks, since movements sufficient to form these would prevent the settling of muds. They may be distinguished from ancient estuarine muds by all these features, and especially the absence of frequent alternations of sand. It is doubtful, however, if the deeper portions of these blue muds have ever been elevated into land surfaces. On the other hand, the shallower belt of marine deposition will be marked by a sandy character of deposits, provided that the rocks of the land can furnish sand, by evidences of shifting current-action and by ripple-marks. A. R. Hunt has shown that the waves of storms may stir the sands of the bottom to a depth of 40 fathoms sufficiently to move gravel and injure living molluscs.[1]

The charts of the United States Coast and Geodetic Survey also show sand and comminuted shells to similar depths, from which it may be inferred that widespread arenaceous and unfossiliferous formations may be formed on the bottoms of shallow seas, and not necessarily in close proximity to the littoral zone.

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[1] "On the Formation of Ripple Marks," *Proceedings of the Royal Society of London*, Vol. XXXIV (1882), p. 1.

Approaching the shore, the material of the shallow bottom becomes coarser and ends in the undertow slope of the beach. This is sometimes coarser than the material of the beach itself,[1] stones of a certain size being swept here by the undertow and only carried back to the beach by the heavier storms. It is to be concluded, therefore, that one of the most striking characteristics of ancient beach-action, a basal conglomerate, is hardly so much a mark of littoral deposition as of marginal marine deposition *bordering* the true littoral zone.

As river deposits of delta surfaces, on the one hand, tend to extend themselves both by building forward into the sea and by building backward over the land, so, on the other hand, marine deposits, as Chamberlin has pointed out, tend to extend themselves in both directions.[2] Toward the deep ocean basins the clays are swept and deposited near their brink, doubtless building out submarine deltas, as is suggested by the submarine platforms of the Caribbean Sea.[3] and by the hypsographic curve of the earth crust given by Penck.[4] In the opposite direction the waves are always at work upon the coast, and tend to cut the sea-cliff landward, except where the supply of material from the land is equal to that removed by the sea. As the wave-beaten material is rolled backward and forward, it is gradually reduced to a fineness where the undertow can sweep it away from the beach-action and allow it to finally settle at some little distance from the land. The result of these activities within the upper portions of the ocean is to cut back all headlands, to fill up recessions in the coast line, and to cut away all islands except where these have been thrown up as barrier beaches by the sea.

The rapidity with which the waves may cut into unconsolidated material has been frequently illustrated by the destruction of recent ash-cones, which in a few months or years have completely disappeared. Barrier beaches, the only form of islands tolerated by the sea, are thrown up where the waves drag and break in shallow

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[1] Dana, *Manual of Geology*, p. 223.

[2] T. C. Chamberlin, "The Ulterior Basis of Time Divisions," *Journal of Geology*, Vol. VI (1898), p. 454.

[3] Bailey Willis, "Conditions of Sedimentary Deposition," *Journal of Geology*, Vol, I (1893), pp. 496, 497.

[4] *Morphologie der Erdoberfläche*, Vol. I (1894), p. 136.

water, and can attain any degree of permanence only where they face a gently shelving land mass.

The waves not only tend to unify and extend the shallow submarine platform, but tend to cut away its highest portions to a certain depth, dependent upon the power of the waves. Thus, by taking nautical charts it is observed that over any district where there is open water the bottom maintains a certain depth close up to the off-shore beach. Facing the open oceans this is usually from 30 to 40 feet, but in more protected places, such as Long Island Sound, it may be but 6 to 12 feet. Thus, up to the line of surf the submarine platform extends without any confusion with the littoral zone.

EXTENT AND CHARACTER OF THE LITTORAL ZONE

The littoral region, as has been shown, is rather sharply delimited from the marine by the trimming action of the sea, marked along a shelving shore by the line of barrier beaches. Where a bold land meets the sea, it is merely the lowest exposed portion of the sea-cliff. On the landward side, however, the littoral is not so regularly defined, but consists of irregular tidal lagoons consisting of three portions; the mud-flats, exposed at low tide, the salt marshes flooded only at high tide, and a rather abrupt transitional mud-slope between them. Both the mud-flats and tidal marshes are cut through by tidal channels, those on the marsh being characterized by meanders.

The littoral finds its greatest development in estuaries or where the land meets the sea in the form of a plain, either a base-plain of erosion, or a river plain of aggradation. The littoral does not show a tendency, like the two previous regions, to extend its limits, since the flood-tide tends to leave sediment upon the tidal marshes, building them up to the extreme tidal limit; and, on the other hand, the tidal scour of ebb-tide tends to remove sediment to the open sea. On the contrary, the forces of both land and sea tend to fill up and obliterate the littoral. On the one hand, the river deposits and the wash from the land creep out over the tidal flats, and, on the other, the sea, by wearing the beach deposits smaller and by removing the finer shore material outward to a greater depth, tends to push its beaches farther inland.

The littoral zone is partly maintained by the contest of the two forces—the rivers building out by irregular delta mouths, inclosing lagoons and providing new tidal marshes; the sea cutting off headlands and sweeping the material along the coast, forming spits which shut off new lagoon spaces.

The chief maintenance of the littoral belt is, however, due to vertical land movements, especially subsidence of a flat land surface, but one still showing slight relief. This may produce extensive estuaries, and the waves, by throwing up barrier beaches in shallow water at some distance from the land, may form a continuous series of lagoons and salt marshes, as is illustrated by the present condition of the seaward margin of the coastal plain of the eastern United States from Long Island southward. The questions of immediate importance in the present connection are those of the width and areal extent of the littoral zone and possible fluctuations in importance in past times, owing to the prevalence of conditions not now operative, such as absence of tides in ancient protected seas, or hypothetically greater oceanic tides due to a possibly greater nearness of the moon. It is first necessary to collect the facts for the argument, by observing the various shore conditions as they exist today. Arranging these with respect to the tidal range, a representative set is as follows, the information being taken largely from the charts of the United States Coast and Geodetic Survey:

OBSERVED RELATION OF TIDES TO THE LITTORAL ZONE

TIDE 1 TO 1.5 FEET (EXAM. MOBILE BAY AND MISSISSIPPI DELTA, GULF OF MEXICO; STORM TIDES THE ONLY IMPORTANT ONES)

Mud-flats at mean low tide, 0.1 to 0.25 mile wide in protected places.

Salt marshes.—Frequently absent. Around Mobile Bay a few up to 2 miles wide. On the delta of the Mississippi (General Chart No. 19) they average 27 miles in width, cut through by the fresh-water channels and showing a poorly developed system of channels for tidal drainage.

TIDE 2.5 FEET (EXAM. GARDINER'S ISLAND AND OYSTER PONDS)

Mud-flats few in number. At mean low tide 0.33 to 0.66 mile wide in protected places.

Salt marshes average 0.25 mile wide.

TIDE 4 TO 6 FEET (VICINITY OF NEW YORK AND NEW HAVEN)

Mud-flats from 0.16 to 0.33 mile wide, of limited development.

Salt marshes in protected inlets behind barrier beaches 0.5 to 1.0 mile wide.

Along river valleys, as north of Newark Bay, they extend some 3 miles from the open water, passing into the fresh-water marshes. Tidal channels fairly well developed upon marshes.

TIDE 7 FEET (SAVANNAH, GA., ENTRANCE TO SAVANNAH RIVER)

Mud-flats 0.33 to 0.66 mile wide. More commonly present than in previous examples.

Salt marshes filling up a former estuary, 4 to 5 miles wide, with a well-developed network of tidal channels ramifying through them.

TIDE 10 FEET (BOSTON HARBOR AND DELTA OF THE INDUS RIVER)

Mud-flats extensive. At Boston they average from 0.5 to 1.0 mile wide, but are cut up by tidal scour into smaller separated areas.

Salt marshes.—At Boston, filling up protected depressions, they average 0.25 to 0.75 mile wide. On the Indus delta a well-developed network of tidal channels, 2 to 4 fathoms deep, and distinct from the distributaries of the river, extends 17 miles from the coast, and this may be taken as the limit at which the salt-water tidal marsh gives place to the fresh-water swamp. Tide reaches 11 feet in spring tides.

TIDE 16 FEET (DELTA OF THE GANGES AND BRAHMAPOOTRA)

Mud-flats.—Extent not mentioned.

Salt marshes.—Extent indicated on the map by means of the tidal channels (see reference later). The fresh-water swamps of the delta are protected from the sea by a chain of sandy islands, separated from each other by tidal channels and known as the *Sunderbuns*, the name evidently signifying severed mounds. This chain of islands averages 58 miles wide, but only the outer half is markedly cut up by tidal channels. Therefore it seems probable that the present tidal flooding extends some 30 miles inland, and the inner portion may have been built at an earlier date. Tidal effects on rivers are of course felt much farther but do not flood wide stretches of their banks.

TIDE 40 TO 70 FEET (BAY OF FUNDY, BASIN OF MINAS)

Mud-flats.—Widest in protected heads of bays. In the basin of Minas, estimated by J. A. Bancroft to average 0.75 mile wide. Along sides of the bay the current of from 6 to 8 miles per hour keeps the channel deep and open, and the sides scoured clean.

Salt marshes.—Shaler speaks of the dominance of the mud-flats over the upper marshes, and the rapidity with which the latter are built up by sediment thrown down at flood-tide when obstructions are built across the tidal marshes. Lyell speaks of thousands of acres having been reclaimed in this way.

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James Fergusson, *Quarterly Journal of the Geological Society,* Vol. XIX (1863), plate, pp. 352, 353.

Basin of Minas:

Charles Lyell, *Travels in North America,* Vol. II (1855), p. 166.

N. S. Shaler, "Sea Coast Swamps of Eastern United States," *Sixth Annual Report* (1885), United States Geological Survey, p. 368.

J. A. Bancroft, "Ice-Borne Sediments in Minas Basin," *Proceedings and Transactions,* Nova Scotian Institute of Science, Vol. XI (1905), Part I, p. 161.

From the preceding facts a number of principles governing the development of the littoral zone may be drawn.

With lunar tides of less than 2.5 feet storm tides become of greater importance. The development of extensive mud-flats and salt marshes takes place in protected places. In exposed places the cutting action of the waves prevents either from forming. Mud-flats exposed at low tide become conspicuous with tides of about 6 feet range. When the tide is 10 feet, these may form belts a mile wide, but broken up by tidal channels. With higher tides there is but little tendency to increase the width of exposed flats, but the material constituting them may become coarser, the Gallegos River in Patagonia, where the tides reach 46 feet, showing lower flats composed of gravels and even of coarse bowlders.[1] With the larger tides the tidal channels for draining the tidal marshes are wide and deep, forming convenient protected passages for the larger vessels through silted-up estuaries or behind the barrier beaches.

The salt marshes are built up to near the upper limit of tidal flooding. Where storm tides are the most important the system of drainage of these marshes is very imperfect. With tidal range of from 4 to 6 feet this becomes developed, and with a range of from 10 to 16 feet they become rivers in size, capable of quickly leading an immense volume of water into the limits of the tidal area, but more important for quickly draining the tidal grounds during the ebb. The width of the salt marshes appears to be less dependent

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[1] J. B. Hatcher, *Princeton Patagonian Expeditions,* Vol. I, Fig. 33, and p. 239.

upon the tidal rise than upon the greatness of the river and its delta which faces the tidal wave. This may be due to the great quantity of sediment furnished to the sea by the rivers, swept back bv the tide and dropped at its flood, or to the subsidence which frequently characterizes such areas and which tends to drown the seaward end of the delta. Probably both causes contribute. This is illustrated by noting that on the Mississippi delta this width of marsh is 27 miles, while in Mobile Bay near by it is from nothing up to 2 miles. At Boston the marshes average less than a mile in width, while the Indus delta, with the same tidal range, shows them at least 17 miles wide. The delta of the Ganges in the presence of a tide of 16 feet is flooded by the tides for a distance of 30 miles, while in the Bay of Fundy and the Basin of the Minas the salt marshes average less than a mile in width.

The conclusion is geologically of some importance. The broad development of a littoral zone is largely independent of tidal influence, since, where the tides are small, oscillations of level through storms may develop it to practically the same width. The topographic character of the littoral zone, as indicated by dominance of mud-flats, size of tidal channels, etc., is, however, dependent upon the tidal range as one factor. Where the land is shelving, as along the eastern and southern coasts of the United States, the shore may be much broken with estuaries, but the land and the water are separated by a littoral, which, including both its upper and lower portions, does not average more than a mile in width. The littoral is therefore of insignificant area compared to the breadth of the coast plains on the one hand, and of the shallow sea on the other.

The littoral becomes broadest where a great quantity of sediment is poured into the sea by a great river and a contest ensues between the sea and the land. But in such places the river, if sufficiently powerful, builds out a land surface delta in the face of the storms and tides, while the undertow of the latter builds out another extensive platform, submerged in gradually deepening water, and ending where a depth is attained of from 50 to 100 fathoms. Even beyond this limit important quantities of the finer sediment are swept, forming occasionally bottom deposits from 200 to 800 miles from land.

It is seen, therefore, that in places where the littoral attains a maximum width of 30 miles there are at the same time far greater areas receiving land and ocean sediments, so that the proportion of the littoral zone is hardly greater than before.

These few places where the littoral attains a maximum width are offset by the thousands of miles of coast-line where the sea is cutting into the land, and the tide rises and falls against a narrow beach at the foot of a sea-cliff; so that the previous conclusion may be further extended to include all continental coast-lines; and it may be stated that, taking the world as a whole, the width of the littoral zone does not average a mile, and therefore comprises but a small fraction of the earth's surface compared with the great extent of marginal marine and even of continental deposits.[1]

With respect to the shallow-water marine formations this remains true under all geological conditions, and therefore remains true for all geological time. But occasionally, in periods when the continental surfaces were physiographically old, of greatly diminished area and supplying but little sediment, continental deposits may well have sunk to less importance than the littoral. During such periods, however, there is a corresponding expansion of epicontinental marine sediments, though at such times of a calcareous character, so that the insignificant proportion of the littoral to the sum-total of other sediments deposited upon the continental platforms would not be greatly changed, and has been a constant feature of the earth's surface.

CAUSES RESTRICTING THE WIDTH OF THE LITTORAL ZONE

The previous examination of open sea and estuarine coasts shows that the width of the littoral is not dependent merely upon the flatness of the shores, nor upon the magnitude of the tidal range. These, while contributory factors, can operate only within certain limits. In order to see why this is so, it may be well to state briefly some of the causes which influence the result.

1. The influence of varying slope of shore may be seen in Fig. 5.

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[1] Chamberlin and Salisbury, *Geology*, Vol. I, p. 352, give the width of the littoral zone as half a mile, the length of the coast-lines of the world as 125,000 miles, and consequently the area of the littoral zone as 62,500 square miles, as against 10,000,000 square miles for the area of the shallow-water zone within the 100-fathom line.

Suppose that the shore, to begin with, is a smooth, gently inclined plane, represented in cross-section by *OB* or *OC*. The level of low tide being *OD*, the volume of water passing *O*, the lowest part of the littoral, will be represented in the one case by the triangle *OAB*, in the other by the triangle *OAC*. But the areas of these triangles are to each other as their bases *AB* and *AC*. Hence in this ideal case the volume, and consequently the mean velocity, of water flowing past *OA* will vary directly with the width of the littoral zone. But Révy has shown that the average velocity is an arithmetical mean between the bottom and surface velocities, and that the swifter the current, the more nearly the bottom velocity approaches the mean.[1]

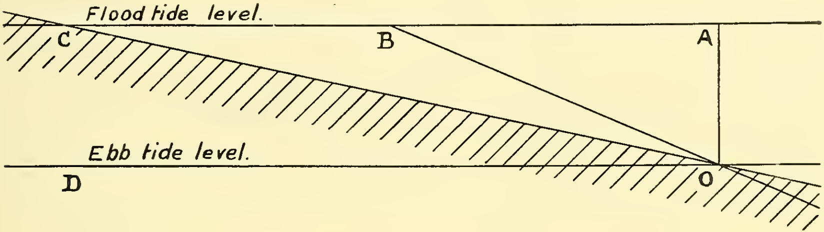

FIG. 5.—Diagrammatic relation of the width of the littoral zone to unadjusted slope of land surface.

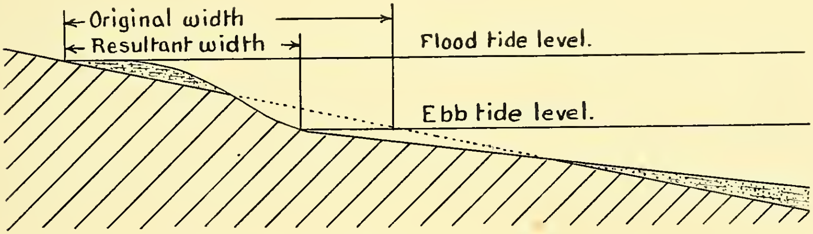

FIG. 6.—Diagram of littoral zone adjusted to slope, wave work neglected.

Therefore the bottom velocity increases somewhat faster than the width of the littoral in the ideal case. But the eroding ability of water varies as the square of the bottom velocity and the transporting ability as the sixth power. On an originally flat shore the mid-tide would consequently possess such scouring power for some distance on each side of the original low-tide limit that, as shown in Fig. 6,

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[1] *Hydraulics of Great Rivers* (London, 1874), p. 147.

the bottom would be cleaned out, part of the detritus swept to the upper tidal limit and deposited, while a larger and coarser part aided by the downward grade would be swept seaward by the ebb-tide.

In nature the land slope is never smooth, and the discharge of the ebb-tide is concentrated along those lines which give the quickest egress and the greatest depth of water, the result being the building up of tidal marshes in protected places, the scouring of tidal channels, and the formation of extensive flats chiefly below the level of low tide. In these ways an originally widely extended littoral zone would be narrowed to a certain stable width for a given height of tide. The above discussion neglects the action of waves, chiefly operative at the upper and lower tidal limits, in exposed situations.

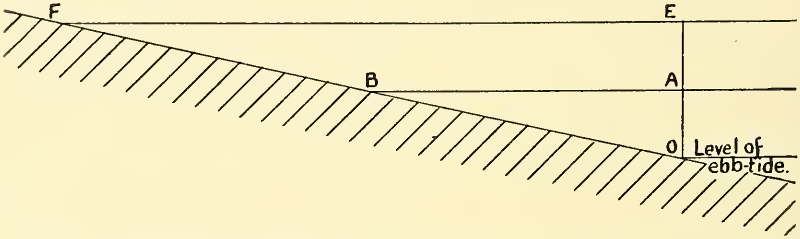

Fig. 7.—Diagram to illustrate relation of littoral zone and tidal scour to height of tide.

2. The influence of varying height of tide may be seen in Fig. 7. Letting *AB* and *EF* be the respective upper limits of tides on a recently invaded shelving shore: the volumes of water flowing past the low-tide limit will be as the areas of the two triangles *OAB* and *OEF*. But these being similar, the ratio of the areas will be given by the ratio of the squares of similar sides. Consequently, the volume, and with it the mean velocity, of the water invading the shore varies at the line *OE* as the square of the height of the tide, *OA* or *OE*. But Révy has shown that as the depth of a current increases the bottom velocity approaches more nearly the mean velocity, until in great depths and in strong surface currents they are substantially alike.[1] *Therefore on an ideal newly formed shore the bottom velocity past the point of low tide will increase somewhat faster than the square of the height of the variable tidal rise.*

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[1] *Op. cit.*, p. 148.

The result as observed in nature is an added scour in regions of high tides by which the bottom is cut away, tidal marshes at the heads of bays or other suitable places are built with great rapidity, and these are dissevered from each other by tidal channels draining the marshes, which in the more striking cases may be sufficiently deep and wide even at low tide for the purposes of commerce. In time, if subsidence does not take place, the tidal marshes become raised by accretion through æolean and organic action until reclaimed from the sea, and the littoral zone is diminished as before to a certain stable width.

CONDITIONS FOR PRESERVAL OF THE SEDIMENTARY RECORD

It has been seen that in the making of the sedimentary record but an insignificant portion would be contributed by the littoral zone. There are still, however, two factors to be considered—that of the preserval of the record, and that of its ultimate exposure to observation through partial erosion.

In order to become part of a permanent geological record, the sedimentary structures must be preserved without obliteration, first, until buried and lithified, and, secondly, indefinitely protected from erosion until some new cycle of activities proceeds to destroy it and while so doing transitorially exposes it to observation.

PRESERVAL OF THE CONTINENTAL AND MARINE RECORDS

In regard to the river sediments, slow subsidence of the region or elevation of an adjoining region is necessary for their continual formation. Each layer of sediment from the flood waters is laid down upon the previously dried and hardened layer, and there is therefore not much tendency to erase the record made on the previous surface except in the lines of the channels. Soil beds, swamp deposits, mud-cracks, and ripple-marks are consequently abundantly recorded in fluviatile formations. Unless, however, subsidence carries at least the basal portions of the deposits below the ultimate base-level of erosion, the formation will be finally destroyed, as is illustrated by the present erosion of the Tertiary river deposits of the Great Plains facing the Rocky Mountains. In river deltas, however, the proper conditions are observed to occur. Here the upper limits are but slightly above the level of the sea, and subsidence in such regions is observed ordinarily to go forward with accumulation. This will indefinitely protect the formation until some new and adventitious geological activity reverses the processes which resulted in the accumulation.

To sum up, then, it is seen that the geological processes which result in the accumulation of desert deposits, if carried to their limit, will ultimately destroy those same deposits, as Passarge has recently shown.[1] The same is apt to be largely true of Piedmont plains of river deposits; but in the case of interior basins, and more especially in deltas, the conditions are most favorable both for temporary and ultimate preserval of the land-surface record.

The same is, of course, true of the record made on the ocean bottom, since this is normally the region of deposit and not of erosion.

CONDITIONS FOR PRESERVAL OF THE LITTORAL RECORD

In regard to littoral deposits it will be seen, however, that the chances are frequently unfavorable for the preserval of its deposits until burial.

1. On an emerging land, such deposits would form a surface veneer and be the first layer to suffer erosion, before even a chance for lithification had occurred.

2. On a stationary or slightly subsiding coast, where delta deposits are encroaching upon the sea, the fresh-water material will fill up the estuaries and lagoons, covering and preserving their records, and crowding the beaches farther out to sea. The littoral deposits in that case would be preserved as old beach, lagoon, and estuarine deposits transitional, in a vertical section, between the off-shore marine deposits below and the fresh-water land-surface record above.

3. Where an old land surface is slowly subsiding, the weak erosive power of the upper portions of the rivers is no longer able to supply sediment for building out deltas against the sea, and there is, on the contrary, a transgression of the sea across the land. Assuming that the land surface slopes gently seaward, the depth of the littoral deposits behind the barrier beach where such exists cannot in general

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[1] "Rumpfflächen und Inselberg," *Zeitschrift der deutschen geologischen Gesellschaft*, Vol. LVI (1904), Protokol., 193–209; review by W. M. Davis, *Science*, Vol. XXI (1905), p. 825.

be as great as the depth of the sea in front. The advancing sea will therefore tend to cut away and destroy whatever littoral deposits may be made in advance of it, as illustrated in Fig. 8*A*. Observations confirming this statement may be occasionally made along a subsiding coast, as that of New England. To illustrate, Boston is found to be sinking at the rate of a foot a century and New York City, according to the most recent estimates, at the rate of 1.5 feet per century.[1]

That the coast between the two cities participates in this movement is indicated by the sharp boundaries of the salt-water marshes.

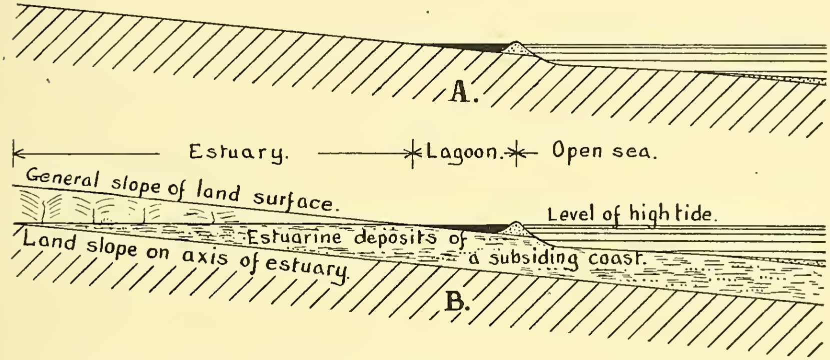

FIG. 8.—*A*, diagram illustrating progressive destruction of littoral deposits by marine planation over a subsiding land. *B*, cross-section on line of an estuary, illustrating part preserval of estuarine deposits during the transgression of the sea over a subsiding land.

These extend sharply to old alluvial slopes which rise at gentle angles from beneath them without any belt of fresh-water meadow being found between. If the land had been stationary for many centuries, the wash from the land, aided by the sediment from the highest tides, would have raised the border somewhat above the salt-marsh level. The opposite condition of affairs indicates therefore continual subsidence, but at a rate so slow that the organic and inorganic detritus, held by the roots of the marsh grass, is able to accumulate with sufficient rapidity to keep the surface at about the level of mean high tide.

A particular instance where the beach may be observed cutting

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[1] G. W. Tuttle, *American Journal of Science*, Vol. XVII (1904), pp. 333–46.

away the older lagoon and marsh deposits may be cited from unpublished observations of Mr. I. Bowman. This is 2.5 miles south of Scituate Harbor, Mass., between the third and fourth cliffs, where the beach has retreated inland from 225 to 300 feet since 1898. The beach ridge is of pebbles, from 100 to 125 feet wide at mid-tide and from 8 to 10 feet above the level of the salt marsh behind it. In consequence of the rapid retreat, the marsh material at present shows at mean and low tide on the *seaward* side of the beach, illustrating the tendency of the sea to cut away the littoral as it advances upon the land.

There are a couple of ways, however, by which littoral deposits may be preserved upon a subsiding flat land. The first is illustrated by the unequal beach-cutting observed along the New Jersey coast.

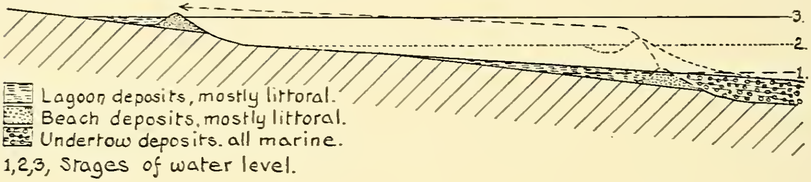

FIG. 9.—Cross-section illustrating occasional preserval of littoral deposits by building up of a beach, stages 1 and 2, without landward movement during land subsidence.

At Long Beach the sea has cut the lagoon space entirely away and is fronted by bluffs. Farther southward the barrier beaches begin and shut off Barnegat Bay. There is known to be a lateral transfer of beach material southwestward along the Atlantic coast. By this means it is possible for an offshore beach to be built up vertically as the coast subsides, the lagoon space behind broadening and deepening, as shown in Fig. 9. Finally, when the lateral supply of material ceases through recession of the bluffs, the beach will be rapidly transferred inland, but the depth of wave-planation may not reach to the bottom of the marsh deposits.

Again, the shore will be more or less indented with shallow river valleys turned into embayments or estuaries, and in these a greater depth of littoral and estuarine deposits may accumulate, and partly escape the marine transgression and planation which ensue with further subsidence. The protective effect will be slightly diminished, however, by the incurving of the spit-bars thrown partly across the mouth of the estuary. Illustrations of this nature are well exhibited along the Atlantic coast of the United States. As seen in cross-section, the bottom line of Fig. 8*B* represents the center line of the estuary bottom, while the depth of the marine planation is determined by the average slope of the land.

In the sedimentary record made, therefore, upon a subsiding land, only a fragmentary littoral record should be preserved at the base, and upon tracing the formation laterally there should be frequent places where the marine off-shore sands, gravels, or conglomerates should rest directly upon the old land surface. This contact of true off-shore marine deposits with the old land surface seems to be the common rule observed upon that most striking of American transgressions, that of the middle and upper Cambrian, across the greater portions of the North American continent, though Dana[1] states that the beds "are in part beach made and wind made sandstones, ... and the layers often bear ripple-marks, shrinkage cracks, worm burrows, and, in some places, tracks of animals." The shrinkage cracks may doubtless be taken as good evidence in this instance of a littoral origin.

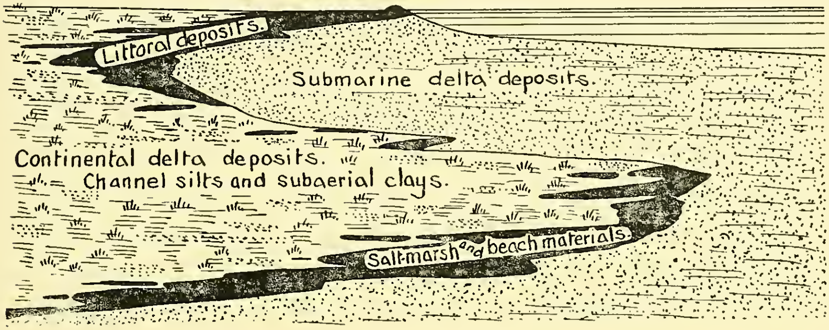

FIG. 10.—Ideal cross-section of a delta, showing geological relations of fluvial, littoral, and off-shore deposits. Vertical scale much exaggerated.

To sum up, it is to be expected that littoral deposits should be found dividing former land surfaces from sea bottoms, commonly present where the land surface is represented by subaërial delta

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[1] *Manual of Geology*, p. 464.

deposits and comprises the *overlying* formation; frequently absent where the old land surface, ordinarily a land erosion surface, *underlies* the marine deposits. The littoral zone is small in local area compared with the occasional delta deposits which border it on the one hand, and the universal marine deposits which border it on the other. As seen in vertical section, therefore, the littoral deposits should have but limited lateral development on any one horizon. If the movement has been the subsidence of an old land, they should not be again encountered in the superior strata, but in the case of the contact of a delta with an epicontinental sea the littoral zone, as shown by the diagram, Fig. 10, might move backwards and forwards as a zigzag line through the vertical section, representing the advance and retreat of the sea as the subsidence on the one hand, or delta-building on the other, dominated at the moment, the littoral deposits dividing the marine from those made upon the surface of the land.

RELATIONS OF CONTINENTAL AND MARINE SEDIMENTATION THROUGH GEOLOGICAL TIME

In the preceding discussion the relative importance in area and volume of modern land, seashore, and shallow-water marine deposits has been discussed. It has been seen that the littoral zone occupies the least area and stands the smallest chance of preserval, while land deposits of various sorts hold second place; most important among these, on account of their favorable chances for preserval, being river sediments, made in interior basins, or as deltas encroaching upon the sea. The marine detrital deposits of the continental margins are, however, the most widespread and important of the three classes.

In discussing these relations they were seen to be dependent upon many broad features, such as the degree of continental uplift and areal extension, recency and magnitude of mountain movements, climatic zones, and other such factors. These have varied widely, however, through past time, and while the geographic details of former ages are largely wanting, still the general character of the terrestrial surface is in a manner known; as, for example, it is known that the Triassic over every continent was in general characterized by broad continental uplift, orogenic movements, and variegated climates, while the Jurassic was, on the contrary, characterized by a spread of epicontinental seas, less rugged and elevated land-masses, and warm, equable climates extending into the polar regions. This conception of world-wide conditions characterizing the several ages, and distinguishing them from each other must, according to Chamberlin, form the ulterior basis of time-divisions and the classification of geologic history. But if the several ages have been characterized by certain relations of mountains, plains, and seas, then they should also be characterized by the kinds of deposits made under these conditions. The most natural method of testing this question would be to study all of the formations of the world belonging to a certain age, and group them according to area and origin. This has been done, and it is the method by which the conclusions in regard to the broader features have been arrived at. But as the very subject under discussion involves the possible confusion of certain unfossiliferous littoral and shallow-water marine deposits with those made upon the land, this method must be reversed, and by basing the arguments upon the known continental relations, as determined by formations in regard to which there is no doubt, conclusions may be reached in regard to the relative importance of deposits of those three classes which should characterize the different ages. This may be of value in suggesting discriminations not otherwise thought of, but it is not the purpose to offer here criteria for finally and definitely testing the origin of any particular formation. The latter question must, of course, be finally settled by a detailed study of the formation in the field and in all its aspects.

As introductory to this discussion it may be well to restate briefly certain of the principles which are found to govern the development of several classes of deposits at the present time.

Where young and lofty mountain ranges stand sharply above the surrounding country there will be much local waste on the Piedmont plains at their feet. If at least one slope faces the interior of a continent, this will result in extensive continental deposits, perhaps accentuated by conditions of aridity. Down-warped interior basins may also receive deposits. For effective delta building, however, there must be a submerged continental platform, or epicontinental seas, and Chamberlin has pointed out[1] that the effect of the greater earth-movements has been to temporarily reduce to a minimum these shallow submerged portions of the continent. Such movements of continental uplift, or rather down-sinkings of the ocean basins, seem, however, to carry up portions of the crust to heights notably above the plane of isostatic equilibrium, from which they gradually settle back toward equilibrium by virtue of the slow fluency or quasi-fluency of the rocks.[2] At the same time, base-leveling is proceeding from the margins of the continents, reconstructing new coastal shelves, whose edges tend to become submerged both by the slight filling of the sea with sediment and by the settling back of the continental platforms. Assuming the truth of these general laws of major earth-movements, subaërial delta-building encroaching upon the shallow seas would attain greater importance as the erosion verged toward maturity, since the amount of landwaste increases; the streams, now being graded, carry it through to the shores, and submerged continental platforms have had time to form. At the same time, the deposits of arid interior basins and of Piedmont slopes will diminish in importance, and finally become more or less eroded.

Finally, as the continent becomes topographically old, the mountain slopes become subdued, the burden of the rivers lessens, they can no longer build out extensive deltas against the seas, noteworthy land deposits no longer form, and slight elevation of the ocean sursurface will cause it to widely transgress the base-leveled land.

Turning to the marine deposition of mechanical sediments, they should be observed to immediately increase in volume following continental uplift, several chief types being noted according to the nature of the land and the movement of uplift. If from a near-by mountain range, the sediments will be coarse in nature and formed through rock disintegration more largely than through decomposition. If from an older coastal plain, the marine deposits will comprise siliceous residues from a previous period of erosion. If from a decomposed regolith of a former near-by low-lying land, the sediments will be

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[1] The Ulterior Basis of Time Divisions and the Classification of Geologic History, *Journal of Geology*, Vol. VI (1898), pp. 449–62.

[2] *Ibid.*, p. 455.

marked by an abundance of leached argillaceous and ferruginous silts discharged at numerous points along the coast. If from a distant mountain system, the material will be similarly fine-grained, but will show less decomposition and leaching, and be discharged in great quantity by great rivers at a few widely distant points. Thus there are a variety of types of marine sedimentation, the material becoming more uniform in character and more widely spread over the growing circum-continental shelves as the erosion passes into the stages of maturity. Finally, with old age the amount of mechanical detritus greatly lessens, the conditions for limestone formation approach near to the shores, but greensands and the limy shales are still indicative of the presence of land-waste long after all *subaerial* detrital deposits have ceased to form.

Even in old age, however, it is still possible that slight regional uplifts and warpings may result in a temporary renewal of rapid erosion, since under such circumstances the regolith will have formed a deep and voluminous mantle to the continent, readily removed and swept to sea upon the least rejuvenation of the rivers. If the movement is accompanied by an adjacent down-warping in a continental interior, the deeply decayed rock mantle may be swept into it and be built up by river aggradation as a continental deposit, which further warping may carry beneath the sea.

GENERAL APPLICATIONS TO GEOLOGICAL HISTORY

Having sketched these outlines of the relations of continental and marine sedimentation to the broad earth-movements which have separated and individualized the geological ages, it will be in order to apply them, by way of illustration, to certain typical periods. It will be seen that they suggest, though they do not prove, rather different interpretations for certain formations from those which have been ordinarily held.

Pre-Cambrian æon of continental extension.—It is a matter of familiar knowledge that nearly everywhere the marine deposits of the Cambrian lie upon a far older and unconformable basement. Occasionally the Cambrian appears to have a downward unfossiliferous extension, as in the southern Appalachians, or sometimes rests unconformably upon older, usually barren sediments, but little or no more metamorphosed than itself, as in Montana and in Arizona. More frequently, however, over all the continents it rests directly upon steeply dipping gneisses and schists. These structures, characteristic of the zone of rock-flowage, indicate widespread and profound erosion previous to the Cambrian transgression, and therefore a period of wide and long-enduring continental extension.

The usual concept of the development of the North American continent embodied in the textbooks of the past begins with the widespread submergence of the late Cambrian and early Ordovician. From that stage Dana has long since shown how the continent through the Paleozoic gradually, and with many regressions, gained in dry land.

Walcott considers, however, that the prevailing view of the geographic distribution and extent of the continental area at the beginning of Paleozoic time is too restricted, and that the continent was larger at the beginning of the Cambrian period than during any subsequent epoch of Paleozoic time.[1] At this date (1891) Walcott had not yet separated the underlying belt formation of Montana from the Cambrian, and consequently considers this portion of the Northwest to have been beneath the sea during Lower Cambrian time. With the discovery of an uncomformity separating the Belt from the Middle Cambrian,[2] this statement in regard to the extent of the early Cambrian land is further justified, and will probably be considered by those familiar with the subject as very conservative.

LeConte also emphasizes the significance of the Pre-Cambrian record of erosion, the subject being briefly stated in his *Elements of Geology*.

A truer appreciation of the facts of the world-wide Pre-Cambrian unconformity may finally lead to the erection of this Pre-Cambrian period into an æon of continental extension as widespread and as long-enduring as that of the Mesozoic and Cenozoic.

Yet it is only the end of this period, as marked by the Lower Cambrian unconformity, which is known with any accuracy. On going backward in time, evidences of repeated orogenic movements

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[1] "The North American Continent during Cambrian Time," *Twelfth Annual Report* (1891), U. S. Geological Survey, Part I, p. 562.

[2] C. D. Walcott, "Pre-Cambrian Fossiliferous Formations," *Bulletin of the Geological Society of America*, Vol. X (1898), p. 210.

are encountered widely separated in time, deforming older basins of sediments, and resulting in erosions and unconformities. It is not to be implied, therefore, that such formations as the Belt of Montana and the Grand Canyon terranes, because they lie immediately below the Middle Cambrian, were necessarily deposited in an *immediately* Pre-Cambrian period.

From the thickness of their detrital accumulations situated in the interior of the continent, they probably belong to interior basins of subsidence within rather wide land masses. That these basins were, at least during a part of the time, connected with the open sea is shown by limestone formations, thousands of feet in thickness, which they contain.

In the Lewis and Livingston Ranges Willis has measured a thickness of the Algonkian of about 10,000 feet, without either the upper or lower limits being visible. Of this from 4,500 to 5,300 feet are argillites and quartzites, while 5,400 feet are limestones, divided into two great formations.[1]

Near Helena, in west-central Montana, Walcott has estimated the total thickness of the Belt terrane at 12,000 feet, of which 7,600 feet consist of argillites and quartzites, the remainder, as before, being divided into two great limestone formations.[2] This region is possibly not far from the limits of the original basin during much of the time of deposition, since the Belt formations disappear from between the older gneisses and the younger Cambrian some 60 miles to the south.

In the Pre-Cambrian Grand Canyon series, exposed in northwest Arizona, Walcott gives the Unkar and Chuar terranes a combined thickness of 11,950 feet, of which about 400 to 500 feet are limestones, and about 1,000 feet lavas. The remainder are sandstones and argillites.[3]

In view of these great thicknesses of sandstones and argillites accumulated in interior basins of Montana and Arizona at a time of at least considerable continental extension, the hypothesis of a subaërial origin by river aggradation may well be held in mind as a possibility for certain formations, as well as the more common

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[1] *Bulletin of the Geological Society of America*, Vol. XIII (1902), pp. 316, 317.

[2] *Ibid.*, Vol. X (1898), p. 204.

[3] *Fourteenth Annual Report*, U. S. Geological Survey, Part II, pp. 508–12.

hypothesis of the accumulation of such materials at the bottoms, or within the margins, of shallow seas.

Again, in the Lower Cambrian, according to Walcott, the eastern side of the narrow Appalachian trough appears to have been a bold and precipitous mountainous area. In the trough itself beneath the Olenellus sandstone occurs a great series of variegated shales.[1] These are of course no proof of land accumulation, but the geographic relations of land and water were such as to suggest the possibility that delta deposits may have been built out into a trough which later, by a slackening of erosion or a greater subsidence, allowed the region to pass from largely subaërial to marine conditions, the marine transgression being marked by the deposit of the Olenellus quartzites.

In conclusion it is suggested that the Pre-Cambrian and Lower Cambrian ages of wide continental extension offered conditions favorable for the accumulation of the several types of subaërial deposits, and that in the interpretation of the mechanical sediments of those times this possibility should be always held in mind. The presumed absence of a fossilizable land fauna and flora in the life of those periods would remove the possibility of proving a continental origin through such secure means.

Paleozoic epicontinental basins.—During the Eopaleozoic the continents became largely submerged, but in the Neopaleozoic partial emergence was the rule, varying from fairly extensive land conditions at times (in late Silurian and Lower Devonian), as has been shown by Ulrich and Schuchert,[2] to submergence possibly nearly as complete as that of the Ordovician. At times mountain-making forces and regional uplift operated on an extensive scale, as is witnessed, for example, by the enormous mass of Upper Devonian sediments along the northeastern portion of the Appalachian trough from which Willis computes that the uplift supplying these sediments corresponded in volume to a mountain range similar to the Sierra Nevada,[3] and the sediments deposited in the Old Red Sandstone

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[1] "The North American Continent during Cambrian Time," *Twelfth Annual Report,* U. S. Geological Survey, Part I (1891), pp. 536, 551.

[2] "Paleozoic Seas and Barriers in Eastern North America." *N. Y. State Mus., Bull. No. 52,* pp. 633–663, 1902.

[3] *Paleozoic Appalachia,* Maryland Geological Survey, Vol. IV (1902), p. 62.

basins of the British Isles, Norway, and the Arctic islands to the north.

This mountain-building, taken into consideration with the restricted nature of the interior sea of eastern North America between the Cincinnati axis and the eastern border, forms geographic conditions which should favor the development of extensive deltas filling up shallow seas and giving rise to the formation of subaërial deposits. Turning to the strata themselves to find an answer to this suggestion, one notes the sparingly fossiliferous character of the Catskill group of the Upper Devonian and the fact that the few fossils found are those of fishes, Eurypterids (Stylonurus), and some fresh-water lamellibranches (Amnigenia), suggesting that, occasionally at least, subaërial deltas may have covered considerable regions, and should be looked for by a critical study of textures and structures. Many geologists would grant this possibility, though it has found but little recognition in geological literature.

That differences of view among able living geologists may be held upon the subject of the Paleozoic formations is indicated by the fact that Willis, as a result of his prolonged and detailed studies of the Appalachians, interprets the Tuscarora (Medina) sandstones of Maryland as submarine coastal plain deposits,[1] while more recently Grabau, in a preliminary paper, advances the hypothesis that the Siluric conglomerates and sandstones are part of a huge subaërial fan, whose apex was in southeastern Pennsylvania.[2]

This is not mentioned with the intention of urging the continental point of view, since the cleanly sorted character of much of the formation would seem to indicate to the present writer that prolonged sorting by waves, rather than the limited sorting and variable character of river work, had been concerned. It might well be, however, that an alternation of conditions has occurred, marine deposition dominating in one district, river work in another.

Of the Paleozoic formations it is in the coal-measures, however, that the relations between continental and marine deposits are most distinctly shown and most fully appreciated; largely because the climatic conditions were such as to lead to the formation of swamp

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[1] *Op. cit.* (1902), pp. 55, 56.

[2] "Physical Characters and History of Some New York Formations," *Science*, New Series, Vol. XXII (1905), p. 533.

jungles whenever delta surfaces were exposed to the air without either uplift sufficient to produce erosion or subsidence sufficient to result in burial. With occasional exceptions, which may be due to river driftage, it is conceded that the coal was formed *in situ*, and thus each coal-bed becomes a determined land surface, although once in a swamp condition.

The analogy of the carboniferous swamps with those existing at present upon delta surfaces or buried beneath the later river deposits has been perceived and pointed out since the time of Lyell. This analogy, together with the usual absence of marine fossils and the occasional presence of land or fresh-water forms in the associated strata, has led to the well-founded belief in the chiefly fresh-water or brackish-water origin of the coal-measure shales and sandstones of Nova Scotia, the Pennsylvania anthracite basins, and other regions. But over the western portion of Pennsylvania and much of the continental interior, beds of limestone with marine fossils occur at intervals through the coal-measures, indicating in those regions periodic invasions of the sea.

From these facts it is inferred that periodic subsidences took place, allowing transgressions of the widespreading epicontinental sea across the submerged delta surfaces. But the absence of the limestones nearer the shore and in basins like that of Nova Scotia, where the great thickness of shales, sandstones, and conglomerates testifies to rapid erosion and sedimentation, indicates that subsidences did not allow the sea to reach this far inland, but that it was kept out by the rapidity of river aggradation, which, as the basin subsided, distributed mud, sand, and gravel *pari passu* over the old forest swamp. Thus, the same conclusion is derived inductively as that previously arrived at by deduction concerning the phenomena of a subsiding delta region, where it was concluded that the marine and continental portions should be broadly interfingered, the sea cutting in from one side, the rivers building out from the other, and the littoral being a relatively unimportant transition zone resulting from the contest between the two.

Statements might be quoted from able writers in which it is assumed that the subsidences were of an oscillatory nature, and that the reclamation of the land surface from the sea was due largely to uplifts which would cause the sea bottom to just emerge above the sea-level when coal-swamps would form, while subsidences would carry it downward, maintaining depths of 100 feet or more during which sediments were being deposited.

Upward oscillations are, of course, not to be excluded, but in regard to the major cause of land-surface reclamation the following may be quoted from Geikie:

> It has been assumed that, besides depression, movements in an upward direction were needful to bring the submerged surface once more up within the limits of plant growth. But this would involve a prolonged and almost inconceivable see-saw oscillation; and the assumption is really unnecessary if we suppose that the downward movement, though prolonged, was not continuous, but was marked by pauses, long enough for the silting-up of lagoons and the spread of coal jungles.[1]

LeConte emphasizes the same conclusion as to the cause of the alternation of strata; it being due not to crustal oscillation, but to the operation of two opposing forces, one depressing (subsidence), the other upbuilding (river deposit), with varying success.[2]

Dana also states that, when

> under verdure, the surface must have lain for a long period almost without motion; for only a very small change of level would have let in salt water to extinguish the life of the forests and jungles, or have so raised the land as to dry up its lakes and marshes. Hence the grand feature of the period was its prolonged eras of quiet, with the land a little above the sea-limit.[3]

It is inconceivable that uplifts should have terminated and the land rested quietly almost indefinitely when it was brought exactly to the sea-surface, and it has been shown in the earlier part of this article that the sea and land always tend to be differentiated.

It is seen then that, supposing a small subsidence of, for example, 100 feet to take place, the river building would on the landward side keep pace with it. The coal-jungles would first be quietly flooded with fresh-water lagoons, as over portions of the Ganges delta. In these clays would be laid down, quietly burying and protecting the extinguished forest, and preserving within itself numerous fossils of ferns and leaves. Following this, the shifting river distributaries would deposit sand, or possibly even gravel, the whole

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[1] *Text-Book of Geology*, 4th ed. (1903), p. 1018.

[2] *Elements of Geology*, revised ed., p. 390.

[3] *Manual of Geology* (1895), p. 708.

covered continually with sufficient vegetation to leach out by its decay the iron from the deposited sediments, but not standing in water, and therefore finally destroyed by oxidation.

On the seaward side the subsidence brings about a transgression of the sea with considerable erosion of the forerunning transitional littoral zone, or even of the underlying fluviatile and swamp formations, such as is sometimes observed to have occurred in the coal-measures of Illinois, Kentucky, and Missouri. In order to observe the process of land-reclamation by the river deltas from the sea, suppose, to continue the example, that the subsidence has been sufficiently rapid for the sea to gain 10,000 square miles from the land with an average depth of 50 feet, at which time the subsidence ceases.

The Ganges annually carries across its delta to the sea sufficient sediment to cover one square mile 221 feet deep; the Mississippi annually discharges into the Gulf of Mexico sufficient to cover one square mile 268 feet deep. Applying these figures to the hypothetical case, and assuming that one-half of the discharged sediment goes to make the fore-set beds by which the delta is built outward, it is seen that the Ganges would completely reclaim this area in 4,524 years, the Mississippi in 3,730 years. These, however, are two of the greatest rivers. But even if the carboniferous rivers discharging across the region of the Appalachian coal-fields delivered but a tenth part of the detritus borne to the sea by the Ganges and the Mississippi, it is seen that the transgressive effect of the supposed subsidence would be completely nullified in periods of 45,240 and 37,300 years. During this period of quiet and of land extension, conditions for the formation of coal would exist over much of the delta surface not actually traversed by the rivers, the swamps by the deposit of organic débris keeping pace to some extent with the distributaries raising their beds as the delta advances, and thus tending to prevent the wandering of the rivers across them.

In the present connection it is desired to emphasize not only the upbuilding but the outbuilding capacity of rivers, by which, if their sources are in highlands, their deltas may rapidly push into and fill up shallow epicontinental seas. Under such circumstances it is largely a question of the rate of river deposition and the volume of the sea to be filled.

In conclusion, then, it may be said that during the Paleozoic the eastern margin of the United States witnessed repeated uplifts and occasional mountain-making movements, which poured down great quantities of sediments into a shallow and at times restricted interior sea. These conditions should lead during times of rapid erosion to extensive subaërial deltas; sometimes temporary fresh-water marshes or periodically inundated desert flood-plains; sometimes verdure-covered swamps and plains: deltas showing great thicknesses of subaërial beds advancing to a considerable distance into the sea, alternating with periods of relatively more rapid subsidence or slackened erosion when the sea would transgress across the subsiding delta. At present the coal-beds, and the occasional presence of shells of fresh-water facies in the associated dark shales, are considered the only decisive evidence of such conditions, but the absence of coal-beds does not prove the contrary side of the question.

Mesozoic and cenozoic continental deposits.—The possibility of the occurrence of Mesozoic continental deposits has been widely recognized in both the New and Old World, especially for the closing stages of the Paleozoic and the opening of the Mesozoic, when the continents appear to have been broadly uplifted concomitantly with orogenic movements, and conditions of coldness and aridity occurred in many parts of the world, coldness and humidity in others. The conditions seem to have been of a somewhat similar nature to those recurring at the end of the Tertiary and enduring in a measure to the present time. It does not seem necessary, therefore, in the present connection to enter into a detailed discussion of the possibly or probably subaërial Mesozoic deposits of Europe, Asia, and America. Neither is it necessary under the present heading to discuss the deposits of the Tertiary and Quaternary still enduring at the surface, since it is the accumulated knowledge of these which has been used as the key and the test of this discussion, and it is by a further study of them that added light will be shed upon the past.

Correction.—Through a printer's error the titles of Figs. 3 and 4 in Part I, pp. 347 and 349, were transposed.

Reviews and Book Notices

An Introduction to Astronomy. By Forest Ray Moulton. London-New York: The Macmillan Co., 1906. Pp. 557.

As geology is the domestic chapter of astronomy, the broad-minded geologist cannot be indifferent to the appearance of a synoptical treatise which brings within easy reach the essential advances in this old but ever new and fascinating science. Dr. Moulton's book is eminently opportune and welcome, since it covers in clear and firm terms those phases of astronomy which are just now most serviceable to the student of the genesis of the earth. In the first fourteen chapters the book sets forth the methods by which the science is developed, the important features of the solar system, and the mechanical principles involved in celestial dynamics. The selection of the matter is notable in that the most fundamental and essential facts are chosen, rather than those that are of most spectacular and superficial attractiveness. Perhaps in no other book of its kind is there so large a proportion of the things that it is essential for one to know, if one is to follow the progress of astronomical geology, as in this treatise, modestly styled an introduction to astronomy. And as these come from the hand of a specialist in celestial mechanics, they may be accepted with unusual confidence. A notable feature of the treatment is the close tying of facts to principles, by virtue of which the facts teach the principles, and the principles give the facts coherence and meaning, and help one to hold them.

On the firm grounding of facts set forth in the first fourteen chapters, the evolution of the solar system is discussed with a fulness and precision found in no other astronomical work of its grade. The views of Thomas Wright and Kant are briefly noticed, while those of Laplace, Lockyer and George Darwin are more fully treated. The facts that support the Laplacian view and its modifications are cited and set over against the facts inconsistent with it, especially those that have been developed by recent studies and discoveries. The planetesimal or spiral-nebular hypothesis is as fully set forth as the limits of such a work permit, and, naturally, as coming from one who has taken an essential part in its development, in an appreciative and sympathetic way. Dr. Moulton's treatment is in many respects different from that of Chamberlin, though completely in harmony with it, and to those to whom the mathematical form of treatment is helpful it will doubtless be found more acceptable. It may, however, be easily followed by those who are not deeply versed in mathematics, as only the simpler formulæ are introduced. In the summary at the close of this chapter on evolution, after a word of warning that this theory should not be accepted as final, since many phenomena having a critical bearing upon it are yet to be developed, Dr. Moulton says:

> The development of a spiral nebula by the near approach of two suns seems to be a necessary consequence, though this point needs further elaboration. The development of some such a system as ours from a small spiral nebula of the type considered seems to be inevitable. So far as the details have been worked out, nothing directly contradictory to the theory, or even seriously questioning it, has been found, while it explains admirably all the main features of the system. It can be safely said that, at present, this hypothesis satisfies all the requirements of a successful theory much better than any previous one.

The final chapter is devoted to stars and nebulæ in which, as before, the selection of the important things is notable. The work is to be heartily commended to the geologist who wishes a brief and trustworthy summary of the recent developments in astronomical science. T. C. C.

A Preliminary Report on a Part of the Clays of Virginia. By HEINRICH RIES, PH.D. (Geological Survey of Virginia, Bulletin No. II, 1906.) Pp. 184, 15 plates, 10 figures.

The investigation of the clays of Virginia has been well begun, and when completed it is proposed to publish a volume on the clay industries of the state. So far attention has been confined to the coastal plain belt. The expressed purpose of this work is to determine (1) the extent, qualities, and applicability of the clays; and (2) whether the clays now being utilized could be used for making other and better products than are now being made from them. To this end many samples were collected and carefully investigated both chemically and physically. The results of these investigations together with instructive discussion of the origin, properties, and mode of occurrence of clay, methods of mining and manufacture, etc., are embodied in this report.

The first chapter, forming Part I of this report, treats of the "Geology of the Virginia Coastal Plain" and was contributed by William Bullock Clark and Benjamin LeRoy Miller. The interpretation of the Sunderland and other Pleistocene formations is given in unqualified terms as though unquestioned science, with no intimation to the reader that the interpretation is questioned and other interpretations advanced. The public are entitled to know the true state of the case. E. W. S.

Geology of the Central Copper River Region, Alaska. By WALTER C. MENDENHALL. (U. S. Geological Survey, Professional Paper No. 41, 1905.) Pp. 133, 20 plates and maps, 11 figures.

The area described lies in the central and northern parts of the copper River Basin—one of the most interesting regions in southern Alaska. It came into prominence in 1898, at the time of the great stampede to the Eldorado of the north. Some of those who overcame the difficulties of getting into the Copper River country were rewarded by finds of considerable copper and gold deposits.

Three great mountain ranges cross the area—the Chugatch, the Wrangell, and the Alaskan. Mount Wrangell itself is an active volcano which constantly gives forth great volumes of smoke and vapors. Mount Sanford, one of a number of extinct volcanoes, is 16,200 feet high—the highest peak in the region. The southern side of the Alaskan range is a great fault scarp, and Mr. Mendenhall believes the whole Copper River valley to be due to a sunken fault block. He also thinks it probable that this sinking was the result of the outpouring of the Wrangell lavas.

Another interesting scientific contribution is the description of 6,000–7,000 feet of Permian strata in the upper Copper River valley. The fauna is much more closely related to that of the great limestones of India than to the fauna of the Mississippi valley Permian. This is probably one of the best developments of marine Permian in the world. E. W. S.

Geology of the Boulder District, Colorado. By N. M. FENNEMAN. (U. S. Geological Survey, Bulletin No. 265, 1905.) Pp. 101, 5 plates, 11 figures.

The principal topic of this report is the gas and oil of the district, but it treats also of the physiography, stratigraphy, structure, geologic history, and its other economic resources. These are: water, building-stone, grindstone, lime, clays, and coal. The area lies at the foot of the Front Range, and has its appropriate topography of plains on the east, and mesas and foothills on the west. The rocks are nearly horizontal sedimentaries on the east, and the upturned edges of the same against the Archean mass on the west. The oil-producing formation is the Pierre. The producing wells are in a narrow north-south belt, which was found to be the area of a monoclinal fold. Shooting of wells was found to have an injurious effect in many cases, the flow of such wells decreasing after the shooting. Thirty-nine thousand barrels of oil were produced in 1903. One gas well furnishes 3,000,000 feet per month. E. W. S.

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DISCOVERY OF THE DISK OF ONYCHOCRINUS, AND FURTHER REMARKS ON THE CRINOIDEA FLEXIBILIA

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The Disk of Onychocrinus

In the year 1888 Wachsmuth and Springer[1] published their "Discovery of the Ventral Structure of *Taxocrinus*," based upon a remarkable specimen of *T. intermedius* from the Kinderhook group of the Subcarboniferous, at Le Grand, Iowa. Until that time nothing whatever had been known concerning the structure of the tegmen in the Crinoidea Flexibilia; but numerous theories about it had been discussed, all of them based upon the assumption that it was in the nature of a closed vault analogous to that of the Camerata, and supposed to be common to all the paleozoic Crinoids. The specimen above mentioned, however, demonstrated that in *Taxocrinus*, and presumably in the Flexibilia generally, the tegmen had an open mouth, surrounded by five oral plates, with ambulacra passing in between them, after the manner of the Recent Crinoids. This interpretation has been accepted by all subsequent writers, and our figure of the tegmen of *Taxocrinus* has been copied in almost every treatise on Crinoids or general paleontology published since that time.

In that paper it was stated that traces of alternating ambulacral plates had been seen in a specimen of *Onychocrinus*, but not the orals,

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[1] *Proceedings*, Academy of Natural Science, Philadelphia, November, 1888, p. 337.

nor any part of the perisome. Messrs. Lyon and Casseday, in their description of *Onychocrinus exsculptus*,[1] gave a partial description of the vault, which they thought to be similar to that of the Asteroidea. They observed, extending toward the arms, "five rays composed of two rows of large, granulose pieces, one row alternating with the other," and in the fields bordered by these five rays some interstitial pieces which were "very small, granulose, and arranged without any apparent order." They were unable, from the fragmentary condition of their specimens, to obtain any information as to the central portion.

As the genus *Onychocrinus* represents the most specialized form of the group—one of the latest developed and latest surviving—it has seemed a matter of special interest to ascertain the exact structure of its ventral side. Its calyx exhibits, in a striking degree, the two characteristics of the group—massiveness and flexibility. Except at the very base, where they are rather thin, the plates are thick and heavy, and are closely laid together, like bricks in a pavement. The interbrachial system connecting the rays dorsally is composed of strong and thick plates, while the brachials are of great depth, and have a very shallow ambulacral groove. Nevertheless, the plates of this powerfully built calyx must have possessed an immense amount of mobility among themselves, for we find it preserved in a great variety of positions. In some specimens the rays are folded together, and in others they are spread out horizontally. These changes of position, while they involve all the brachial and interbrachial plates, did not cause any marked opening or gaping of the sutures; but in some singularly perfect manner the plates seem to have been capable of sliding upon each other by their apposed surfaces, and thus accommodating themselves to any degree of flexure.

The tegmen of such a calyx must necessarily have been of an extremely pliant nature. But all attempts to obtain it, in sufficiently perfect condition to disclose the nature of the mouth and oral structures generally, have hitherto proved futile. At Crawfordsville, Ind., where two species have been found in large numbers, the specimens almost always have the rays so closely folded together that the tegmen cannot be got at, and, besides, the preservation of fine details

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[1] *American Journal of Science*, (2), Vol. XXIX, p. 79.

at that locality is poor. At Burlington specimens of this genus have not been found in a matrix soft enough to permit the exposure of such delicate structures. At Le Grand, where the *Taxocrinus* disk was found, *Onychocrinus* does not occur—not having been developed in America, so far as yet known, earlier than the Upper Burlington Limestone.

The only known material which seemed to offer a possibility of discovering the tegmen of this genus was that from Indian Creek, Montgomery County, Ind., where *Onychocrinus ulrichi* was obtained in considerable numbers; many of them with the rays completely spread out horizontally, and imbedded in a fine-grained, homogeneous matrix, admitting of minute cleaning. In collecting, these were usually found with the dorsal side exposed and the ventral side embedded, and when the collection was first made from that locality, several such specimens were cleaned without yielding the desired result. Remnants of the disk were observed in some, broken and lying in confusion in the bottom of the cavity, and showing but little of the structure. It was clear that the disk was of such extreme flexibility that it had been forced by the pressure of the calcareous matrix down into the dorsal cavity, and was generally broken and displaced. Recently I undertook the search afresh, and by very delicate manipulation had over a dozen of the best specimens with outspread rays completely freed from the matrix on the ventral side—a very tedious and laborious operation, and sometimes sadly destructive of fine specimens. Some were dissected by the removal of the calyx plates, in hope of gaining access to the under side of the disk.

These efforts were finally rewarded by uncovering, in several specimens, the tegmen in such position as to give a complete elucidation of the structure. The exceptional condition of the specimens, and the exceedingly fine and homogeneous character of the material in which they were imbedded, were all that rendered the discovery of these details possible. With the light afforded by them several others in which the structures were only partially preserved—though much displaced—became easily understood. The construction of this disk is upon the same general plan as that of *Taxocrinus*, but exhibits a very interesting modification of it. It is gratifying to find, in this new discovery upon an additional genus, a full confirmation of our former interpretation of the tegmen of the whole Flexibilia group.

The two most instructive specimens are figured herewith (Plate IV, Figs. 1 and 2), and another which gives a good general idea of the disk (Plate IV, Fig. 3). Fig. 1 will be readily understood by the simple statement that it is the ventral surface of the disk. In Fig. 2 we see the inner floor, or under side of the same structure, which has been exposed by removing the basal, radial, brachial, and interbrachial plates. The disk is so pliant and frail that it is invariably found more or less sunken down, and lying on the bottom of the dorsal cavity. This is why it appears concave in Fig. 1, and convex in Fig. 2. The greater portion of the disk was clearly membranous, with calcareous spicules and granules imbedded in it; except in the oral center, and in the ambulacral regions, which are occupied by rows of large elongate, alternating plates, more or less tumid exteriorly, and keeled on the under surface. These converge in the middle into a rounded, open mouth, which is surrounded by a pyramid of four small, triangular oral plates, meeting a fifth large one on the posterior side. This posterior oral is the most remarkable feature of the disk. It is of enormous size relatively to the other structures, and is very thick and heavy. It is preserved in nearly all the specimens in which the ventral side was cleaned, but as it was usually found lying detached in the bottom of the dorsal cavity, its identity was not recognized until after I found it in place in this specimen (Fig. 1). It is spade-shaped, and the end toward the oral aperture is somewhat hollowed to form one side of the mouth. Both the exterior and interior surfaces of this large plate are shown in the figures—the latter view being at the upper part of Fig. 2. In Fig. 1 this plate seems to be divided by a transverse suture, but I do not find this to be so in other specimens.

The four smaller oral plates are delicate, and they seem to vary somewhat in shape in the different specimens—sometimes appearing quite slender and elongate, and irregular in size. Much of this irregularity, however, may be due to the accidents of fossilization, producing such compression and displacement as might greatly modify the shape and proportions of these delicate structures. In the specimen represented by Fig. 1, two of these plates are perfect and undisturbed, the third somewhat flattened laterally, and the fourth is pushed partly under the others, so that not much of it can be seen in this view. They are triangular, and fit closely together at the sides, forming a small pyramid. As they lie in the bottom of the calyx they seem to stand somewhat erect, but in their natural position, with the disk normally distended, it is probable that they would appear more flattened, like the orals in the recent genus *Holopus* (Plate V, Fig. 8). They were perhaps also movable, capable of opening and closing at the will of the animal. These small orals are not always so regular as this. Fig. 4, Plate IV, which is an enlarged view of the central part of the disk in another specimen, shows the irregular, elongate, toothlike appearance which they sometimes present. The rounded object at the right of the three linear plates is evidently a foreign body, but the other four suggest a stage of almost complete resorption.

The ambulacra are composed of relatively heavy, elongate plates. They meet by close sutures, and are convex on the outer surface. The inner surface is marked by keel-like elevations, which may have served as lines for muscular attachment. They extend from the oral center along the rays to the point of bifurcation, beyond which they have not been traced; but they no doubt follow the arms in a modified form. The three anterior ambulacra pass in between the bases of the four small orals in a similar manner as they do between the plates of the oral pyramid in *Holopus*. The two posterior ambulacra first meet the outer corners of the large oral—at which points there are some larger plates, apparently serving as braces, or supports, for the tegmen—thence they run along the edges of the posterior oral, which sometimes appears to be grooved, and pass in toward the mouth at the junction between it and the smaller orals. Whether these strong alternating plates were covering pieces arching over the food-grooves, or were merely some kind of subambulacral plates forming a support for more delicate plates which were not preserved, or for an ambulacral structure composed only of soft parts, I am unable to determine. The variation in size and shape of ambulacrals in the living Crinoids is very great, and there is no reason why plates as large as these may not have served as covering pieces, opening out when the orals did to admit the inward passage of the food-bearing currents.

The connecting integument between the ambulacra was membranous, reinforced by a close growth of calcareous particles similar to what has been observed in *Taxocrinus*, *Uintacrinus*, and the disk of many Recent Crinoids. It extends far out along the rays, bordering the ambulacra as far as they have been traced. It is extremely frail in the fossil, and is of a slightly darker color than the calyx plates.

In this species the anal plates are very prominent, rising from the posterior basal in the form of a finger-like series, which makes a reverse curve toward the ventral side, the distal end going to the right. It is finely preserved in several of the specimens, but does not appear so plainly in Fig. 1, Plate IV, where it has fallen under the posterior edge of the large oral; but in Fig. 3 it is perfectly shown. It is composed of strong and solid plates, well rounded dorsally, and connecting at the inner side with the membranous integument of the disk, which is sometimes found folded longitudinally alongside of it. This anal appendage does not seem to be actually a tube, as I cannot detect any longitudinal opening or canal through it. In one specimen I find it standing apart from the other plates, and the inner side entirely enveloped in the membrane—thus indicating that the row of strong plates more probably served as a support for a soft tube or opening formed by the protuberance of the membrane itself.

The exact position of the anal opening has not been observed, but it was no doubt at or near the end of the anal series. So far as I can see, the distal end becomes merged in the perisome of the disk, and it is probable that the aperture for the hind gut was at that point. In all the specimens the structures are broken down and displaced in this part, being involved in the downfall of the large posterior oral, so that the exact fact cannot be ascertained. I have no doubt that the anal structure was substantially the same as in *Taxocrinus intermedius*, in which, however, the anal opening has not been definitely located.

In considering the significance of the disk of *Onychocrinus* as disclosed by these discoveries, we must refer to the observed course of development of the larva in one of the living representatives of the Flexibilia, *Antedon rosaceus*. Of this I take the following abstract from Dr. W. B. Carpenter's account[1] of this species in its Penta-

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[1] *Philosophical Transactions*, 1866, p. 727.

crinoid stage, between the time of emergence from the embryo and that of casting off the stem, reference being had to the figures herein:

The animal consists in the first instance of the stem and calyx alone, not even rudiments of arms being distinguishable. The calyx completely incloses the visceral mass, its oral valves when drawn together meeting over the mouth, and when these open out it takes the form of an inverted bell. Its oral part is composed of five oral plates, the approximation of which forms a five-sided pyramid with its truncated apex pointing upwards—though they are usually erected as separate valves, to allow the oral apparatus to be projected from within them. The mouth of the bell, when the oral valves are expanded, is entirely occupied by the oral tentacular apparatus. The general aspect of the young Pentacrinoid, as seen with the tentacular apparatus retracted in a spirit specimen, is shown in Plate V, Fig. 1. The oral plates are triangular in form, their apices pointing upward, but capable of closing so as to form a five-sided pyramidal cover to the calyx (Plate V, Fig. 3). With the further development of the Pentacrinoid, a remarkable change takes place in the relative position of these orals. They do not increase with the other elements of the growing calyx. They continue to embrace the circle of oral tentacles, the diameter of which comes to bear a smaller and yet smaller proportion to that of the ventral surface of the disk; and thus it comes to pass that the circlet of oral plates detaches itself from the summits of the radials on which it was previously superimposed, and is *relatively* carried inward by the great enlargement of the circle formed by the latter—the space between the two series being now filled in only by the membranous perisome, which is traversed by the five radial canals (ambulacra) that pass out from the oral ring between the oral valves to the bifurcation of the arms (Plate V, Fig. 7).

Before the body of the Pentacrinoid drops off its stem, an incipient resorption of the oral plates is discernible, commencing along the margins of the apical portion, so that these plates lose their triangular form and become somewhat spear-shaped (Plate V, Fig. 7). This absorption continues in various degrees; sometimes the upper half of the oral plate disappears, and in other cases the marginal portions only of the upper part of the plate have been removed, leaving a sort of central tongue projecting upward; finally, soon after the Crinoid becomes free, they completely disappear.

The condition presented by the disk of *Onychocrinus* may be considered to be somewhat approximate to that of the last stage of the *Antedon* Pentacrinoid before it casts off the stem, and before the orals are finally resorbed (Plate V, Fig. 7). In the irregularity in the size and shape of the orals in these fossils we may perhaps recognize some of the different stages of absorption in the *Antedon* larva as above described.

We may also compare the morphological condition of our disk with that of P. H. Carpenter's remarkable recent genus *Thaumatocrinus.*[1] His solitary specimen, of which I reproduce one of his figures (Plate IV, Fig. 6), was very small, probably in a young stage. If we imagine it in a more mature condition, with the orals pushed inward and made relatively smaller by the growth of perisome, and the anal tube more or less enveloped by it, we shall have a disk somewhat analogous to ours. Of course the enormous posterior oral of the *Onychocrinus* disk does not find a parallel in any of the recent tegmens. Its pronounced bilateral symmetry is a paleozoic characteristic, strongly marked among the Camerata and Inadunata, as well as in many of the Flexibilia. It is possible that the posterior oral is a madreporite, as has been found in many Cyathocrinidæ. It seems to be perforated with somewhat scattered pores in several specimens, one of which I figure, twice enlarged (Plate IV, Fig. 4). This may be something like the water-pores in the orals of *Holopus*, as shown in Carpenter's figure above cited (Plate V, Fig. 8).

Since obtaining the above-mentioned specimens, I have succeeded in exposing the disk of a specimen of *Onychocrinus exsculptus*, from Crawfordsville—a thoroughly distinct species. While by no means so perfect, it shows that the structure is substantially the same. I have also obtained another disk of *Taxocrinus*, from a much later horizon than *T. intermedius*, which exhibits the same characteristics as the latter species.

FURTHER REMARKS ON THE CRINOIDEA FLEXIBILIA

In a paper in the *American Geologist* for August, 1902 (pp. 88 ff.), I offered some suggestions looking to the systematic arrangement of

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[1] *Philosophical Transactions*, Royal Society, Part III (1883), p. 919.

the Impinnata division of the Crinoidea Flexibilia, dividing them into two main family groups—Ichthyocrinidae and Taxocrinidae. Some of Angelin's Silurian genera, as stated at that time, were arranged with doubt. Since then I have received from Mr. G. Liljevall, of the National Museum at Stockholm—who has at my request made a careful examination of the Swedish material belonging to this group—a set of fine drawings of the principal specimens of Angelin's genera, embracing all the types figured in the *Iconographia Crinoideorum* that can be found, and some other specimens not heretofore figured. These drawings, made with the unrivaled skill and care which characterize all of Liljevall's work, have made clear some points hitherto obscure on account of the notorious inaccuracy of Angelin's figures, and have also led to some unexpected results. In view of the importance of some of these observations, and their bearing upon the classification of this group, I have thought it advisable to publish a brief account of them now as a preliminary note to the work upon it which I have in preparation.

It was shown in the paper above cited that in the family Taxocrinidae there is a progressive variation in the position of the radianal, similar to and somewhat parallel with that observed in the Inadunata, viz.: from a primitive position directly under the right posterior radial, to an oblique position under the lower left corner of that radial in the Silurian, and finally to complete elimination in the Carboniferous. It now appears that there is a similar variation and succession in the position of the radianal among the Ichthyocrinidae. *Anisocrinus* and *Clidochirus* prove to have a large radianal; in the latter in a radial position directly underneath the right posterior radial, as if it were the lower half of it, as in *Temnocrinus;* while *Lecanocrinus* and *Pycnosaccus* have it smaller, and located obliquely under the left part of the right posterior ray, as in *Gnorimocrinus. Homalocrinus* also has the radianal in the primitive position, but it is smaller than in the two first-named genera. In *Mespilocrinus* and other carboniferous forms it has disappeared altogether.

The greatest surprise, however, has been to find a somewhat similar condition among forms which have been referred to the genus *Ichthyocrinus.* The genus has been heretofore considered by everybody as the simplest of all, having a perfectly symmetrical calyx, without anal or interbracial plates, and persisting in this simple form from the Silurian to the Carboniferous. It now develops that this is not true for the Silurian species. Liljevall, while making the drawings for me above referred to upon specimens in the Museum at Stockholm, called my attention to the fact that in all Gotland *Ichthyocrini* the right posterior ray has an extra plate, just like *Temnocrinus tuberculatus*. By cleaning the base of some specimens so that the infrabasals could be seen, he was able to locate the right posterior ray by its being in line with the small infrabasal. It was in this ray that the extra plate was invariably found, smaller than the radial, sometimes visible laterally and sometimes hidden by the column. Here, evidently, was also the radianal in its primitive position. I have much pleasure in according to Mr. Liljevall the credit for this sagacious observation of a fact which had escaped the notice of all of us.

This at once suggested the idea that probably the same thing would be found in the Silurian *Ichthyocrini* from England and America; and an examination of the published descriptions immediately furnished abundant indications of it as to the American species. Hall's figures and diagrams of *I. laevis*,[1] and of *I. simplex*[2] show an extra plate in one ray. So also do his figure of *I. subangularis*,[3] and Ringueberg's figure and description of his *I. conoideus*.[4] A similar condition was indicated in Weller's description of *I. subangularis*,[5] where he says the radials are "generally unequal," and "costals two, rarely three, in each ray." In all of these there appeared to be in one ray four primary plates, instead of three as in the others, though in none of them was the position of the infrabasals accurately shown, so as to determine which ray possessed the extra plate. Indeed, without special preparation the infrabasals cannot often be seen in this genus. Nevertheless, with the facts shown by the Swedish specimens, there seemed no reason to doubt that the irregular ray was here also the right posterior.

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[1] *Palæontology of New York*, Vol. II, Plate 43, Figs. *2a* and *2e*.

[2] *Ibid.*, Plate 46, Fig. *2e*.

[3] *Twenty-eighth Report*, New York State Cabinet of Natural History, Plate XVI, Fig. 13.

[4] *Annals*, New York Academy of Sciences, Vol. V, No. 6, p. 301.

[5] *Bulletin IV*, Chicago Academy of Science, p. 146.

These observations suggested also the idea that, if this should prove to be the fact in the Silurian and not in the Carboniferous species, then we should have a further and most interesting example of evolution in the elimination of the radianal from Silurian to Carboniferous times, within what has been considered as a single genus. With a view to ascertaining the facts definitely, I undertook a careful examination of my specimens, with additional preparation, sometimes grinding off part of the base to expose the infrabasals; and I have also since then had in hand for study good specimens from the Niagara of Canada and New York, most obligingly loaned me by Mr. Byron E. Walker, of Toronto, and Dr. E. N. S. Ringueberg, of Lockport, N. Y. This examination gave the following results:

Silurian Species

I. pyriformis (?), from the Wenlock Limestone, Dudley, England: In a large and quite perfect specimen I removed the stem, and by grinding succeeded in exposing the infrabasals; along with which appeared a radianal under the right posterior radial. This is invisible in a side view, but appears on the flat part of the base, only half as large as the radials in the other four rays (Plate IV, Fig. 3). Another specimen of true *I. pyriformis* in my collection, and three others since examined in the British Museum, show the radianal.

I. laevis, from the Niagara: Eight specimens from New York and Canada show infrabasals and radianal (Plate VI, Fig. 1).

I. subangularis, from the Niagara: Five specimens from Indiana and Illinois show infrabasals and radianal (Plate VI, Fig. 2); and numerous others among the casts of *I. corbis* found at Milwaukee and Chicago which do not preserve the infrabasals, distinctly show the impressions of the radianal.

Carboniferous Species

I. burlingtonensis, Lower Burlington Limestone: Six specimens preserving the rays all around show uniformly a radial and two primibrachs, without any sign of a radianal (Plate VI, Fig. 15). Two of them have the infrabasals well preserved, one both externally and internally.

I. tiaraeformis, Keokuk Limestone, Tennessee: Besides the type, I have five specimens suitable for this study—two from the original locality at White's Creek Springs, Tenn., and three from near Louisville, Ky. Four of them have all the rays visible, and they all show perfect symmetry below the first bifurcation, the rays having uniformly the radial and two primibrachs, without any radianal. In these specimens there is some irregularity in the secundibrachs, one having 4–4 in all rays, and the others having 4–4 in some rays and 4–3 in others. In another specimen the rays are not fully preserved, but the condition is such that, in addition to the radials and some primibrachs, they show the basals and infrabasals very plainly, both internally and externally, and there is no radianal. In the type specimen, however, from the Troost collection in the National Museum at Washington, which preserves all rays intact, there is an extra plate in one ray, which has radial and three primibrachs, while all the others have two primibrachs, with variations of 4–3 to 4–4 secundibrachs. The infrabasals are not visible, and it is impossible to judge whether the extra plate is in the right posterior ray or not. The lower plate in the ray having the extra one is of the same size and shape as the lower plate in the other rays, and does not exhibit the difference which characterizes it in the Silurian specimens. In view of the uniform absence of a radianal in all other Carboniferous specimens, I think we are warranted in considering the presence of an extra plate in this one as a case of sport—just as we have in some specimens an occasional straggling interbrachial.

In *I. greenei*, from the Keokuk Limestone of Indiana, only three rays are visible, each of which has the radial and three primibrachs.

What the condition of the genus was in the Devonian we do not know. It is supposed to occur in the Chemung of New York, but all the specimens that I have seen are too imperfect to afford any information. If any reader of this paper should possess a specimen of *Ichthyocrinus* from the Devonian, with the base or all five rays preserved, I should esteem it a great favor to be advised of the fact.

The result, therefore, of the examination of actual specimens considered to be *Ichthyocrinus* is:

1. All Silurian specimens, without exception, have a radianal in primitive position under the right posterior radial.

2. All Carboniferous specimens (with the solitary exception above

noted) have a perfect pentamerous symmetry below the first bifurcation, and thus have no radianal.

Hence we have in this form an evolution from the Silurian to the Carboniferous, just as is found from

Sagenocrinus to *Forbesiocrinus*,
Gnorimocrinus to *Taxocrinus*,
Clidochirus to *Mespilocrinus*.

The process here shown, substantially parallel with what takes place in the Inadunata, is the elimination of the radianal in paleontological time by rising, or being lifted upward, from beneath the radial, analogous to the migration and disappearance of the anal plate in the larval stages of *Antedon*, of which I shall have more to say later on. If these views are correct, it follows that the Carboniferous form should be separated generically from the Silurian. As *I. laevis*, from the Niagara, is the genotype of *Ichthyocrinus*, it seems proper to retain the genus for the Silurian species and any other that may prove to have a radianal. I therefore propose for the Carboniferous form, and all that may be without a radianal, the genus *Metichthyocrinus*.

As already intimated, *Anisocrinus* and *Clidochirus*, two of Angelin's Silurian genera, also prove to have an unsymmetrical calyx, owing to the presence of a radianal underneath the right posterior radial. In *Clidochirus* it is directly under the ray, in the position of an inferradial (Plate VI, Fig. 7). This is shown in Angelin's figure of *C. pyrum.*[1] The original to his Fig. 6, Plate XVII, which is a restoration from an imperfect calyx, and incorrectly drawn as to the part preserved, is a right anterior view of a weathered specimen of this species; the lower part of the calyx, showing the anal side, is figured herewith (Plate VI, Fig. 8). There is also a third specimen in the Stockholm collection which shows the characters perfectly (Plate VI, Fig. 7). The difference between the two genera is that *Anisocrinus* has the interbrachials all around, while *Clidochirus* has none except at the anal side. The radianal of *Anisocrinus* is not quite so regular in its position as in the other genera having this structure. In *A. interradiatus* it is large, and well underneath the radial. Angelin's figure of his only specimen, Plate XXII, Fig. 18, does not show any

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[1] *Iconographia Crinoideorum*, Plate XXII, Fig. 23.

radianal, but it is perfectly developed in the specimen (Plate VI, Fig. 9), and also in another one since found. In *A. angelini* W. and Sp. (figured by Angelin as *Lecanocrinus macropetalus*) his first specimen[1] has no radianal, and the figure is correct in this respect; but the second specimen[2] has a very distinct radianal, situated obliquely under the left corner of the right posterior radial; while in a third specimen, found since Angelin, the radianal is large, and fully under the radial (Plate VI, Fig. 10). It is quite possible that the first specimen does not belong to this genus, as there is some difference also in the arms.

These two genera differ from *Homalocrinus* and *Calpiocrinus* in having very large basals. It is interesting to note that both of them occur in America. *Lecanocrinus greenei* of Miller and Gurley,[3] and *L. oswegoensis*,[4] both belong unquestionably to *Anisocrinus*. Miller and Gurley's figure of *L. greenei* shows nothing of the radianal, which is plain enough in the specimen, cut off from the lower left part of the right posterior radial (Plate VI, Fig. 11); but in the other species it is shown in their Fig. 16 (Plate VI, Fig. 12). The *Clidochirus* is an undescribed form from our western Silurian.

Liljevall's drawings also enable us to understand the rare genus *Calpiocrinus*, which turns out to be a very curious and extraordinary affair (Plate VII, Figs. 1–8). Angelin described it as having three basals and no parabasals, or, as we should say now, three infrabasals and no basals. Wachsmuth and Springer[5] were much puzzled by the fact that this genus, as described by Angelin, seemed to have but one ring of plates below the radials; but expressed the opinion that this ring of plates "is the analogue of the underbasals, and that the true basals, if not absent, are exceedingly rudimentary." Dr. Bather, on the other hand,[6] states that *Calpiocrinus* "has minute, often obsolete IBB, but fairly large BB." The facts now disclosed show that Angelin's description was wrong; but that Wachsmuth

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[1] *Ibid.*, Plate XIX, Fig. 3, and Plate XXII, Fig. 24.

[2] *Ibid.*, Plate XIX, Fig. 4.

[3] *Bulletin No. 8*, Illinois State Museum, Plate III, Fig. 28.

[4] *Ibid.*, No. 4, Plate III, Figs. 15, 16.

[5] *Revision of the Palæocrinidæ*, Part I, p. 38.

[6] Lankester's *Treatise on Zoölogy*, Part III, p. 189.

and Springer's interpretation of the conspicuous ring of plates was substantially correct. As a matter of fact, there are two rings of plates below the radials—i. e., both infrabasals and basals; but the remarkable thing about it is that the infrabasals are developed to an extent and in a manner unknown in any other Crinoid. In many dicyclic forms the infrabasals lie within the ring of basals, abutting against them by their lateral faces; and they are naturally subordinate in size and position. But here they overlap the basals to such an extent as to sometimes wholly conceal them, and not only them, but also the radials, and even part of the first primibrachs (Plate VII, Fig. 6). In some cases two or more of the basals are visible as mere points (Plate VII, Figs. 3, 8); but usually only the posterior basal projects (Plate VII, Figs. 2, 4). In one specimen no basal at all is to be seen, and the large infrabasals appear externally to be directly surrounded by the radials (Plate VII, Fig. 5).

The three unequal infrabasals form a relatively enormous growth, far exceeding in size the basals, and enveloping them somewhat after the manner of the centrodorsal in *Thiolliericrinus* and other Comatulae. The actual relation of the two sets of plates is shown in specimens like Fig. 6, Plate VII, where the infrabasals have been partly removed, and the basals become plainly visible beneath them, five in number. Thus the basal elements of the calyx are the same as in the group generally—3 IBB, and 5 BB—and the small infrabasal is usually located, as it should be, under the right posterior ray. In addition to the information furnished by Liljevall from the specimens at Stockholm, I have several good specimens of this genus in my own collection, which fully confirm the foregoing observations. There remains no longer any doubt of its real structure, and the genus must therefore be considered as representing a definite, though extravagant and therefore short-lived, modification of the Crinoid plan, in a direction not heretofore noted.

This condition seems to be an exaggeration of that which obtains in many of the Flexibilia, where the infrabasals have a tendency to overlap the basals like a column plate, as in *Forbesiocrinus* and *Taxocrinus*. In these cases the union with the column seems to be stronger than with the calyx; the infrabasals are frequently fused with the top columnal, and remain firmly soldered to it when the column is detached from the calyx.[1] That is what has happened in the specimen figured herein (Plate VII, Fig. 20), where the infrabasals have separated from the calyx in this manner. This feature is the result of the general fact, discovered by Wachsmuth and Springer,[2] and accepted by subsequent authors, that in the Flexibilia generally the top columnal is not the latest formed, as in the Camerata and most Inadunata, but remains as a persistent proximale. This has been believed to be a fundamental character, evidencing the independent nature of the group—though the proof of its universality is, in my opinion, not complete, and there are apparent exceptions to it. The remarkable example of regeneration mentioned by me in my former paper on this subject,[3] where the calyx of a *Taxocrinus* was restored by new growth upon the infrabasals and one basal, is strongly confirmatory of this idea, and suggests that in this group the axial organ as the seat of vitality in the animal, was located very low in the calyx—i. e., within the infrabasals and extending down into the proximal part of the column.

Homalocrinus, which Angelin founded on a single species, *H. parabasalis*,[4] is of a similar type, but the basals are larger and not so much concealed by the overlapping infrabasals (Plates VII, Figs. 9, 10, 11). I was at first disposed to consider it as congeneric with *Calpiocrinus*, until Liljevall's careful study of the type specimen brought to light a small radianal lying beneath the right posterior radial. Then it occurred to me that this was the condition of certain specimens from the Wenlock Limestone of Dudley, England, which had for a long time puzzled me—and for which in my former paper I had suggested the name *Leiocrinus*—and that they would fall nicely under *Homalocrinus*. They accentuate the differences between *H. parabasalis* and *Calpiocrinus*, having larger radianal and more prominent basals. I give figures of two of the specimens (Plate VII, and Figs. 12, 13), and propose for them the name *Homalocrinus dudleyensis*. So far as I know, these two genera are the only Crinoids in which such a peculiar development of the infrabasals is found.

There is a notable difference between them in the arm structure—

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[1] *North American Crinoidea Camerata*, Plate II, Fig. 4*b*.

[2] *Ibid.*, p. 39.

[3] *American Geologist*, Vol. XXX, p. 97.

[4] *Iconographia Crinorde'rum*, Plate XVI, Fig. 29.

Calpiocrinus having twenty main arm branches or trunks, about equal, each pair bearing ramules inside the dichotom; while *Homalocrinus* has ten such main branches. The first, or lowest, ramule is usually the largest, and may sometimes branch again. Variations in this respect give rise to intermediate forms, and while well-marked specimens of the two genera are strikingly distinct, it is easy to see how the two arm characters shade into one another. In *C. fimbriatus* (Plate VII, Fig. 1) it will be seen that the ray bifurcates into two equal divisions, and each of these divides again into two main branches or trunks of about equal size, from the inner side of each of which are given off three or more lateral ramules. In *H. parabasalis* (Plate VII, Fig. 9) and *H. dudleyensis* (Fig. 12) the first bifurcation in the ray produces two main arm branches having similar ramules, of which the lower one is the largest. If this lower ramule increases further, until it approaches the size of the outer branch, and also begins to give off in turn subordinate ramules, then we shall have the condition, approximately, of Fig. 1. Thus we may expect to find intermediate stages of this progression; and when the lower ramule of the ten-branched form becomes considerably enlarged, we are in doubt whether upon this character to call it *Homalocrinus plus*, or *Calpiocrinus minus*. And then comes the old question: Shall we throw them all into one genus because of the connecting links, or maintain the genera upon their typical forms? Of course, the correlation of the radianal, if present, will avoid this difficulty; but I find this to be quite unequally developed in the English forms of *Homalocrinus*, and it is probably so in the Swedish—being so small in the type specimen of *H. parabasalis*. In the former some of my specimens have it only half the size of the radial, some about equal to it; and in some, not otherwise distinguishable, I cannot see it at all. I think the difference in this respect may be partly due to the unequal development of the infrabasals, which may sometimes conceal the radianal, which in this form is located wholly within the ring of basals, as in *Sagenocrinus*. This may also be considered as an interesting case showing how, under the influence of an extravagant modification, characters otherwise important were greatly overshadowed, and a close and rapid transition occurred, tending to produce an intermingling of such characters.

Phillips' genus *Euryocrinus*, which has been heretofore considered a synonym of *Ichthyocrinus*, may now be assigned a definite place in the analysis of the genera. Thanks to the courtesy of Dr. Bather, I have recently had the opportunity to examine the type specimens, now in the British Museum; and they demonstrate very clearly the generic distinctness of this form. It has the regular dicyclic base of the Flexibilia, with 5 BB and 3 IBB—the latter more or less atrophied, or resorbed by the very large axial canal; and it has a series of large anal plates, completely filling the posterior area, together with a small development of interbrachial plates. It has the habitus of the *Ichthyocrini*, and stands close to *Parichthyocrinus*, from which, however, it is well distinguished by the anal structure.

I am also now enabled, by the aid of Liljevall's drawings and some interesting specimens in the British Museum, to treat more definitely the genus *Pycnosaccus*, which was formerly placed as a probable synonym under *Lecanocrinus*. It has fairly large interbrachial areas, which are apparently without well-defined plates, such as are in *Anisocrinus*, but were evidently filled by small, irregular plates which are not preserved in any of the specimens thus far seen. The calyx as observed is strong, and much wrinkled or folded exteriorly. It also frequently has but a single primibrach.

Cleiocrinus, from the Lower Silurian of Canada, which was before arranged with this division of the Flexibilia, may now be left out of it, except as a probable transition form. From an investigation I have recently made of all the known material, this proves to be an even more extraordinary and anomalous genus than *Calpiocrinus*, being probably an intermediate form between the Camerata and the Flexibilia. It has the pinnulate arms and five infrabasals of the dicyclic Camerata, combined with the pliant calyx, with plates united by loose suture, of the Flexibilia.[1]

I exclude from the list of Flexibilia the genus *Rhopalocrinus*, which may be considered as an intermediate form between the Flexibilia and the Inadunata. It has a strong ventral tube, rising high up between the arms. It lacks the pliant calyx of the former group, but rather resembles a dicyclic Symbathocrinoid, and would readily fall under the Inadunata but for the presence of a slightly developed interbrachial system.

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[1] *Memoirs*, Museum of Comparative Zoölogy, Harvard, Vol. XXV, Part 2.

Professors Waagen and Jahn, in Vol. VII of the *Silurian System of Bohemia*, have described a new genus, *Caleidocrinus*, from Stage d 4 of the Bohemian section, which they place near the Taxocrinidae of Angelin, and which Mr. Bather[1] assigns to the Flexibilia Impinnata, and considers to be "a genus that approaches the common ancestor of *Ichthyocrinus* and *Taxocrinus*." Through the kindness of Professor Jahn, who made a special trip to the locality near Zahoran for me, I have been favored with some specimens of *C. multiramus* in as good condition as they are usually to be obtained. They occur in a schist, and all specimens thus far found are so flattened by pressure that none of them show all five rays, and I doubt if it is certain whether the anal side is distinct or not. The condition of preservation is such as to render observation on some points very uncertain. Messrs. Waagen and Jahn[2] say of this:

> The skeleton and elements constituting the body of these sea lilies are changed into a ferric hydrate. By reason of this change there exist only the negative impressions of half the calyx, which are filled with a powder of ferric hydrate.

They state that the figures on Plate 63 are very defective, and they give other figures in the text, partly of the same specimens and partly from better specimens. Even of these text-figures, however, they say on p. 109:

> The preservation of the interradius (*ir*, Figs. 276—316 of the text), and of the anal interradius (*a*, Figs. 276–316 in the text), is so defective that if we can, in some cases, observe the position of the plates which compose them, it is never possible to determine their number.

I have six good specimens in the condition described by the authors, viz., impressions in the matrix filled with powder of iron oxide; and one rather larger than usual in which, by rare fortune, the skeleton of the Crinoid is preserved intact. I have also wax casts of the specimens from which Figs. 1–2 and 11–14 of Waagen and Jahn's work were made, kindly sent to me by Professor Dr. Perner, of the Royal Museum at Prague. In none of these have I been able to identify satisfactorily any interbrachial (interradial) or anal plates. Not having seen all the specimens on which the figures are based, I do not deny the existence of such plates; but I wish to suggest

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[1] *Annals and Magazine of Natural History*, July, 1900, p. 112.

[2] *Op. cit.*, p 107.

that in specimens preserved as these are it is extremely difficult to determine such structures with certainty. Many foreign bodies may become lodged between the rays which might, in the chemically changed condition of the fossils, be mistaken for small, irregular plates. One may even mistake for interbrachials what may be only fragments of arms, as has actually occurred in one case I know. In my specimen with the substance of the Crinoid preserved the radial and brachial plates are well defined, and there is certainly no sign of any plates meeting their margins between the rays. Assuming them to exist, however, as figured by the learned authors, they may be taken to form part of a flexible integument, and the structure would be in a condition analogous to that of the Carboniferous genus *Nipterocrinus*, although otherwise there is no resemblance between them.

Nothing is known of the base; whether it is dicyclic or monocyclic cannot be ascertained from the specimens. The habitus of this form seems to me rather like that of the Inadunata, from which it is separated only by the supposed interbrachial structures. It is certainly a strange and interesting genus, as to which we may well wish for more information. If it had been found in the Jurassic, instead of the Ordovician, I think no one would have hesitated to place it among the Pentacrinidæ.

Dr. Bather bases his conclusion as to the ancestral character of this form upon the statement that it is "older than any flexible genus hitherto known, and the interest is enhanced when we see how its structure accords with its age in the eyes of the evolutionist;" and that "Flexibilia have not hitherto been known earlier than the Wenlock age." In making this statement he must have overlooked the specimens of *Taxocrinus* described by Billings under *Lecanocrinus elegans* and *L. laevis*,[1] which are much older than the Wenlock, and at least as old as the stage of *Caleidocrinus*. They occur in the Trenton Limestone of the Lower Silurian, or Ordovician, at a horizon which has been considered by geologists as substantially equivalent to the Bala of England, which Bather takes to be about equal to the Stage d 4 of Bohemia. And it is, of course, much older than the Wenlock, which is the age of the Upper Silurian, approximately equivalent to the Niagara of America.

[1] *Canadian Organic Remains*, December, IV, Plate IV, Figs. 3, 4.

In the second family group, as formerly defined, subsequent observations have led me to make some important modifications of the arrangement heretofore proposed by me. It has long seemed desirable to find some basis for separating the Silurian species of *Taxocrinus* from the Carboniferous. Considering the changes that have taken place in other types of this group, and especially since the discovery of the facts above stated as to the *Ichthyocrini*, it seemed to me to the last degree improbable that such a form as *Taxocrinus* should persist from the Lower Silurian to the latest Subcarboniferous, without any modification of more than specific importance. Yet upon the basis of any of the characters hitherto regarded as important in this group I was unable to find satisfactory ground for distinction. I was at first strongly disposed to believe that the Gotland species must all, if correctly observed, prove to have an unsymmetrical calyx—that is, with a radianal—and thus belong to *Gnorimocrinus*. But a careful re-examination by Mr. Liljevall of all the specimens at Stockholm, with detailed drawings of each, has convinced me that Angelin's *T. rigens* and *T. oblongatus* have no trace of a radianal. The type specimens of *T. elegans* and *T. laevis*, from the Lower Silurian of Canada, do not show the anal side, but when discovered I should expect to find a radianal.[1]

Finally, however, the solution presented itself in a very simple matter, which has been overlooked hitherto in all researches upon the classification of this group, but which, upon consideration, appears to be of considerable importance. It lies in the condition of the rays below the first bifurcation—that is, of the brachials of the first order. On account of some irregularity in a few cases noted by early observers, it has been handed down as a tradition, and religiously observed, almost since the time of Phillips, that such irregularity in the branching of the rays was a characteristic of the whole group. This fact seems to have diverted attention from the real significance of this structure. In the *Revision of the Palæocrinoidea* this opinion was expressed, and in proof of it allusion was made to the differences in the rays of *Ichthyocrinus*, which are discussed herein, and shown to

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[1] Since the above was written, specimens of both species have been found showing the posterior side, and each has a large radianal in primitive position under the right posterior ray.

be due to the presence of a radianal uniformly in one ray; and to the case of *Forbesiocrinus agassizi*, which will be considered later. I have often heard Wachsmuth emphasize the statement that not only are there irregularities in the rays, but that such irregularity was a positive character of the group.

If we take a specimen like *Taxocrinus affinis* Mueller,[1] we see that the ray bifurcates on the second plate above the radial; or, in other words, the ray has two brachials of the first order, or primibrachs. Examining then the figure of *Taxocrinus splendens* M. and G.,[2] from Crawfordsville, Ind.—the best known Carboniferous species, and found under other names in collections the world over—we shall find that the bifurcation of the ray occurs on the third plate above the radial; that is, it has three brachials of the first order, or primibrachs. The first of these plans is that which prevails throughout the Camerata, with a few exceptions, some of which can usually be explained by the anchylosis or syzygial union of two plates. It now proves to be a fact that it is also the structure of almost every one of the Silurian and most of the Devonian forms of the Flexibilia, with a very few exceptional cases, some of which I believe may be traceable to abnormal specimens. It follows feebly down into the Carboniferous in the genera *Synerocrinus*, *Wachsmuthicrinus*, *Mespilocrinus*, and *Metichthyocrinus*, all of which are rare fossils. It ceased in the Paleozoic, so far as we know, with the Keokuk Limestone, nothing of that form having been seen from the Warsaw, St. Louis, or Kaskaskia, beyond a few individually exceptional cases. Afterwards it appears to have resumed its sway in the group, for it prevails through the Mesozoic and to the present time in the great genera of the Flexibilia Pinnata—*Apiocrinus*, *Millericrinus*, *Uintacrinus*, *Antedon*, and *Actinometra;* the two primibrachs in the later two genera being sometimes united by syzygy.

The second plan, while it may be exceptionally indicated by a few cases in the Silurian and Devonian, became the leading feature of the Carboniferous Flexibilia, where it is conspicuous in numerous species of the widely distributed genera *Taxocrinus* and *Forbesiocrinus*, from the Waverly to the Kaskaskia; *Parichthyocrinus* in the

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[1] *Mon. Echinod. Eifler-Kalkes,* Schultze, Plate 4, Fig. 2.

[2] *Bulletin No.* 8, State Museum of Illinois, Plate 5, Fig. 3.

Burlington and Keokuk; until the culmination of the group in *Onychocrinus*, some species of which regularly add another primibrach. It prevailed exclusively during the Warsaw, St. Louis, and Kaskaskia, after structure No. 1 had disappeared.

Occasional abnormal specimens occur in these genera, but they are rare, and no more than might be expected to occur in a structure so powerfully modified as this. In order to test the possible importance of these exceptions, I tabulated the facts as observed in two abundant species, representing the two leading genera of plan No. 2, with three primibrachs, viz., *Forbesiocrinus multibrachiatus* L. & C. (not the Crawfordsville species erroneously so labeled in many collections, but from a different horizon and locality), and *Taxocrinus spendens* M. & G. (which is the well-known Crawfordsville species labeled in some collections *T. multibrachiatus*, and in some *T. Meeki*). Both were prolific species, flourishing abundantly in two different horizons and localities—thus furnishing the right conditions to show irregularity if it exists. Of these I have a large number of specimens in which five rays are exposed. In thirty such specimens of *F. multibrachiatus*, ranging from very young to adult, all have the regular three primibrachs throughout, except three specimens, which have two primibrachs in one ray. In *T. splendens*, out of eighty-nine specimens—

77 have the regular	3 IBr throughout,
4 have	4 IBr in one ray,
6 have	2 IBr in one ray,
2 have	2 IBr in two rays.

All other rays of these are regular.

Variations as great as this are to be found in the strongest characters of almost any group in nature. Out of a large number of *Pentremites godoni* I have no less than thirty-two specimens with only four rays, and seven with six rays. I have a *Taxocrinus*, otherwise perfect, which has only four rays—there being no sign whatever of a fifth. The seeker after good luck will find by diligent search more four-leaved clovers than he will exceptions to the regular brachial arrangement of *Taxocrinus* and *Forbesiocrinus*.

The case of *Forbesiocrinus agassizi* has been cited as a decisive example of irregularity in this group, being said to vary from one to three primibrachs. I have never seen a specimen with only one, although it might happen as a mere abnormality; but the case is a most interesting one upon the actual facts. This species, from the Burlington Limestone, systematically and regularly departs from the brachial arrangement of all other described *Forbesiocrini*, in having but two primibrachs. It is a rare species, and specimens are especially rare in which all rays are exposed; but usually at least three are visible, enabling us to see the prevailing type. I have thirteen specimens, and have observed seven in other collections, all of which show two primibrachs in the visible rays. There is another form occurring still more rarely in the Burlington Limestone which has the normal arrangement of three primibrachs. It is considerably smaller than *F. agassizi*, but strongly resembles it, and has hitherto been assumed to belong to it. It might be treated as of the same species, which would thus exceptionally embrace representatives of structures elsewhere widely distinct; or, what is perhaps the more rational view, good reason may be given for separating *F. agassizi*, both specifically and generically.

In *Taxocrinus* also there is some irregularity of this kind among certain Devonian species; that is, some individuals have two primibrachs, while others of apparently the same species have three. In a specimen of *Taxocrinus intermedius* from the Kinderhook two rays are irregular, and in the type of *T. nobilis* from the Mountain Limestone, one. Here the Devonian and Lower Carboniferous may be considered the transition period, in which the three primibrachs were being established in the genus. There is also to be seen in occasional specimens in the Kaskaskia a tendency toward reversion to the two-primibrach structure.

Ichthyocrinus greenei, of the Keokuk Limestone, is the only example of *Ichthyocrinus* or its carboniferous representative with three IBr in more than one ray. It is known only from a single specimen, which does not expose the anal side; and we cannot be certain of its generic relations, notwithstanding its close superficial resemblance to the typical *Ichthyocrini*.

I am not concerning myself, however, with the few exceptional cases which may be found; but if anyone will examine such a series of the four leading genera above mentioned as I have before me, with hundreds of specimens of wide geographical distribution and great vertical range, he will see that there is not the slightest doubt of the validity of the distinction between the two plans of structure. If irregularity in the rays were a prevalent character, we would expect, in species of many genera, numerous variations in the number of primibrachs in different rays of the same individual. But we do not find the number varying indiscriminately among the rays; as a matter of fact, such cases are extremely rare. Besides those above noted, I have seen such variation in scarcely a dozen specimens among all the genera, and these are mostly confined to a single ray. We do not find, to any appreciable extent, intermediate forms—not, indeed, so many as might be expected. *Lecanocrinus*, and its allied form *Pycnosaccus*, exhibit some irregularity in a tendency to a single primibrach instead of two. The few known specimens of *Pycnosaccus* vary from one to two plates, both in the primibrachs and secundibrachs. The Silurian species of *Lecanocrinus*, in which the rays are preserved in many specimens, show very few exceptions to the rule of two IBr; but in the Devonian, on the eve of the extinction of the genus, there appears to have been more variability, although our materials for testing it are very meager. Of Schultze's *L. roemeri*, in the only two specimens I know preserving the arms, the number of IBr varies as follows: No. 1, 2–1–1–1–1; No. 2, 2–1–2–2–1. There is also a specimen from the Silurian of Sweden, something like *Calpiocrinus*, which has one IBr all around except in the posterior ray, where an additional one appears, perhaps a radianal. These cases may be explained by supposing the two IBr to have been coalesced by syzygial union, as occurs among the living Comatulae. In *Onychocrinus ulrichi* there is some variation from the rule of four IBr, some rays having three, and others five. This was at about the extinction of the group, of which *Onychocrinus* represents the most extravagant development.

Of course in the Silurian those species with a primitive radianal have a partial equivalent of three IBr in the right posterior ray; but that is constant, and is otherwise accounted for; and it does not affect the rule which prevails throughout the four regular rays. What was the morphological process by which this modification took place, I am unable to explain. The developmental history of the group indicates a tendency to get rid of the extra plate in the right posterior ray, if we have been right in considering that plate—both in this group and in the Inadunata—as a radianal. But the change was not characterized by any indiscriminate individual variations; it must have taken place directly from one structure to the other, through mutations in species and genera. Out of twenty-six specimens of *Temnocrinus tuberculatus* showing the posterior ray, but a single one fails to show the radianal as I have described it.

In the Silurian, the plan of two IBr prevailed almost exclusively—only two generic forms, represented by *Gnorimocrinus loveni* in Sweden, and *Taxocrinus orbignii* in England, having three IBr throughout. One abnormal specimen of *Gnorimocrinus expansus* has three IBr in one ray, and one of *G. tubuliferus* has it in at least three rays. So far as I know, these are all the exceptions in the Silurian. The change was more notable in the Devonian, where some species have both two and three IBr and about one-third of the species heretofore referred to *Taxocrinus* appear with three IBr throughout. The *Taxocrinus* with two IBr persisted into the base of the Carboniferous with one or two species in the Kinderhook and Waverly; but from there on the three IBr structure became universal in this and related genera. The few exceptional cases we know in individual specimens do not fill the gap between the two structures. It was a decided morphological change, affecting the entire brachial system, and as to the *Taxocrini* it took place chiefly in the Devonian.

It follows from these considerations that the Silurian and most of the Devonian species of *Taxocrinus* should be separated generically from those of the Carboniferous. Since *T. tuberculatus* has been removed to form the type of *Temnocrinus*, on account of the possession of a radianal, there remain three species originally referred to the genus by Phillips: *T. nobilis*, *T. macrodactylus*, and *T. egertoni*. In discussing them under his first name, *Isocrinus*,[1] he says that *T. nobilis* and *T. macrodactylus* have four "costals." It is clear that he includes what we now call radials and primibrachs, for on p. 29 he says: "the pentagonal columnar joint is surmounted by five plates (the pelvis of Miller), alternating with which, and above them, are

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[1] *Pal. Foss. Cornwall*, p. 30.

five rows of broad costal and scapular plates, four in each, the last being cuneiform." As *T. nobilis* and *T. macrodactylus* have hitherto been taken as the typical forms of the genus, and according to Phillips' diagnosis they possess the brachial structure No. 2, it seems proper to retain the name for the Carboniferous species and such Devonian or Silurian ones as prove to have this structure. For those species of *Taxocrinus* having the original structure of two primibrachs I propose the genus *Eutaxocrinus*, including provisionally the Silurian *T. oblongatus* and *T. rigens*, which are probably one species, and tend toward *Dactylocrinus* in the arm structure.

In attempting to arrange the genera of the Flexibilia into families, or other subgroups, we have to choose between several kinds of modification on which to base them. We know the life-history of one genus of the Flexibilia Pinnata, viz., *Antedon*. Considering that to represent, in a general way and to some extent, the phylogenetic history of the group, we may assume that its ancestral form would be something like the early larval stage of *Antedon*, with the addition of a radianal, of which no trace or suggestion has yet been found in the embryological researches on that genus, as I understand them. This would give us a dicyclic Crinoid, with a radianal; an anal plate between the posterior radials; two primibrachs, the second one axillary and followed by arm branches; and the ventral side surmounted by a closed pyramid of oral plates. I have attempted to represent the dorsal side of such a hypothetical Crinoid by Fig. 9 on Plate II. The lines of modification from such a form on the dorsal side would be:

a) In the radianal, by migration upward.

b) In the anal system by (1) extension upward in vertical series not connected with brachials, and replacement laterally by perisome; (2) increase upward and laterally in connection with the brachials; (3) elimination of the anal plate.

c) In the brachial system by (1) increase in the number of primibrachs; (2) variation in the mode of branching of the higher brachials or arms.

d) In the interbrachial system, by growth and multiplication of supplementary plates between the rays.

On the ventral side we might expect modification in the same way that we see in *Antedon*, viz., a growth of perisome between the radials and orals, gradually separating the latter plates from the raidals and carrying them inward toward the center. This would give the condition found in *Onychocrinus* and *Taxocrinus;* but the cases in which these structures are preserved in the fossils are too few to enable us to trace any of the successive changes.

a) The first of the above modifications of the dorsal side has been already discussed, both in this and my former paper; and it has been shown that there are to some extent parallel modifications of this character in the two families as formerly defined, which might form the basis of some lesser groups. But the radianal was early eliminated in this group, being known only beyond the Silurian in two Devonian species, and modifications on this line do not cut much figure in the delimitation of the families. There are still some troublesome questions of interpretation among the Swedish species, owing to irregularities. Several of them are represented by only a single specimen, and this in some cases abnormal. These cases will be left for consideration hereafter in greater detail, in the hope also that the discovery of further specimens will throw new light upon them.

b) The generic distinctions based upon the other modifications of the posterior, or anal, area, coming under the second category, are really very striking—more so than can be well expressed in terms of brief analysis. Aside from the matter of the radianal, there are two plans of structure of the anal area, which run side by side from the Silurian to the Carboniferous. They start with the primitive anal plate of our supposed ancestral form, and diverge upon the two lines 1 and 2 indicated above.

1. The first of these plans is one which represents a solid support or backing of an anal tube. It is marked by a vertical row of strong, rounded plates, originating on the posterior basal, rising with a very gradual taper to a considerable height between the rays, and having the appearance of a small, rounded arm. It is connected with, or rather seems grown into, the pliant integument of small, irregular plates which formed the perisome, or ventral covering in this group.

As I have shown by the tegmen of *Onychocrinus*, the perisome developed between the radials and the orals, carrying the latter relatively inward until, instead of covering the whole ventral side as in the very early *Antedon* (Plate V, Fig. 3), they occupied only a small space in the center of the disk, into which the ambulacra converged after traversing the perisome (Plate IV, Fig. 1). In the present modification of the anal side it would seem as if the perisome began to grow with similar energy toward the dorsal side and down between the rays, so that it encroached upon the anal plate on either side as far as the posterior basal; while the upward extension of that plate took the form of a simple vertical series of rounded plates. Hence this armlike row of anal plates is usually found, in well-preserved specimens, bordered upon one or both sides by small, irregular plates, which were a part of the perisomic integument lying between them and the adjacent rays (Plate IV, Fig. 5). This plated integument, in addition to being pliant, was also very fragile, and its preservation in the fossil state is very uncertain and irregular. Sometimes it evidently fell to pieces when exposed between the rays, and no trace of it is found preserved; sometimes it was folded deeply inward between the rays, and so covered with matrix that it has not been observed in the fossils. This has often led to misconception of the real structure, and to misrepresentation of the facts in illustrations. For instance, it was at one time a matter of dispute whether the genus *Taxocrinus*, as then supposed to be represented by *T. tuberculatus* from Dudley, possessed any interbrachial connection between the rays, beyond a possible single plate. Proper cleaning now discloses, in many specimens of that species, the integument of small plates rising high up between the rays and their divisions. The characteristic appearance of this armlike series of anal plates, and also of the perisomic integument, is well shown in Wachsmuth and Springer's figures of *Taxocrinus intermedius*,[1] and also in the various figures of *Onychocrinus* herein (Plate IV).

Sometimes the rays lie so close together that they touch the anal series on both sides, and the bordering integument is thus folded inward so that it cannot be seen from the exterior. Nevertheless,

[1] *Proceedings*, Academy of Natural Science, Philadelphia, November, 1888, Plate XVIII.

the anal plates usually preserve their rounded appearance, and do not seem to form part of the calyx wall, or to be suturally connected with contiguous rays. Such cases as this give rise to difficulties of interpretation, because these are some forms in which the anal plates rise into a single vertical series connected by suture with the adjacent brachials, and flush with them. These must be distinguished from the cases just alluded to, where there is a rounded, armlike row of plates, so closely crowded by the rays that there is neither any part of the integument visible, nor any vacant space on either side, but which were evidently not joined to the brachials by suture. Both cases would answer the description "anals in a vertical series," and yet they undoubtedly represent the two distinct plans, which here, as elsewhere, run into perplexing transition forms.

The armlike row of plates, while not tubular, but on the contrary formed of thick and solid plates, is supposed to compose the dorsal support of an anal tube, formed by the outward growth of the perisome caused by the extrusion of the rectum. If we sometimes in descriptions call this row of plates "tube-plates," or the "anal tube," it must be understood as a conventional term—used by many former writers in this sense—to avoid circumlocution, and not as implying that the plates themselves are hollow, or strictly form the wall of a tube.

Now the position of this row of plates shows in a striking manner the effect of that strange influence which has modified the bilateral symmetry of almost every genus in this entire group. The small infrabasal is almost invariably located under the right posterior ray; the radianal originates under the right posterior ray; it migrates from this position upward until it disappears, but always to the right of the median line; if the arms have an asymmetrical distortion, it is to the right, never to the left. And so this vertical series of anal plates is affected by that tendency, which persists long after the radianal has disappeared. The posterior basal on which it rests is excavated into a sort of shallow socket, like the articulating facet of a radial, on the right shoulder of the plate, so that we will usually see a small tongue or angle of that plate rising up to the left of the base of the anal plate higher than to the right; or, if the socket-like excavation is not so plain as this, the upper edge of the basal is distinctly sloped to the right.

Not only so, but the anal series itself leans to the right, so that the vacant space, or the plated integument if it is preserved, is always widest at the left; and the anal plates are sometimes found firmly cemented by pressure to the side of the right posterior ray, leaving no other plates visible at that side, and giving an appearance of sutural union which must be guarded against in studying these fossils. The shape and position of this anal row of plates are subject to much variation, owing to pressure in fossilization, but the dextrorse asymmetry is almost the invariable rule. There does not seem to be in this form any special equivalent of the anal x. It would naturally be the lowest plate, resting on the posterior basal—the original plate of the *Antedon* larva, or of our supposed prototype—but it has been so encroached upon by the growth of perisome at the sides that it is relatively small, and the plates of the series show only a gradual taper from the proximal end upwards.

This plan of anal structure began in the Lower Silurian, and is found in the Taxocrinoid genera, with or without a radianal, from *Eutaxocrinus* and *Gnorimocrinus* in the Silurian, to *Taxocrinus* and *Onychocrinus* in the Carboniferous, surviving until the Kaskaskia, long after the other plan was extinguished. Being thus so characteristic of that line of genera, it may well be called the Taxocrinus plan. It has persisted to the present time, being found in a very characteristic form in *Thaumatocrinus* (Plate IV, Fig. 6).

2. The second plan is that of a simple extension of the anal system by the addition of other plates of similar solid nature to that of the original plate, and which are joined by sutural union to the adjacent plates of the posterior rays, and also with each other; so that, as far as they extend upward, they are incorporated into the calyx walls in the same manner as the plates of the other interbrachial areas. The posterior basal is either simply truncate, followed by one plate; angular, followed by two plates; or truncate with sloping shoulders, followed by three plates; but in each of these cases all the plates, and others of a similar nature succeeding them, form by sutural union (of course of the loose order characteristic of the whole group) part of the calyx wall.

This form of anal structure is found from the Silurian to the Carboniferous. The primitive stage of it is found in such genera as

Lecanocrinus (Plate VI, Fig. 13), and *Anisocrinus* (Plate VI, Fig. 10), in which the posterior rays arch over the anal plate, leaving no vacant space above it. In *Calpiocrinus* we see its simplest extension by the addition of single plates in succession above it (Plate VII, Fig. 7). In *Temnocrinus* we have a further modification by the addition of two or three plates abutting on the anal (Plate VII, Fig. 15). The development was rapid, for in another Silurian genus, *Sagenocrinus*, in which the dextrorse asymmetry caused by the presence of a radianal is still a feature, we have a perfect example of this plan in its fullest extension, where the anal area, following upon an angular posterior basal, is completely filled to the height of several orders of brachials, with solid plates, forming a regular continuation of the calyx wall. Because of its remarkable development in that genus, this form of anal structure may appropriately be called the Sagenocrinus plan. It is carried forward with equal perfection into the Carboniferous by the genus *Forbesiocrinus*. in which the radianal has been eliminated; and it ends in the Keokuk and Warsaw with species in which the asymmetry of *Taxocrinus* forms without a radianal has nearly disappeared, and the bilateral symmetry of the calyx is almost perfect. In most cases, however, asymmetry may be seen in the longer slope of the right shoulder of the posterior basal (Plate VII, Fig. 20). Where the posterior basal is truncate, the succeeding plate may be taken as the anal *x*, but where it is angular, as is most frequently the case, the anal *x* is apparently split in two, giving rise to two or more series of other plates above. While there are thus a few cases, as indeed we find also in the Silurian in forms like *Calpiocrinus*, which seem to be bilaterally symmetric, yet it is a fact that the dextrorse aysmmetry remains also as a general characteristic of this form as well as the Taxocrinus form. If the posterior basal is angular above, the right sloping face is generally the longest, and the series of plates following it a little the largest; if it is truncate and followed by one large plate which is angular above, the same remark may apply to the second plate; if it is truncate with sloping shoulders, the series from the right shoulder usually seems a little the stronger, and rises higher along the ray than the others.

Between such genera as *Calpiocrinus*, *Temnocrinus*, and *Sagenocrinus* there are considerable variations of this plan; but throughout its entire range—except in certain peculiar transition cases to which I will allude later—there is no suggestion, in the external form, of any such structure as an anal tube.

Under this form, as well as the first, the modification reached the phase of the entire disappearance of the anal plates, first in the Silurian without disturbing the radianal, as in *Ichthyocrinus*, and afterwards in the Carboniferous with complete elimination of that plate, as in *Metichthyocrinus*.

Looking at these well-marked examples of the two plans, one cannot fail to be impressed with their complete distinctness as they stand side by side in the Silurian (Plate VII, Figs. 16 and 18), and in the Carboniferous (Plate VII, Figs. 17 and 20). They run a somewhat parallel course during the greater part of the paleontological history of the group, but not to the end. The Sagenocrinus plan ceases with the genus *Forbesiocrinus* in the upper part of the Keokuk or Warsaw Limestone, while the Taxocrinus plan survives to the last in the genera *Taxocrinus* and *Onychocrinus*. The latter is thus the one character connected with the anal structures which survived from the Lower Silurian to the extinction of the group in the higher Carboniferous, and is continued to the present time in one genus of the Flexibilia Pinnata. Only one specimen belonging to the Flexibilia Impinnata is known from rocks later than the Kaskaskia, and that is an Ichthyocrinoid from the Lower Coal Measures, of which the calyx is unfortunately wanting. When its characters are made known by future discoveries, I shall expect to find it with an anal side of the Taxocrinus type.

Notwithstanding the evident distinctness of the two plans, their early divergence from a common origin which can with reasonable probability be inferred, and their long duration as independent lines of structure, it is nevertheless a curious fact that they also tend to run together, in a sort of convergent evolution, toward the close of their history. I can show most beautifully by actual specimens how this has occurred in the Carboniferous between *Forbesiocrinus* and *Taxocrinus*, not so much in the way of individual variations as in the modification of species. We have a species of *Forbesiocrinus* in the Keokuk Limestone with a firmly plated anal area, in which there is a well-marked vertical series imbedded in the middle, but usually tending toward the right. On the other hand, there is in the same formation, and at apparently the same horizon, a form of *Taxocrinus* in which, while the anal series is rounded and prominent, and merges plainly into the perisome above, the plates of the bordering integument, though still pliant, are strong and heavy, and apparently united to the adjacent brachials by loose suture. In these the modification begun in the last case has evidently been carried to a phase in which the strong structures composing the *Forbesiocrinus* plan have broken down in the anal area, and given place to the opposite one. It thus happens that we are sometimes in doubt to which of the two genera a species ought to be referred; and much of the confusion and shifting of opinion as to the relations of these genera is traceable to the failure to take proper account of these transition forms.

There was thus a sort of struggle for existence between the two plans, and it would seem that the group adhered in the end to that structure which was in best accord with its flexible characteristics; and we may perhaps infer that the Sagenocrinus plan, which tended more in the direction of the Camerate structure, was finally extinguished by reversion to the other one. This was fully accomplished in the Kaskaskia, where there is a species described by Hall as *Forbesiocrinus whitfieldi*,[1] and better illustrated by Miller and Gurley under the name *Taxocrinus wetherbyi*;[2] and of which Wetherby's *Forbesiocrinus parvus*[3] is a young individual—which has the habitus of the highest-developed *Forbesiocrinus* in everything except the anal side, where it is a perfect example of structure No. 1. In fact, the general character of the *Taxocrini* in the St. Louis and Kaskaskia Limestones is that of a strong interbrachial structure in the regular areas, combined with a weak and flexible one in the anal area, containing the conspicuous tube and its bordering integument.

In the first family—Ichthyocrinidae—structure No. 2, in its earlier stages, was the prevailing type, viz., one large plate, with perhaps the addition of a few smaller ones above it, completely filling the area. *Parichthyocrinus* alone of the genera hitherto assigned to the Ichthyo-

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[1] *Geological Survey of Iowa*, Part II, p. 632.

[2] *Bulletin No. 6*, Illinois State Museum, Plate 4, Fig. 3.

[3] *Journal of the Cincinnati Society of Natural History*, Vol. II, Plate II, Figs. 4*a*–*b*.

crinidae, has the Taxocrinus anal structure thoroughly developed. Only its habitus of closely abutting arms differentiates it from *Taxocrinus*, and it must therefore be considered simply as a somewhat abrupt transition form from the Taxocrinidae toward the Ichthyocrinidae, or *vice versa*. But it is most interesting to note that in certain forms referred to *Lecanocrinus* we can almost see the transition actually going on, in the same horizon and locality. In *L. macropetalus*, from the Niagara group at Lockport, N. Y., we have a most characteristic example of the first family—a rounded, ovoid crown, with a perfectly even surface, with rays and arms flat dorsally and in close contact throughout (Plate VI, Figs. 13, 14). It has a single very large anal plate rising above the level of the radials, and curving to a point between the rays, which abut upon it at either side and close over it in an arch. This plate is without depressions of any kind, and is perfectly flush with the general curvature of the crown. In certain other species from the same locality and horizon, this plate begins to be depressed at the sides from the upper end down, so as to leave a ridgelike elevation in the middle, quite resembling the base of our so-called anal tube, while the full dimensions of the plate are still retained. In some specimens of these forms we can see this median ridge continued by a second small rounded plate, of the same form and size, the large anal having lost its pointed angle and become truncate to support this new plate. Here we have the beginning of our armlike anal series. If the process is pushed a little further, so that the depressed lateral margins of the large anal plate become replaced by perisome, we shall have a complete Taxocrinus anal side, and our *Lecanocrinus* will have been transformed into a *Gnorimocrinus*. It is now very curious that the tendency is actually in this direction as to those other characters on which the two families have been separated; for along with these changes in the anal plate there appear marked depressions between the rays and their divisions, which become rounded, with strong tendency to divergence in the upper portions, and to long and delicate arms. Hall's *Lecanocrinus ornatus*,[1] and Ringueberg's *L. nitidus*, *L. incisus*, and *L. excavatus*,[2] are forms in which this interesting modification occurs. I have de-

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[1] *Palæontology of New York*, Vol II, Plate 44, Figs. 2*a–m*.

[2] *Bulletin*, Buffalo Society of Natural History, Vol. V, Plate 1, Figs. 5, 6, and 7.

scribed this as a modification from *Lecanocrinus* toward *Gnorimocrinus.* Of course, we do not know which way it really was, and it is quite possible that the process of modification was in the opposite direction.

Which of these two plans was the primitive one we cannot determine from their paleontological history, as they both doubtless run far back into the obscurity of pre-Silurian epochs. The earliest known species of undoubted Flexibilia type—*Taxocrinus elegans* and *T. laevis* from the Trenton Limestone—I believe to have the Taxocrinus anal side;[1] and, on the other hand, *Cleiocrinus*, from the same horizon, which is at least a transition form with some flexible characteristics, has the opposite anal plan. There is, however, to be considered the question whether the morphological differences which gave rise to this structure have not continued to the present time in the Flexibilia Pinnata; and we may, in that connection, venture an opinion as to their probable origin.

The modifications in the external form of the calyx were undoubtedly due to differences in the position of the anus. If the gut issued from the visceral mass laterally, and remained there, the growing skeleton would be affected by its position, even to the extent of simulating its outline; and the lower down it issued, the more pronounced would be the separation of the rays by the tubelike structure. If it issued ventrally, and from the center of the disk, the skeleton would not be influenced by it at all, but should have perfect pentamerous symmetry. Between these two extremes we should have a wide range of variation in the outward form and arrangement of the anal side. And we may suppose that, as it shifted from a very low, lateral position, toward the margin of the disk, the tubelike row of plates would gradually disappear, or lose its identity by becoming incorporated in plates suturally united to the rays, like those of the regular interbrachial areas. By the time it had shifted well into the central part of the disk, all anal plates would be eliminated from the skeleton. Or the shifting might have taken place in the opposite direction, and the order of the changes in the skeleton have been reversed accordingly; although the first is more in accordance with

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[1] This supposition is confirmed by the discovery of specimens since the above was written.

the observed facts. Such shifting in the position of the rectum is a fact well known in the embryology of the Echinoderms;[1] and it may be remarked that there are instances, both among the Camerata and the Inadunata, where the anus passed out through the test below the level of the arm-bases.

Fortunately for the purpose of our comparison, the only Crinoid whose embryology we know belongs to the Flexibilia. It has been the subject of elaborate and splendid researches by several distinguished and able investigators. The course of development of the anal plate in the larva of *Antedon*, as brought out by the works of these eminent men, lends force to the above suggestion.

Sir Wyville Thomson's account[2] of it is as follows:

> About the period of the development of the second radials, a forked spicule makes its appearance in one of the interradial spaces between the upper portion of two of the first brachial plates. This gradually extends in the usual way till it becomes developed into a round, cribriform, superficial plate. Simultaneously with the appearance of this "anal" plate, a cæcal process like the finger of a glove rises from one side of the stomach and curves toward the plate. The plate increases in size, becomes inclosed in a little flattened tubercle of sarcode, and maintaining its upright position it passes slightly outwards, leaving a space on the edge of the disk between itself and the base of the oral plate immediately within it. Toward this space the cæcal intestinal process directs itself. It rises up through it in the form of an elongated tubular closed papilla. The summit of the papilla is finally absorbed, and a patent anal opening is formed.

Dr. W. B. Carpenter continued the researches begun by Sir Wyville upon the development of *Antedon rosaceus*, and he has given,[3] with most admirable illustrations, the complete history of the anal plate. For the convenience of readers who may not happen to have this work at hand, I reproduce a few of his figures—some on a different scale of enlargement—which will assist me in explaining the thought I have in mind. In quoting some parts of Carpenter's description, I refer to the figures on my own plate instead of to his original numbers. He gives the following statement of the first appearance and subsequent history of this plate (p. 727):

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[1] Bury on "Early Stages in the Development of *Antedon rosacea*," *Philosophical Transactions*, 1888 B, p. 294.

[2] "On the Embryology of *Antedon rosaceus*," *Philosophical Transactions*, 1865, p. 529.

[3] *Philosophical Transactions*, 1866, pp. 671 ff.

> Between two of the radials, and at the same level with them, an unsymmetrical plate early shows itself, the subsequent relation of which to the vent proves it to be an *anal* plate (Plate V, Fig. 4). . . . . Simultaneously with the appearance of the anal plate, a slender digitate process arises from one side of the stomach, and curves toward that plate: this constitutes the rudiment of the Intestine.

This is at a very early stage. At a little more advanced stage, shown by Figs. 5 and 6, Plate V, the account proceeds:

> The single anal plate originally interposed between two of the first radials (R. R.), being attached not so much to the neighboring plates as to the visceral mass, begins to be lifted out (as it were) from between them with the development of the anal funnel; and the space left by it is partly filled up by the lateral extension of the two radials between which it was previously interposed, but which do not yet come into complete contact (p. 732).

At a still later stage:

> The anal funnel (Plate V, Fig. 6) is now a very conspicuous object, the anal plate (x) which it bears on its outer side being altogether lifted out from between the two first radials which it originally separated (p. 734).

The anal plate finally disappears altogether before the adult stage is reached, and the anus takes up its permanent position toward the margin of the disk.

Thus we see that the position and movements of the anal plate are not governed by its connection with other plates of the aboral side, but that they depend upon the shifting and development of the gut, to which it is at an early stage attached. And we can readily trace, in the movements of the plate thus indicated, striking analogies to some of the anal conditions observed among the paleozoic genera.

Now we have, in the two great living genera of the Flexibilia Pinnata, just such differences in the position of the anus—though in less degree—as we have supposed to occur among the ancient forms; viz., that of *Antedon* being excentric, while that of *Actinometra*, alone of all known living Crinoids, is absolutely central. The excentricity of *Antedon*, while producing an anal plate in the larval skeleton, is not sufficient, or sufficiently persistent, to affect the form of the calyx in the adult, which in both genera has perfect pentamerous symmetry. It may be, therefore, that we have in these living genera a reminiscence of the long struggle among their paleozoic antecedents between these opposing tendencies.

We may also be warranted in supposing, from the observed course of development of the anal structures in the larva of *Antedon* as above described, that the Taxocrinus plan represents the earliest and most primitive form, and that the modifications of this in paleontological time were those which tended toward the disappearance of the row of anal plates, with its border of perisome, and the substitution of regular calyx plates, suturally connected with the adjacent rays. Hence the outcome of the struggle in paleozoic time was the survival of the original plan, and the suppression of the modified one.

3. The third modification of the anal structures, which also runs from the Silurian to the Carboniferous, is that in which the anal plate has altogether disappeared, and it is merely a further extension of one of the preceding. This occurred in the Silurian in the genus *Ichthyocrinus*, while still retaining its primitive radianal, which it did not get rid of until the Carboniferous, where, in the genus *Metichthyocrinus*, we have a Crinoid with perfect pentamerous symmetry, so far as the external test shows. Two genera in the division with divergent arms reach this stage also in the Carboniferous—*Wachsmuthicrinus*, in which traces of bilateral symmetry can be seen in the slightly larger size of the posterior basal, and *Nipterocrinus*, in which the pentamerous symmetry seems to be perfect. This modification apparently did not much influence the history of the group.

c) The first modification in the brachial system—i. e., in the number of primibrachs—has already been described and discussed as to its details. There can be little question that the primitive form in this respect was that with two primibrachs. It belongs to the *Antedon* larva, and it prevailed almost exclusively in the Silurian. The few cases in which there is but one primibrach may be explained by the syzygial union of two of the primitive brachials, just as happens in some species of the living *Antedon*, without changing the fundamental plan. The addition of another primary brachial simultaneously in all of the rays, producing the 3-IBr structure, cannot be explained in any such way, and the occurrence of this form in the Silurian is so limited and exceptional that it may scarcely be said to have had a beginning before the Devonian. It is clearly the successor of the first one, in the paleozoic. The two-IBr structure continued from the Silurian through the Devonian, and into the Carboniferous, with constantly diminishing importance, ending, so far as known, in the Keokuk Limestone; but reappearing with the Flexibilia Pinnata in the Mesozoic, and continuing to the present time. The three-IBr structure, on the other hand, having barely made a beginning in the Silurian, shows a steady increase through the Devonian and Carboniferous, and prevailed exclusively in the Warsaw, St. Louis, and Kaskaskia, in the genera *Forbesiocrinus*, *Taxocrinus*, and *Onychocrinus*, with a slight tendency in *Taxocrinus* of the Kaskaskia, to reversion to the original form. Therefore this is not a case of parallel development, but is that of the suppression of the earlier structure, and its replacement by the later one, which disappeared only with the extinction of the nonpinnulate division of the Flexibilia toward the close of the Carboniferous. In the latest and most extravagant genus of the group, *Onychocrinus*, it shows a tendency to further development by the addition of another brachial, not sporadically, but constantly, as a well-defined character among species. From the tenacious grip that this structure had upon several of the strongest genera, it must be regarded as a morphological change of much importance, strongly affecting the phylogenetic history of the group; but yet subordinate, in my opinion, to the great differentiation of the anal structure, and therefore not available for defining large divisions.

The second brachial modification is marked by interesting changes in the mode of branching of the rays above the first axillary from a more or less regular division of the rays by successive bifurcations—dichotomy—to one into large main branches, or arm-trunks, bearing ramules on one or both sides—heterotomy. Both were established in the Silurian, and continued through the Devonian and Carboniferous, and were in force, side by side, in the genera *Taxocrinus* and *Onychocrinus*, at the close of the Subcarboniferous in the Kaskaskia. The dichotomous plan, which was probably the primitive one, was by far the most prevalent throughout; and the heterotomous plan was a modification which, while it ran parallel to the other until the end of the group, did not supplant it. The differences arising out of this modification afford very good characters for generic distinction.

d) The modification in the plates of the interbrachial areas might properly have been considered in connection with those of the anal side, inasmuch as they all belong to the system of supplementary plates, as distinguished from that to which the brachials belong. Sir Wyville Thomson was led by his researches on the embryology of *Antedon*[1] to regard the skeleton of the Crinoid as composed of two systems of plates, which he states to be thoroughly distinct in their structure and mode of growth. These he designated as the *Radial*, and the *Perisomatic*, systems of plates. The former are distinguished by being chiefly made up of peculiar fasciculated tissue of parallel rods, while the latter commence as simple cribriform films embedded in the outer layer of the perisome, and thicken by a repetition inwards of the same diffuse areolar tissue. The Radial system he considers to include the joints of the stem, the centrodorsal plate, the radial plates, and the plates of the arms and pinnules, or brachials. To the Perisomatic system he refers the basal and oral plates, the anal plate, the interradial plates sometimes seen between the second radials, and any other plates or spicules that may be developed in the perisome of the cup or disk. Dr. Carpenter,[2] while not agreeing altogether with Sir Wyville as to the grounds of differentiation of these plates, substantially recognizes the two systems of radial and perisomatic plates as defined by him, except that he ranks the basal plates with the former instead of the latter.

Wachsmuth and Springer[3] divided the plates of the Crinoid skeleton into *primary* and *supplementary* plates; the former including the stem joints, infrabasals, basals, radials, brachials, orals, and ambulacrals, and the latter the anal, interbrachial, and interambulacral plates. According to either of these groupings of the plates, the anals and interbrachials fall under the same category. It was also demonstrated by Wachsmuth and Springer[4] that all plates interposed between the rays, from the basals to the orals, whether interbrachial or interambulacral, belong morphologically to the same ele-

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[1] *Philosophical Transactions*, 1865, p. 540.

[2] *Ibid.*, 1866, p. 742.

[3] *North American Crinoidea Camerata*, pp. 38–105.

[4] "The Perisomic Plates of the Crinoids," *Proceedings*, Academy of Science, Philadelphia, 1892, pp. 345–75.

ment. Hence it follows that, if in the growing Crinoid certain spicules of the ventral perisome developed into well-defined plates, which remained permanently in a definite position in the axils between the radials or brachials, they would become the interbrachial (or interradial) plates as we know them; so that whether a certain form has interbrachials or not depends upon the extent to which the perisome developed downward into the axils.

Some traces of the development of this element are to be found in the *Antedon* larva. Sir Wyvill Thomson[1] thus describes their occurrence:

> In one or two cases I have observed about the time of the first appearance of the anal plate a series of five minute rounded plates, developed interradially between the lower edges of the oral plates and the upper edges of the basals. These interradial plates sometimes remain permanent in the mature *Antedon rosaceus*, and they appear to be constantly present in some species, as for instance in another and rarer British form, *A. milleri*. They usually occur, finally, in groups of three or five. They are irregular in form, and they resemble the anal plate in structure and mode of growth.

Dr. Carpenter figures two clusters of these plates, as seen at the inside of the calyx;[2] and J. S. Miller shows one such plate in each axil of his *Comatula fimbriata*,[3] which he calls "intercostal plates or joints." These observations of the so-called interradial plates in *Antedon* have been rather discredited by some subsequent authors in the course of controversial discussions, but I see no reason for questioning them. The occurrences as described seem to me entirely in harmony with the morphology of the group, and if they had not already been seen, I should confidently expect them to be found by further research.

It is evident from Dr. Carpenter's figure that these plates are more conspicuous on the interior of the young *Antedon* than at the exterior; in other words, that the growth is from within outwards. This accords very well with the observed facts among the fossils of this group. I have many specimens showing how the interbrachial plates diminish in size and number from the interior of the calyx to the exterior. In many cases where they are well developed on the

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[1] *Op. cit.*, p. 540.

[2] *Philosophical Transactions*, 1866, Plate 39, Fig. 7.

[3] *Natural History of the Crinoidea*, Frontispiece, Fig. 2, G.

inside they appear as mere points at the outer surface, and often they do not pass through the wall; so that in a given interradius we may count twice as many plates interiorly as exteriorly. In some genera which are usually without any such plates, a straggling one is occasionally seen, and it is quite probable that, if we could see the interior of all the specimens, we should find many instances of such plates which have not come to the surface. It is a fact thoroughly established that these plates multiply with the growth of the individual; but it would seem that in those forms in which the rays are more or less contiguous, and tend to arch over the interbrachial areas, the plates are crowded by the growth of brachials, and to a certain extent reduced or suppressed at the outer surface of the calyx. In genera like *Taxocrinus*, *Forbesiocrinus*, and *Uintacrinus* the variance of the interbrachials with age is very marked, young individuals in some species having none at all, while the adults are profusely supplied. In *Wachsmuthicrinus*, which has no anal plate, the interbrachials are still more variable, being present or absent in the adult of the same species. In *Nipterocrinus*, and probably in *Pycnosaccus*, and the form described by Angelin as *Forbesiocrinus obesus*, the perisome extended down to the radials as a plated integument, without developing any well-defined interbrachial plates.

Notwithstanding the irregularities in some cases above mentioned, the varying development of the interbrachial plates affords important characters for classification in this group. In some genera the perisome did not extend down between the rays in such a manner as to form any permanent plates in the interbrachial areas; in others they were abundantly developed. Both forms extend from the Silurian to the Carboniferous; the first being characteristic of a little group of genera which may be taken as the typical Ichthyocrinidae, and correlating with another character to be mentioned presently. The tendency in the paleontological history of the group generally is the same as in the individual, viz., toward an increase in interbrachials. But few forms without such plates are found after the Silurian, while in the Carboniferous their presence in considerable numbers is the general rule. Nevertheless, the latter stage was fully attained in the Silurian in the genus *Sagenocrinus*.

There is another modification, not suggested by anything apparent in the primitive type, but affecting the general form and habitus of these Crinoids in a way that is of considerable practical importance. Anyone who has had occasion to arrange the fossils of this group cannot help being struck by the presence of two general types. One is marked by a tendency of the calyx and arms to form a globose, ovoid, or pyriform crown, in which the arms lie in close contact—although in some genera the lower part of the rays are separated by wide interbrachial areas, above which they come together again. In the other, on the contrary, the tendency is toward a spreading crown, caused by the increasing divergence of the rays upward. In the first the plates of the rays and arms, and the intervening interbrachial structures when present, are for a considerable distance up more or less flush with one another exteriorly, so that the general curvature of the crown is but little interrupted. In the second, the rays and their divisions are rounded exteriorly, and the interbrachial spaces relatively depressed, so as to emphasize the appearance of divergence above alluded to.

Between such forms as *Ichthyocrinus* or *Lecanocrinus* on the one hand, and *Taxocrinus* or *Onychocrinus* on the other, there is not the slightest difficulty in distinguishing by the above character. But there are occasional species, otherwise characteristic of the first group which are pretty deeply furrowed between the rays and arms, and some of the second whose arms are habitually rather closely packed together, which we could not so readily assign to their respective groups, except for their evident connection with related genera whose characteristic species fall within them without any trouble. On the other hand, there are a few forms which we are inclined to transfer from the group which they superficially resemble, because of some peculiar association of other characters which indicate a probable closer relationship elsewhere.

Now, I confess myself unable to point out any satisfactory morphological basis for the difference in habitus between these two divisions, and I have much doubt as to its structural importance. Yet it is so constant and well marked in many cases, and affords such a palpable and convenient means of separation in this perplexing group, that we find it of some use in our classifications. It formed a rather too prominent basis of my former arrangement. Both forms existed in the Lower Silurian, and continued into the Carboniferous; the first one greatly diminished and ending in the Keokuk Limestone, with a single exception—probably a transition form—in the Coal Measures; and the second continuing with increasing importance to the end of the Subcarboniferous. The first division comprises a little group of rare genera, mostly confined to the Silurian, but with evident descendants in the Devonian and Carboniferous. They are mostly small, *Ichthyocrinus* alone occasionally attaining a considerable size. In the number of primibrachs and the absence of interbrachials they fall together nicely, and in the structure of the anal side they represent, for the most part, an earlier stage of development of the *Sagenocrinus* plan than those of the other division. The second division, with the divergent arms, embraces genera of both forms of brachial modification, and also the two leading types of anal structure. It appeared in the Silurian, and steadily increased to the close of the Kaskaskia, where it is represented by its most conspicuous example, *Onychocrinus*.

It is evident that most of the modifications above considered have influenced the line of succession from the primitive type of this group, and its separation into subordinate divisions. Each one of them is doubtless a factor entering into the classification that nature has made—though of very different values—and the probability is that every natural division which has been produced is a composite product, the resultant of the interaction of two or more of these tendencies to modification upon independent lines. Just how much influence each has had in fixing the line of succession we have no means of determining. It is possible to arrange the genera upon the basis of either one of the leading morphological changes I have mentioned; but whichever is selected for this purpose, we find our arrangement more or less disturbed by some of the others. For example, a fairly satisfactory arrangement could be based upon the modification of the primary brachials, which would correlate quite well with other characters, if it were not for the fact that this would throw *Sagenocrinus* and *Forbesiocrinus* into different families; whereas the connection betewen these genera is so evident, and the line of descent so probable, that we cannot feel like accepting any scheme which compels their separation. We cannot, of course, represent lines of descent in space of two dimensions, so that anything in the way of a diagram or table would be imperfect, even if we knew all the facts. Still less is it practicable when many of the relationships rest wholly in conjecture.

In some groups of the Crinoids family divisions are most sharply marked. No one need ever be in doubt, from inspection of the calyx alone, whether a Camerate Crinoid belongs to the Rhodocrinidae, Melocrinidae, Actinocrinidae, Batocrinidae, Platycrinidae, or Hexacrinidae. This cannot be said of the Flexibilia. By reason of the fundamental difference in construction of the two groups, there is not in the latter that sharp demarkation between calyx and arms which is so characteristic of most of the Camerata. Here, on the contrary, in by far the greater number of the genera, the calyx passes into the arms by imperceptible gradation, so that in the fossil state, being usually unable to see any part of the tegmen, we cannot tell with certainty where the calyx ends and the arms begin. The different modifications of this structure also shade into one another by various transitions, which is the reason why groups of family rank may be formed, as above stated, which differ somewhat according to the character which is taken as the basis of division.

Nevertheless, it seems possible to form a reasonable opinion as to the relative importance of the characters, as the basis for large divisions:

1. The differentiation of the anal area, being found completely developed in the earliest Silurian, and continuous almost to the end of its history, may be taken as marking the most primitive division of the group. It evidently dominated the lines of descent throughout, and should therefore be accorded first importance in the definition of families, all others being subordinate modifications, affecting one or the other of these lines, but probably not interrupting them.

2. The presence or absence of interbrachials affords a useful basis of subordinate divisions.

3. The differentiation of the brachial system in the number of primary brachials, although evidently affording characters of much importance, is one which has impressed itself with varying force

upon the two primitive lines, and not in a parallel progression. It may be assumed to be a subordinate modification, marking the limitations of genera, and perhaps of sub-family divisions.

4. The difference in general form and habitus, while not explainable upon any known morphological ground, and therefore with our present knowledge apparently of less value than either of the foregoing, nevertheless furnishes a ground for division which is of some practical importance in the construction of a table, and it may therefore be given a rank in our classification perhaps higher than it at present logically deserves.

The other modifications are so palpably limited in their effect upon the history of the group that they need not be considered except in the separation of genera. I do not believe that the higher arm structure is a good character for the definition of families. It appears in parallel successions in other groups of the Crinoids, where it is most interesting in the development from more or less equal branching to radial extensions in the form of main arm-trunks or branches bearing subordinate ramules. This is conspicuously shown among the Camerata in several of the best defined families, viz., in the Rhodocrinidae from *Rhodocrinus* to *Ripidocrinus;* in the Melocrinidae from *Glyptocrinus* to *Melocrinus;* in the Actinocrinidae from *Actinocrinus* to *Steganocrinus;* in the Platycrinidae from *Platycrinus* to *Eucladocrinus;* and in the Hexacrinidae from *Arthracantha* to *Hexacrinus.* Yet there can be no thought of questioning the arrangement of these beautifully defined families on account of these arm characters, or of contending that they represent anything more than a minor variation.

The arrangement of which I am at present in search is one for practical utility, that will facilitate the study of this group; and I am not attempting to express fully the phylogenetic relations of the various forms even as I might conceive them to be, although I have tried to recognize some of the evident lines of descent. Taking as a basis the primitive differentiation of the anal system, the Flexibilia Impinnata may be divided into two groups, and the first of these may be again divided upon the interbrachial system and the general form and habitus. This will give three main divisions, A, B, and C; of which A and B will agree with each other and differ from C in the anal structure, while they will differ from each other in the interbrachials, and partly in the form. In this way the known genera of this group—with the exception of some transition forms whose place is difficult to assign—will fall into three principal family divisions, which differ from each other in various degrees, according as one or the other character is given the greater importance. Each of them contains further groupings of genera upon some of the other characters, which might be given subordinate designations according to our notions of their value.

This might be considered an imperfect attempt to work out the resultant of the several modifications which I have mentioned, and it necessarily encounters difficulties which can be evaded only by some arbitrary—and perhaps temporary—disposition of the disturbing elements. As to these no scheme will ever be perfectly satisfactory, and there will always be some shifting of opinion by different observers, and even by the same observer from different points of view. For instance, as to some of the characters, we cannot always give them the same order of precedence in the tables. If we had genera showing every possible combination of the modifications we have discussed, it might be practicable to construct a table with some uniform order of sequence. We do not, however, find all such combinations, and it is quite conceivable that they were never all accomplished. But it is also to be confidently expected that some additional ones will yet come to light, and we can readily point out some vacancies to be filled by future discoveries.

These three families are not so very different from those heretofore proposed, although the grounds upon which they are defined are considerably changed. In my former paper, above cited, I arranged the genera into two main family groups, based upon the difference in the habitus and general form; and I stated that the second family might perhaps be divided into two subgroups. There is no very material difference in the general arangement I now propose, except that I carry this suggestion a step farther, and erect the two subgroups into families of equal rank with the first, thus bringing in an additional family—Sagenocrinidae—between the other two; while also restricting the first group within somewhat narrower limits.

The definitions of a number of the genera differ considerably from those given by Wachsmuth and Springer in the *Revision oj the Palaeocrinidae*, Part I. Discovery and research since that time have greatly added to our information touching this group, which was then by no means well understood. In *Gnorimocrinus* the typical species is *G. expansus* Ang.,[1] and several of the species listed under this genus in the *Revision* are now found to belong to other genera. For instance, *G. excavatus* Schultze doubtless belongs to *Dactylocrinus;* and perhaps *G. oblongatus* and *G. rigens* also. *G. ovalis*, *salteri*, *interbrachiatus*, and *austini* I have referred to a new genus, *Protaxocrinus;* while *G. loveni*, by reason of its possession of three primibrachs, and a radianal in addition under the right posterior ray, will form the type of another new genus, for which I propose the name *Meristocrinus*.

In *Lithocrinus* the typical species is *L. divaricatus* Ang. (including *L. robustus* syn),[2] which has no radianal; while for *L. obesus*, which has a radianal, and apparently a different interbrachial structure, I have found it necessary to propose a new genus, *Cholocrinus*.

Under *Onychocrinus* there are two well-marked types, represented by *O. ramulosus* and *O. exsculptus*, which probably might be separated generically. The first has three primibrachs, and the latter four; and besides this, the habitus of the two species is so distinct that they can be recognized from the smallest fragments. The *exsculptus* type runs from the Burlington to the St. Louis, and probably to the Kaskaskia, and the *ramulosus* type from the Keokuk to the Kaskaskia.

In like manner, I think it probable that *Forbesiocrinus agassizi* with its two primibrachs, should be separated from the other species of the genus, which all have three. In fact, the analysis of the genera indicates the definition of other new genera which will have to be proposed, in order to cover cases already known or hereafter to be discovered.

The analysis of the Flexibilia genera here given is an improvement upon the former one, resulting from the foregoing observations. In considering any such arrangement, reasonable latitude must be allowed in construing descriptive terms, which cannot be made to fit all cases by any hard and fast lines. It must not be forgotten

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[1] *Iconographia Crinoideorum*, Plate XX, Figs. 15, 16.

[2] *Ibid.*, Plate XXI, Figs. 11, 12, 21.

that the most important characters often shade into one another to a greater or less degree. For instance, in speaking of the arm-branching, we cannot confine the term "dichotomous" to such symmetrically dividing rays as are found in *Cyathocrinus;* but it must be taken to mean simply that the rays divide by a more or less regular bifurcation, as opposed to those in which the branches are given off in the form of lateral ramules markedly smaller than the main trunk, as in *Onychocrinus*, which we call "heterotomous." So as to whether the arms are contiguous or divergent, the terms are relative and not absolute; and while, as in other characters, the extremes are well marked, the two plans of arm arrangement sometimes approach each other so closely that all we can say in some genera is that the tendency is in one direction rather than the other. In the matter of interbrachials, there are really two kinds of plates: the regular, strong plates that occur in the axils, and the small irregular plates or granules forming the pliant integument which extends from the tegmen, in varying degrees, and for varying distances, down between the rays and their divisions. When in the descriptions we speak of "IBr plates," we mean the former.

It must also be remembered that it is impossible in any such scheme to represent the exact degree of relationship of genera, even as we understand it to be. We necessarily grade our divisions according to the greater or less generality of the characters; and we find in some cases that this will throw into different larger groups two genera that we should upon other grounds place next to each other.

Bearing in mind these qualifications, the following analysis may be found fairly practical, according to our present knowledge:

ANALYSIS OF THE GENERA

I. Anal plates, when present, incorporated in calyx by sutural union with adjacent rays.
  A. Rays in contact all around, or separated only at anal side; arms contiguous . . . . ICHTHYOCRINIDAE
    a. Radianal.
      i. RA under r. post. R.
        Primibrachs 2.
          Arms dichotomous.
            Anal *x* alone, or followed by others . . . . *Clidochirus*
            No anals . . . . *Ichthyocrinus*
          Arms heterotomous . . . .

ii. RA rhomboidal, obliquely to left of r. post. R.

Primibrachs 2 (exceptionally I).

Arms dichotomous; IBr 2 or 1.

Anal x alone, or followed by others in series. . *Lecanocrinus* (Cyrtidocrinus)

b. No radianal.

Primibrachs 2.

Arms dichotomous.

Anal x with triangular plate above; arms with dextrorse twist . . . . *Mespilocrinus*

c. No anal nor radianal.

Primibrachs 2.

Arms dichotomous . . . . *Metichthyocrinus*

Primibrachs 3.

Arms dichotomous.

(Anal side unknown, but from form of calyx probably not distinct) . . . . (*I. greenei*) . . . .

B. Rays separated all around by interbrachial plates SAGENOCRINIDAE

a. Radianal.

1. Anal area more or less completely filled by solid plates, forming part of calyx wall.

i. Large anal x alone, or followed by others in single series.

Arms more or less contiguous.

Primibrachs 2 or less.

RA more or less under r. post. R., above the line of BB; iBr few.

Arms dichotomous . . . . *Anisocrinus*

Arms heterotomous . . . .

RA variable, either between BB or absent.

Infrabasals very large, enveloping BB.

Arms dichotomous with ramules inside dichotom; iBr few.

10 main arm-trunks; RA generally present . . . . *Homalocrinus*

20 main arm-trunks; RA generally absent . . . . *Calpiocrinus*

Arms more or less divergent.

RA rhomboidal, obliquely to left of r. post. R.

Arms dichotomous; IBr generally 1.

iBr areas wide, occupied by small, irregular plates; IBr not filling distal face of RR *Pycnosacus*

Arms heterotomous; 10 main arm-trunks with ramules inside dichotom; iBr areas wide; IBr not filling distal face of RR.

(L. obesus n. g.) *Cholocrinus*

ii. Anals numerous, in more than one series.
Arms more or less divergent.
Primibachs 2.
RA more or less between BB.
Arms dichotomous; iBr numerous . *Sagenocrinus*
2. Anal *x* and smaller plates occupying only lower part of anal area.
i. Anals in more than one series.
Arms more or less divergent.
Primibrachs 2.
RA under r. post. R., above line of BB.
Arm dichotomous; iBr few . . . *Temnocrinus*
b. No radianal.
1. Anal *x* and smaller plates occupying lower part of anal area.
i. Anals few, mostly confined to single series.
Arms more or less divergent.
Primibrachs 2.
Arms dichotomous.
IBr areas wide; IBr not filling distal face of RR . . . .
Arms heterotomous.
10 main arm-trunks with ramules inside dichotom; IBr few . . . . *Dactylocrinus*
Arms more or less contiguous.
Primibrachs 2.
Arms dichotomous; iBr numerous (n. g.) *Amphicrinus*
Primibrachs 3.
Arms dichotomous; iBr few . . . *Euryocrinus*
2. Anal area filled by solid plates, forming part of calyx wall.
Anals numerous, in more than one series.
Arms more or less divergent.
Primibrachs 3 (exceptionally 2).
Arms heterotomous.
10 main arm-trunks with ramules inside dichotom.
iBr numerous . . . . . . *Lithocrinus*
Arms dichotomous
iBr numerous . . . . . *Forbesiocrinus*
c. No anals nor radianal.
Arms more or less divergent.
Arms heterotomous. Primibrachs, 2.
10 main arm-trunks with ramules inside dichotom

iBr variable or absent . *Wachsmuthicrinus*

Arms dichotomous; Primibrachs 3.

iBr areas wide; IBr not filling distal face of RR., and connected by integument of small plates.

IBB undivided . . . . *Nipterocrinus*

II. Anal plates, when present, not united by suture with adjacent rays, but in armlike series, more or less separated from them by perisome.

C. Arms generally divergent. . . . . TAXOCRINIDAE

a. Radianal.

i. RA under r. post. R.

Arms dichotomous; iBr few (*T. ovalis*, n.g.) *Protaxocrinus*

ii. RA obliquely to left of r. post. R.

Arms dichotomous; iBr few.

Primibrachs 2 . . . . *Gnorimocrinus*

Primibrachs 3 . . . (*T. loveni*, n. g.) *Meristocrinus*

b. No radianal.

i. Arms dichotomous; iBr variable.

Primibrachs 2 . . . (*T. affinis*, n. g.) *Eutaxocrinus*

Primibrachs 3 . . . . *Taxocrinus*

Arms contiguous . . . . . . *Parichthyocrinus*

ii. Arms heterotomous; iBr variable.

20 main arm-trunks with ramules inside dichotom;

Primibrachs 2 . . . . *Synerocrinus*

10 main arm-trunks, with ramules.

Ramules unilateral, outside of dichotom;

Primibrachs 3 . . . . *Oligocrinus*

Ramules bilateral, branching in clusters on both sides of dichotom; Primibrachs 3 or more.

Onychocrinus

c. No anals nor radianal.

INTERMEDIATE FORMS OF UNCERTAIN PLACE

Between Flexibilia and Camerata.

Dicyclic; higher brachials incorporated in calyx by lateral union; calyx pliant, plates united by loose suture; pinnulate; IBB 5; IBr 2; no iBr except at anal side; anal plates in vertical succession, filling area and connected by suture with adjacent brachials . . *Cleiocrinus*

Between Flexibilia and Inadunata.

Dicyclic; 5 simple arms, free from radials up; except for small, irregular IBr of doubtful extent; habitus of *Symbathocrinus* . *Rhopalocrinus*

Base doubtful; arms dichotomous, branching many times; rays free from radials up, except for possible integument of small plates; anal side doubtful . . . . *Caleidocrinus*

EXPLANATION OF PLATE IV

ONYCHOCRINUS ULRICHI M. and G.

FIG. 1.—The ventral disk or tegmen complete, except as to one ray, which is broken off; view from above, anterior side at the top. It shows the pyramid of four small orals at the center, two of them very plain, the third less so, and the fourth, at the left, pushed in under the others and invisible from this view; the large posterior oral with the ambulacra running along the sides, and the anal appendage bent over to the right under its posterior margin. The rows of ambulacral plates are seen extending from the oral pyramid to and along the rays, with the plated integument between them. The whole disk is now concave, having sunk down into the bottom of the calyx, and the view of the large posterior oral is somewhat foreshortened. The infolding ramules of the arms are well shown in two of the rays.

FIG. 2.—The disk of another specimen, seen from the under side—the calyx plates having been removed; posterior side up. This shows the same structures as Fig. 1, only viewed from the opposite side. The opening between the orals, and the undulating under surface of the posterior oral, are well shown; also the keeled inner surfaces of the ambulacrals.

FIG. 3.—Disk of another specimen, same view as in Fig. 1; showing the same structures, but with the curved anal appendage in plain view, and a portion of the plated integument, or perisome, attached to it at the right. The orals are much displaced, and the view of the posterior one greatly foreshortened; a row of strong plates proceeding from the shoulders of the posterior oral is well preserved in this specimen, perhaps serving as a brace for the tegmen.

FIG. 4.—Detail of central part of disk from another specimen; to show the perforate structure of the posterior oral. In order to get a better light on this plate, the specimen is drawn with posterior side up. This specimen shows but little aside from the posterior oral; the anterior orals are in position, in a more advanced stage of resorption than those in the other specimens; the round object at the right is probably a foreign body. The granules in the tegmen seem to be somewhat larger than usual. ×2.

FIG. 5.—Dorsal view of calyx and two complete rays, showing this aspect of the anal appendage.

THAUMATOCRINUS RENOVATUS P. H. Carpenter

FIG. 6.—View of the disk from above; showing the oral pyramid, the marginal zone of small plates between the orals and the interradials, and the anal tube with its appendage of strong plates. The protuberances seen between the arm-bases are the interradials, which separate the radials all around. (After P. H. Carpenter, *Philosophical Transactions*, Plate 71, Fig. 5. ×15.)

(All figures except 4 natural size).

EXPLANATION OF PLATE V

ANTEDON ROSACEUS

FIG. 1.—Early Pentacrinoid larva, spirit specimen, with its tentacular apparatus retracted; showing basals, radials, and rudimentary primibrachs, and the orals opened out. (From W. B. Carpenter, Plate XXXIX, Fig. 1A. ×15.)

FIG. 2.—The same, at a somewhat later stage, spirit specimen; showing incipient

development of arms from the IBr, and the relative increase in size of radials; cirri not yet developed. (W. B. Carpenter, Plate XXXIX, Fig. 1B. ×15.)

Fig. 3.—Skeleton of early Pentacrinoid larva at a little later stage, dried specimen; showing the manner in which the calyx can be, at that stage, completely closed by the folding together of the orals, *o*, *o;* cirri beginning to appear. (W. B. Carpenter Plate XXXIX, Fig. 2. ×35.)

Fig. 4.—Skeleton of Pentacrinoid larva, same stage as Fig. 2, dried specimen; showing anal plate *x* between two radials, and resting on the posterior basal. (W. B. Carpenter, Plate XLI, Fig. I. ×30.)

Fig. 5.—Skeleton of Pentacrinoid larva, in still later stage; showing the anal plate *x* now being lifted up from between the radials; cirri well started. (W. B. Carpenter, Plate XXXIX, Fig. 3. ×25.)

Fig. 6.—Pentacrinoid larva at a still later stage, when almost ready to cast off the stem. The anal plate *x* detached from the radials (which are nearly closed beneath it), and lifted from between them by the development of the anal tube *a*, to which it is attached; centrodorsal and cirri well developed. (W. B. Carpenter, Plate XL, Fig. 2. ×30.)

Fig. 7.—Opposite view of the same specimen, with one ray removed to show the oral apparatus. The orals, *o*, *o*, now completely separated from the radials, and relatively carried inward by the development of the membranous perisome, *p*. (W. B. Carpenter, Plate XL, Fig. 1. ×30.)

Holopus rangei

Fig. 8.—View of the disk, with closed orals, *o*, *o*, perforated; and small plates at base separating the orals from the radials. (From P. H. Carpenter, *Chall. Rep. St. Cr.*, Plate III, Fig. 2. $\times\frac{5}{2}$.)

Fig. 9.—Hypothetical figure of primitive Flexibilia calyx; with infrabasals, radianal, anal *x* between radials, and two primibrachs.

EXPLANATION OF PLATE VI

(On this and the following plate the radianal is shaded with vertical lines.)

Ichthyocrinus Conrad

Fig. 1.—*I. laevis* Conr. Upper Silurian, Grimsby, Canada.

Fig. 2.—*I. subangularis* Hall. Upper Silurian, Waldron, Ind.

Fig. 3.—*I. pyriformis.* Upper Silurian, Dudley, England.

Fig. 4.—*I. pyriformis* (fide Angelin). ×2. Upper Silurian, Gotland, Sweden. From original to Angelin's XXII, 22.

Fig. 5.—*I. intermedius* Ang. ×2. Upper Silurian, Gotland, Sweden.

Fig. 6.—*I. gotlandicus* W. and Sp. ×2. Upper Silurian, Gotland, Sweden.

These figures all show the extra plate—radianal—at the base of the right posterior ray.

Clidochirus Angelin

Fig. 7.—*C. pyrum* Ang. Upper Silurian, Gotland, Sweden. View from right posterior radius.

Fig. 8.—View from posterior interradius of another specimen—the original to Angelin, XVII, 6.

ANISOCRINUS Angelin

FIG. 9.—*A. interradiatus* Ang. Upper Silurian, Gotland, Sweden. Posterior, view; from original to Angelin, XXII, 18.

FIG. 10.—*A. angelini* W. and Sp. Upper Silurian, Gotland, Sweden. Posterior view. × 2.

FIG. 11.—*A. greenei* M. and G. sp. Upper Silurian, Louisville, Ky. Posterior view.

FIG. 12.—*A. oswegoensis* M. and G. sp. Upper Silurian, Oswego, Ill. Posterior view.

In all these the radianal is seen in primitive position directly below the right posterior ray.

LECANOCRINUS Hall

FIG. 13.—*L. macropetalus* Hall. Upper Silurian, Lockport, N. Y. Posterior view, showing radianal obliquely under right posterior radial.

FIG. 14.—*Ibid.* Anterior view of another specimen, to show absence of regular interbrachials.

METICHTHYOCRINUS n. g.

FIG. 15.—*M. burlingtonensis* Hall. L. Carboniferous, Burlington, Iowa. Without any radianal.

OLIGOCRINUS Springer

FIG. 16.—*O. asteriaeformis* Hall. L. Carboniferous, Burlington, Iowa. Anterior view of one of the type specimens; to show the mode of arm-branching.

PARICHTHYOCRINUS Springer.

FIG. 17.—*P. nobilis* W. and Sp. L. Carboniferous, Burlington, Iowa. Posterior view; anals in tubelike series.

NIPTEROCRINUS Wachsmuth

FIG. 18.—*N. wachsmuthi* M. and W. L. Carboniferous, Burlington, Iowa. Basal view; anal side not distinct; infrabasals probably coalesced.

WACHMUTHICRINUS Springer

FIG. 19.—*W. thiemei* Hall. L. Carboniferous, Burlington, Iowa. Basal view; no anal plates, but posterior basal in this specimen the largest.

(Figs. 4, 5, 6, 8, 9, and 11 after Liljevall.)

EXPLANATION OF PLATE VII

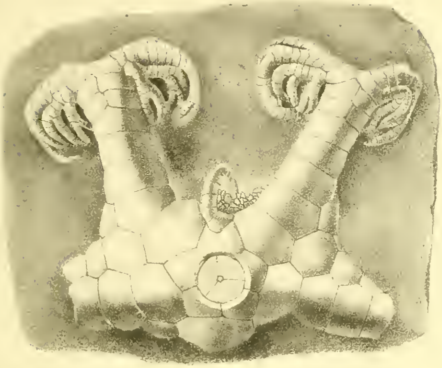
CALPIOCRINUS Angelin

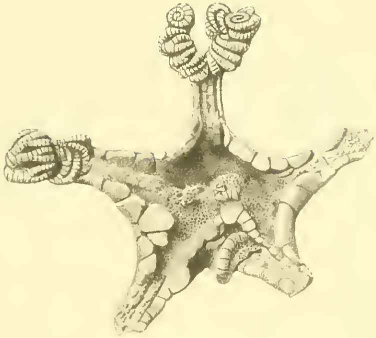
FIG. 1.—*C. fimbriatus* Ang. Upper Silurian, Gotland, Sweden. Anterior radial view; from original to Angelin, XXIX, 77.

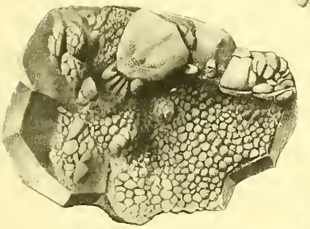
FIG. 2—*Ibid.* Basal view of same specimen; the infrabasals covering the basals except at the posterior side, but partly removed at two places to show points of other basals.

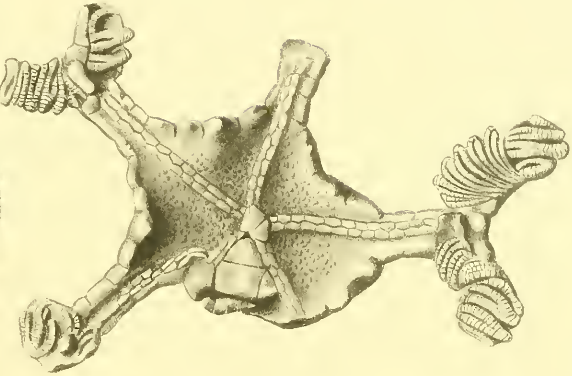
FIG. 3.—*C. heterodactylus* Ang. Upper Silurian, Gotland, Sweden. Basal view of calyx, with column ossicle attached; showing the enormous infrabasals, with posterior and two other basals visible as mere points.

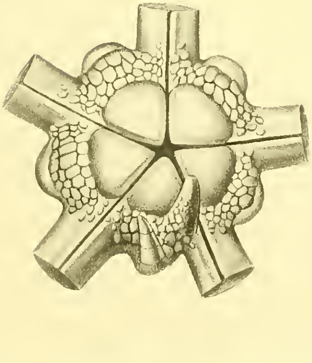
FIG. 4.—*C. ovatus* Ang. Upper Silurian, Gotland, Sweden. Basal view of calyx, from original to Angelin, XVI, 17–19; all basals except the posterior completely hidden by the infrabasals.

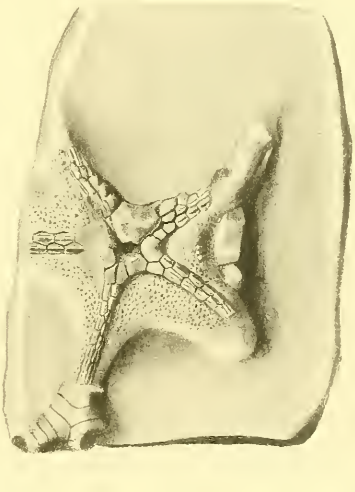


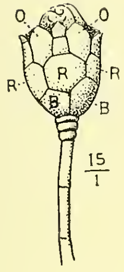












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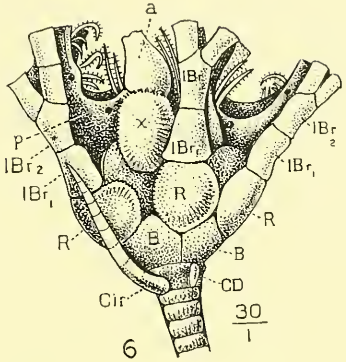

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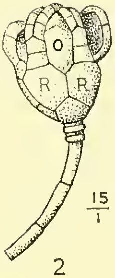

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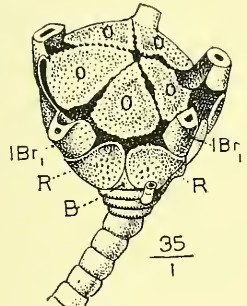

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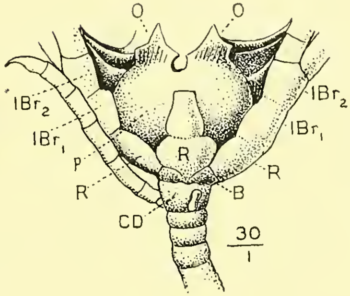

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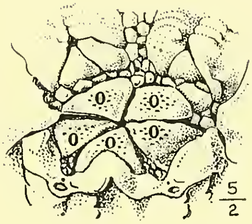

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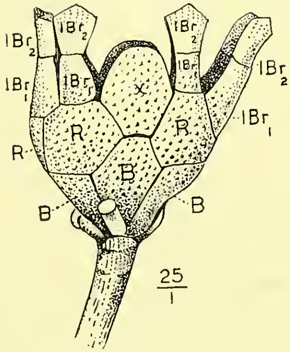

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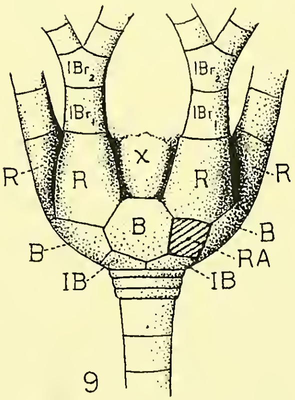

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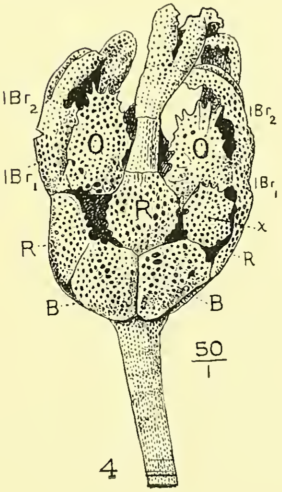

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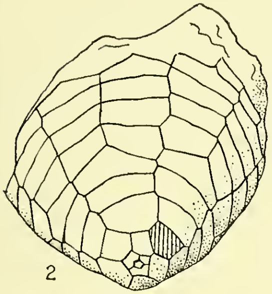
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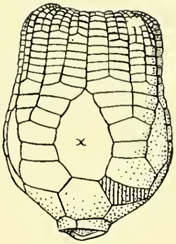
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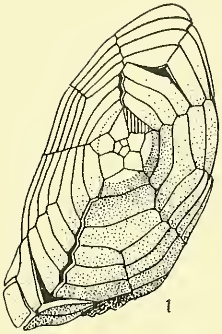
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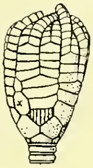
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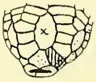
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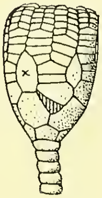
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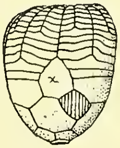
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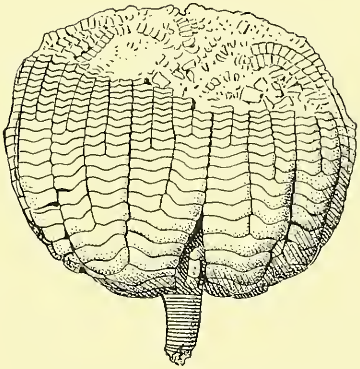
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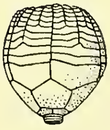
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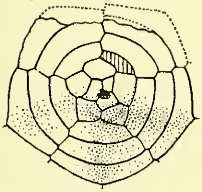
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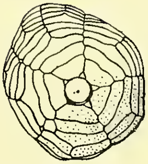
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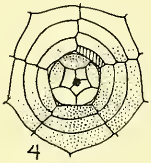
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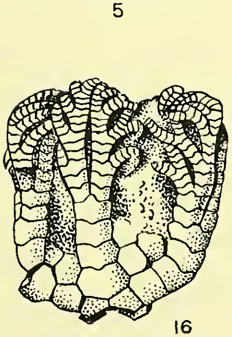
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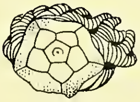
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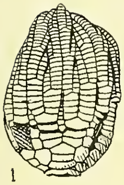
Plate VII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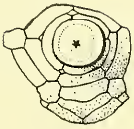
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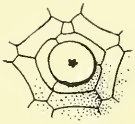
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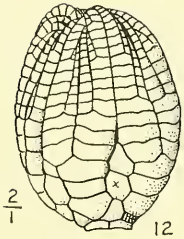

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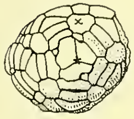
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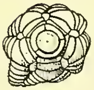
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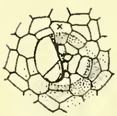
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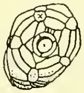
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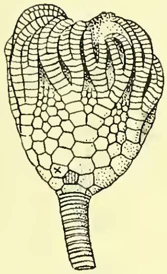
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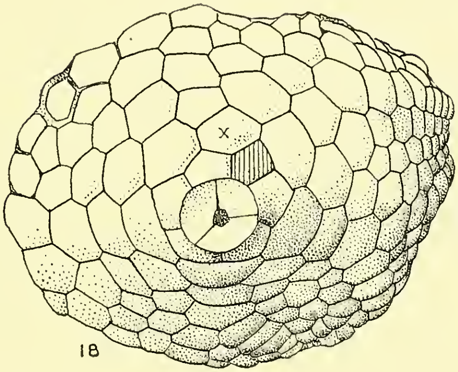
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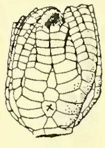
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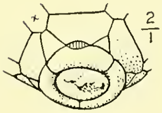

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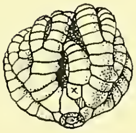
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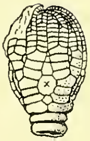
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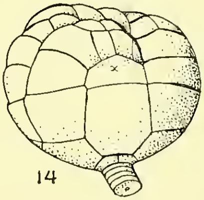
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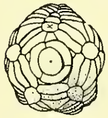
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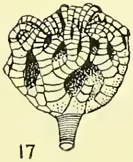
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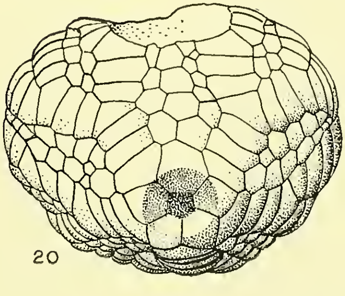
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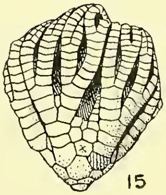
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K. M. Chapman, Del.

FIG. 5.—*Ibid.* Basal view of another specimen, with column ossicle attached; no basal whatever visible.

FIG. 6.—*Ibid.* Basal view of another specimen; the infrabasals enveloping basals, radials, and part of first primibrachs. Part of the infrabasals have been removed, exposing the other plates beneath them, by which their relative positions and proportions can be seen.

FIG. 7.—*C. fimbriatus*, supra. Posterior view of crown with two column ossicles attached; from original to Angelin, XXIX, 7*7b*.

FIG. 8.—*Ibid.* Left anterior radial view of base of same specimen; to show relative proportions of infrabasals and basals.

HOMALOCRINUS Angelin

FIG. 9.—*H. parabasalis* Ang. Upper Silurian, Gotland, Sweden. Posterior view of crown, from original to Angelin, XVI, 29; the very small radianal is visible, directly under the right posterior radial.

FIG. 10.—*Ibid.* Right posterior radial view of base of same specimen; showing radianal more distinctly. ×2.

FIG. 11.—*Ibid.* Basal view of same specimen, showing basals visible all around; radianal cannot be seen in this view. Nat.

FIG. 12.—*H. dudleyensis* n. sp. Upper Silurian. Dudley, England. Posterior view of crown, showing radianal directly under right posterior radial. ×2.

FIG. 13.—*Ibid.* Basal view of same specimen. Nat.

MESPILOCRINUS de Koninck and Lehon

FIG. 14.—*M. forbesianus* de Kon. and Leh. L. Carboniferous, Belgium. Posterior view; no radianal. (After de Kon. and Leh.)

TEMNOCRINUS Springer

FIG. 15.—*T. tuberculatus* Miller. Upper Silurian, Dudley, England. Posterior view of crown; radianal in primitive position as inferradial at base of right posterior ray.

GNORIMOCRINUS Wachsmuth and Springer

FIG. 16.—*Gn. expansus* Ang. Upper Silurian, Gotland, Sweden. Posterior view, from original to Angelin, XX, 16; anals in tubelike series; radianal obliquely under right posterior radial.

TAXOCRINUS Phillips

FIG. 17.—*T. shumardianus* Hall. Lower Carboniferous, Alabama. Posterior view; no radianal; anals in tubelike series, bordered by integument of small plates.

SAGENOCRINUS Austin

FIG. 18.—*S. expansus* Phill. Upper Silurian, Dudley, England. Basal view of a large specimen; radianal within the ring of basals and resting on the infrabasals; anal interredius perfectly filled with solid plates.

FIG 19.—*Ibid.* Right posterior view of smaller specimen.

FORBESIOCRINUS de Koninck and Lehon

FIG. 20.—*F. Washingtonensis* M. and G. L. Carboniferous, Indiana. Basal view of calyx; no radianal, and anal interradius perfectly filled with solid plates. The infrabasals are wanting in the specimen, having been detached with the stem, and fused with the proximal columnar.

(Figs. 1, 2, 7, 9, 10, 11, and 16 after Liljevall.)

STUDIES FOR STUDENTS

RELATIVE GEOLOGICAL IMPORTANCE OF CONTINENTAL LITTORAL, AND MARINE SEDIMENTATION

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PART III. MUD-CRACKS AS A CRITERION OF CONTINENTAL SEDIMENTATION

INTRODUCTION

The previous parts on the relative geological importance of continental, littoral, and marine sedimentation have shown that the bulk of present sedimentary deposits are formed either upon the land or beneath the sea, and that the littoral, restricted to its distinctive limits as that belt of shore exposed between the highest and lowest monthly tides, forms but a relatively narrow transitional zone. Furthermore, it was shown that the chances for preserval of the true littoral deposits are but slight, for if the land is upraised, they are the most superficial deposits and the first to suffer erosion. If the land is slowly sinking, the margin of the sea moving across the land planes away the deposits made in advance of it to the limits of wave action, and this is ordinarily greater than the depth of the littoral deposits. Under these conditions the unlithified deposits formed in advance of the transgressing sea will only be preserved where protected in some manner from the work of the waves which follow.

The most favorable places for the development and also for the preserval of a broad littoral zone were found to be the frontal portions of the larger river deltas. In such places it has been seen that a slow subsidence frequently takes place *pari passu* with the accumulation of river-borne sediment, but the sea does not advance inland, and the littoral deposits are therefore not destroyed, but finally become buried to depths where they are beyond the reach of surface agencies and hence indefinitely preserved. But even in this case the littoral deposits form but a transitional zone between much more extensive and equally well-preserved marine deposits on the one hand and continental flood-plain deposits on the other.

It was furthermore shown that a considerable portion of the sediment of rivers was deposited not beneath the sea, but upon deltas facing and encroaching upon waters of the oceans or their outlying seas. This subaërial deposit of river waste upon deltas not only stands an excellent chance of preserval and incorporation into the geological record, but is ordinarily more important in area and volume than that of the littoral zone which borders it on the seaward side, and becomes most important where the deltas are broadly developed in shallow seas, since the deposits upon the delta surface hold under such conditions, a greater ratio to those deposited in advance of the delta. Even disregarding other important forms of continental deposits, the magnitude of subaërial deltas and the relatively small quantity of the littoral deposits which will be preserved indicate that a much larger place should be given to fluviatile deposits in the geological record and much less to littoral than has been customary in the past.

In that article the distinctive features of the marine, littoral, and continental deposits were incidentally mentioned, as well as the features which they held in common, but the purpose was not to give criteria for their distinction so much as to discuss the relative areal and volumetric importance which they should assume in ancient sedimentary formations deposited under various geographic and climatic conditions. It was urged, furthermore, that formations belonging to these three zones should be sharply discriminated and separated, not only because of the strikingly different conditions under which they were accumulated, but also because of the fundamental importance of such distinction in many problems of paleogeographic and paleobiologic geology.

The present article is supplementary, and it is proposed to take up the subject of mud-cracks as a distinguishing feature and to note to what extent and in what associations they should be expected to occur in various kinds of deposits. Such a discussion seems the more pertinent since in the absence of fossils there are many detrital formations in regard to which there is at present no unanimity of opinion as to whether they were formed by means of either one, two, or three of the following agencies, viz., aeolian, fluviatile, lacustrine, estuarine, or those pertaining to the open shallow sea. It is possible that there are still other formations which have been unhesitatingly ascribed to an origin in shallow seas which may have originated upon the continental surfaces, since on account of the dominance of marine deposition there has always existed a tendency in the absence of fossils of land-dwelling organic forms to ascribe to sedimentary formations an origin beneath the surface of the sea.

METHODS OF ORIGIN OF MUD-CRACKS

The closeness of resemblance between the mud-cracks which are of such frequent occurrence in ancient sedimentary formations of an argillaceous nature and the mud-cracks formed in modern drying mud flats is such that no other origin for these ancient structures has ever been, or seems likely to be, suggested, than that of exposure to the air. They may be formed in any fine-grained argillaceous or limy deposits which upon drying shrink notably in volume. Deposits whose grains are predominantly of sand size cannot give rise to mud-cracks, since when wet the water stands in the pores, and the deposit does not lose markedly in volume upon drying, but only in weight. This limitation in regard to the necessary size of particles requires that the deposit should originate under very quiet waters, which are either removed by evaporation or slowly drained away with bottom velocities of less than a third of a mile per hour, since such a current will lift fine sand.

Mud-cracked surfaces are observed to vary much among themselves. Sometimes they inclose polygons a few inches across, sometimes a foot or more in diameter. In depth they may terminate within a few inches or they may pass downward as many feet. As factors governing the nature of the mud cracks may be mentioned the shrinkage ratio of the deposit; the porosity by means of which water may be conveyed upward by capillarity, tending to prevent shrinkage; the varying nature of the stratified deposit, the cracks not being able to pass through thick strata of sand; the thoroughness of saturation; the length of the period of desiccation; the temperature and dryness of the air. It seems that a thorough observational and experimental study should throw important light upon some of these relations by means of which certain of the conditions attending the formation of mud-cracks in ancient strata could be recognized.

It is possible that a definitive solution is not usually to be obtained on account of the number of the governing factors. But the solution should be narrowed to one of two or three alternatives. For instance, providing that an argillaceous formation is homogeneous throughout, the depth of the crack will probably vary roughly as the square of the time of desiccation. It will also vary with some power of the temperature measured on a centigrade scale, and with some power of the degree of dryness of the air. A knowledge of these values would enable one to say if certain mud-cracks could have been formed in the fortnightly interval between spring tides, or if a season or more of desert heat and dryness were necessary.

As a striking example may be cited the mud-cracks described by Gilbert which penetrate ten feet downward into the variegated shales of the Upper Shinarump of the Jura Trias where exposed on the northern flank of Mount Ellsworth.[1] The formation of these mud-cracks was followed by a complete change of sedimentation at this point into the homogeneous sandstones of the Vermilion cliff group, so that it is quite certain here that the mud-cracks were not formed in the brief interval between two similar tidal invasions. So little is known, however, of the relations between the governing conditions and the characteristics of the mud-cracks that, in the absence of more data, this detailed subject cannot be profitably discussed, and the attention will therefore be turned to the various conditions under which they originate and the associated chemical, textural, and structural features which accompany them in each case.

Such conditions are observed to obtain first, over playas and temporary lakes of arid regions; second, upon the margins of interior lakes; since the latter are peculiarly liable to seasonal fluctuation in level; third, over many river plains as a result of the periodical floods in places where the surfaces are not covered with an arboreal vegetation; fourth, over the higher portions of the littoral zone, where mud-flats or tidal marshes are exposed to the air sufficiently long for the mud-cracks to originate. The littoral in the previous article has been limited to the level which is flooded on the average twice per month by the tides of the new and full moon, since above this limit the tidal flooding is in a manner accidental and occasional and only occurs during abnormally high tides or storms. Mud-cracks will therefore be formed also over an adjacent portion of the continental zone due to unusual elevations of the level of the sea.

CONDITIONS FOR TEMPORARY PRESERVAL OF MUD-CRACKS

Before taking up the detailed discussion of the conditions of origin, relation to other features, and final preserval of mud-cracks, it is desirable to state some conclusions which the writer has reached from observation and experiment upon the conditions necessary for the temporary preserval of the cracks until the stratum shall become buried and form no longer the surface layer.

Experiments were conducted first upon interstratified light brown silty clay and dark brown clay of Champlain age; the former smooth to the fingers, but giving a fine grit to the teeth; the latter

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[1] *Geology of the Henry Mountains* (1877), p. 9.

perfectly smooth to the teeth. Second, upon a modeling clay giving a fine grit and third, upon clay from New Haven harbor, gray-black when wet, light gray when dry, giving a very small amount of fine grit to the teeth. Lack of time did not permit accurate soil analyses to be made of these types.

The Champlain silty clay, firm and strong when removed from the clay pit, was dried and then covered with water. Within from five to ten minutes a stratum half an inch in thickness would soften, swell, and begin to disintegrate, losing all coherency, turning to a creamy mud and the margins sliding down to the angle of repose. The clay and silty clay were then ground up, mixed in nearly equal proportions, allowed to settle in pans from water and dried in the sun. After becoming thoroughly dry and cracked, two out of three pans were baked over gas, one at a temperature up to 70° C., the other above 100° C. This was done in order to test the effects of drying at and beyond the most extreme temperatures of torrid deserts. Upon being covered with water, the swelling and disintegration took place as before, indicating that a mixture of equal parts of pure clay with silty clay would not preserve the stratum from disintegration, and that the highest ranges of temperature found in nature were equally ineffective. Upon drying, cracking, and then rewetting, the lines of the cracks are partly closed by swelling. The remainder becomes filled and veiled with a more fluid mixture, and upon redrying the cracks are established chiefly upon the same lines, indicating a weaker cohesion along the lines of previous cracks. The same feature was observed in the field after a rainstorm, the deeper parts of the cracks having been closed by swelling, but still forming lines of weakness; the upper parts blurred by the slaking of the mud. Upon wetting in the laboratory, adding a new layer, and redrying, the two layers adhered as a unit, and the cracks were twice as widely spaced. Those which formed, however, followed in general previous lines of cracking, and those cracks which did not reopen were still to a slight extent lines of weakness. Finally, the pure clay in strata half an inch in thickness was dried for a couple of weeks at ordinary temperatures, broken, and placed in water. They gradually softened in the course of an hour, but for days retained their sharp edges and showed no tendency to disintegrate, though swelling 5 per cent.

linearly upon the plane of stratification. When rubbed to a batter in water and allowed to dry and crack, the edges disintegrated and the cake softened more rapidly, indicating that the original closer-knit texture had given it superior resistance. Drying and baking up to the boiling-point did not affect the result.

The modeling clay was not baked, but, in all respects tested, behaved like the mixtures of Champlain clay and silty clay.

Finally in August, 1906, excellent opportunities were offered for observing the behavior of the unctious and sticky gray mud of New Haven harbor; a reclamation company building turf walls around many acres of salt marsh land, and pumping water, mud, and sand from the center of the harbor into these artificial reservoirs, the sediment settling and the water draining away. In this way from 6 to 20 feet of sediment were laid down under most favorable conditions for observation. It was found that from mid July to mid August beds of gray mud up to a foot in thickness, resting upon sand, had dried and cracked into irregular polygons 1, 2, and even 3 feet in diameter, the cracks opening from 3 to 4 inches.

Where the mud was thicker, the bottom was still soft, but the top was cracked. Where the water was still standing no cracks had formed, but upon the disappearance of the water they began to appear as wedge-shaped cracks, while the top clay was still soft to the hand and the bottom so fluid as to make walking impossible.

These cracks had formed and the clay underlain by sand had dried and hardened to the depth of a foot during an interval, as stated, from mid July to mid August, during which time the mean temperature was 71° F., the average humidity 0.83, the precipitation, in thirty-one days, 3.0 inches, ten days partly cloudy, and twelve days cloudy.

Rain had failed to efface these cracks, though washing more or less mud into them, especially when the cracks were still young and narrow and the clay not yet hardened. Reflooding by pumping was observed to soften the clay to the consistency of a stiff gelatine and expand it somewhat, but did not obliterate the sharpness of the cracks even in the course of days; and where mud or sand was washed over the surface, the cracks were permanently buried and preserved. Where filled with similar mud and redried, the filling may be detected, even where the crack fails to reopen, by the interruption of the faint lines of stratification at the margins and a slightly marked weakness along this line. When this mud was beaten up with the water, dried quickly over gas and then recovered with water, the air rapidly escaping from the many minute bubbles produced an audible simmering, and the mud, originally so retentive of its form, soon fell into a mush. It was also observed that the dry natural clay was subject to a slight exfoliation upon rapid wetting. These facts point out the importance of close texture, obtained by slow subsidence and long standing under water before drying. This requires the moisture to be transmitted slowly, by capillary action, and allows the mass to expand as a whole.

The conclusions from these observations and experiments will doubtless be somewhat modified by more extensive observations in suitable regions, but may be preliminarily stated as follows:

A mud-cracked loam or silty clay, even when the sand particles are imperceptible to the fingers, is an unfavorable material for the preservation of its detailed surface structures, except possibly when remaining moist, so that but little swelling and exfoliation take place. Upon being wet by rain, the rapid swelling and disintegration of the surface stratum would turn the surface of such a deposit into a creamy mud, which, if remaining *in situ*, might preserve upon redrying blurred impressions of the previous cracks and other larger surface features, but which would be peculiarly liable to be swept away and intermingled with the detritus of the following flood similar to the one which left the material. Even if the flood sweeps down from the mountains upon previously unwet desert plains, the few minutes of wetting necessary would suffice to destroy the detail of surface features before a sufficient new layer of sediment could be laid down. This would seem to explain the mud-lakes into which many playas are transformed during the rainy season. Upon such a formation becoming lithified, the record of mud-cracks might be greatly masked, if not entirely obliterated. The development of joint planes, and even a faint cleavage, would add to the difficulty of detection. Where the finer details of the original surface are preserved, however, or the sharp surfaces of stratification between unlike laminæ, it would seem impossible that the mud-cracks could become completely obliterated. This, therefore, may be a test as to their former presence or absence.

A pure clay, slowly subsiding from quiet waters, and wet sufficiently long to become compact upon drying, would retain its mud-cracks upon rewetting, either by rain previous to flooding or by the flood waters themselves. Such a clay, on account of its tenacity, resists erosion even by quite rapid currents, as is seen from the presence of occasional areas of sticky blue mud on relatively shallow and open parts of the coastal shelf. In case such a sun-baked clay is covered and its cracks filled by a similar layer, it should retain a clear record of the cracks, provided it possesses a well-defined bedding cleavage, since such a cleavage will be interrupted at the margins of the cracks. Such pure and massive clay deposits form, however, the rocks most susceptible to dynamic metamorphism, and a pressure cleavage, even if developed upon the bedding planes, would tend to mask any previous interruptions. Frequently, however, such clay deposits from standing water will be interstratified with more or less arenaceous deposits swept along the bottom by the rising floods. Such sandy wash filling the cracks of the previous clay layer would give a persistent record to the buried mud-cracks. If the sand be sufficiently coarse not to shrink markedly upon drying or swell upon rewetting, the combination of the two kinds of laminæ should give a maximum opportunity for the complete preserval of mud-cracks, footprints, raindrops, and other surface markings. It is noteworthy that this is the typical nature of those beds in the Triassic formations of the Connecticut valley which have preserved such a magnificent record of mud-cracks and footprints. Large portions of these formations, however, consist of rather massive sandy shales or arkoses, and in these the writer has not noted the occurrence of mud-cracks.

On the larger river flood-plains, such as that of the Mississippi, the soil survey of the Department of Agriculture has established three principal types, grouped under the Yazoo series and seven miscellaneous types. Of these ten types only two are clays. The Yazoo clay—a heavy, drab clay loam—occupies low areas back from the low, flat ridges which form the front lands near the stream courses. It is a frequent type of soil. The Sharkey clay is a stiff, impervious clay occupying the lowest portions of river bottoms and subject to annual overflow. Both are characterized by sun-cracks—a characteristic not ascribed to the other types of soil. It is noteworthy that the purer clay, and therefore that more favorable for the preservation of mud-cracks, is deposited, not from flowing, but rather from stagnant back waters, the one at high-water stage, the other when the water-level is lower. Only a portion of the deposits of the larger flood-plains are, therefore, well fitted to retain surface impressions until buried, and this principle must be carried into the past.

It is seen that mud-cracks may originate in pluvial climates, but the thick mat of vegetation apt to form under such conditions would tend, wherever it existed by the binding action of the roots, to prevent cracks from forming. An arid valley climate, therefore, and abundant sediment would be more favorable conditions for the broad development of mud-cracks. Rock decomposition, rather than disintegration at the sources of supply, the mark of a pluvial climate, should, on the other hand, be favorable as furnishing a larger proportion of pure clay mixed with the coarser material.

In conclusion, it is seen that special conditions are necessary for a complete temporary preserval of mud-cracked surfaces even where continued sedimentation without intervening erosion occurs. In formations which show traces of mud-cracks it is to be anticipated that other, more or less argillaceous layers may also have been exposed to the air. Sediments swept along by broad, slow-moving waters will ordinarily possess too much loam for the good preserval of mud-cracks. But where the flood waters stand quietly before being drained away, or where the loam is strained out or settles at another place, the fine clay will settle, forming a deposit free from sand, and capable of retaining even the faintest markings made upon its drying sufrace.

MUD-CRACKS OF PLAYAS

Description.—The characteristics of these may be best appreciated by quoting from Russell's descriptions of the present and extinct lakes of Nevada.[1] Speaking of the ephemeral lakes forming either after the rainy season or even after a single storm he says:

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[1] *The Physiography of the United States* (American Book Co.), Monograph 4, pp. 105–10.

Should the storm continue, the sheets of water in the valleys will expand, and possibly become many square miles in area. Such lakes are always shallow, and always yellow with mud in suspension. When the sun breaks through the storm clouds, evaporation becomes active, and the lakes gradually contract their boundaries, and perhaps in a few hours or in a few days are entirely dissipated. When the water has disappeared, absolutely barren mud plains remain, which harden under the sun's heat, and become cracked in all directions as their surface contracts in drying. The lake beds then have a striking resemblance to tesselated pavements of cream-colored marble, and soon become so hard that they ring beneath the hoof beats of a galloping horse, but retain scarcely a trace of his foot-prints.

Such bare, level mud plains are characteristic features of the greater part of the valleys of Nevada, and are known in Mexico and adjacent portions of the United States as playas. The lakes to which they owe their origin are termed playa lakes. . . . . The largest ephemeral lake of Nevada is formed during winter months on what is known as Black Rock Desert in the northwestern part of the State. This desert valley is irregular in shape, and has lateral valleys opening from it. Its length from northeast to southwest is over one hundred miles, and its average breadth twelve or fifteen miles. In summer it is almost entirely without tributary streams, except such as are fed by hot springs. In winter many brooks descend the mountains to the east and west; and the channel of Quinn River, which enters the basin from the northeast, is transformed into a veritable river. The course of this stream in summer is marked only by a dry channel, with an occasional water hole; but in winter it is flooded so as frequently to be impassable to a man on horseback, and has a length of upward of a hundred miles. Its waters then spread out on Black Rock Desert, and at times form a long narrow lake from 450 to 500 square miles in area. Although seldom over a few inches deep, it is impassable on account of the softness of the mud forming its bottom. Many times the "lake" is a vast sheet of liquid mud, and for this reason is known as "Mud Lake" by the settlers of the region. This name is not distinctive, however, as many other playas have the same name attached to them. . . . .

The winter lakes on Black Rock and Smoke Creek deserts, as in many other similar instances, do not occupy the entire valley bottom, but are surrounded by a broad fringe of what to the eye appears level land. This broadening tract is covered with sagebrush and other desert shrubs. In early spring many flowers beautify the ground, and fill the air with a faint perfume. The playas left by the desiccation of the lake, however, are always barren. Not a plant takes root in their baked and hardened surfaces. Where these mud-plains meet the surrounding areas clothed with desert shrubs, there is often a belt of ground that is soft and marshy in winter, and frequently retains something of this character after the lakes have disappeared. In summer it becomes white with salts brought from below by ascending water, and left on the surface when evaporation takes place. These efflorescent deposits become unusually abundant about some of the hot springs, and are then apt to contain borax in addition to the sulphate and carbonate of soda, common salt, etc., which make up the bulk of such incrustations. . . . .

North Carson and South Carson lakes are of the playa type, but are more persistent than the lakes of Black Rock and Smoke Creek deserts. They sometimes hold their integrity for a succession of years, but evaporate to dryness during seasons of more than usual aridity. North Carson Lake is rudely elliptical in outline, and is from 20 to 25 miles across from east to west, and about 14 miles broad from north to south. That its depth is never over a few feet, has been shown by examining its bed when dry. . . . .

Hundreds of other inclosed basins, particularly in southern Nevada, are partially flooded in winter in a similar manner to those already enumerated, and become desert plains of hardened mud in summer. Various portions of the region surrounding Nevada, and especially those embraced within the boundaries of Utah, Arizona, and California, experience changes similar to those just described, and illustrate some of the most striking peculiarities of a region where the topographic and climatic conditions favor the existence of temporary lakes.

Numerous playa lakes are also found in Australia and in Africa, especially in the Kalahari, and may be looked upon as common features of desert regions where the regolith is not sufficiently deep and sandy to absorb all of the occasionally precipitated water. Playa formations are not necessarily accompanied by conspicuous saline deposits since the clay washed in, and subsiding each year prevents re-solution of the buried salts and may largely exceed them in quantity. The amount of salt will also depend upon the area of the playa to the catchment area and the extent to which ground water contributes. In old desert regions such as the Kalihari there may be thus wide playa surfaces where water stands for a longer or shorter period. Speaking of the Kalihari, Brewer states that "Lake Ngami is fresh in the rainy season, but covers much less surface in the dry season, and is then brackish; and the other lakes of this desert are described as brackish rather than salt."[1]

Nature of the geological records.—The preceding is a description of playa surfaces. In the absence of descriptions of partially eroded playa deposits seen in cross-section the following statement of the characteristics which they would presumably show when incorporated into the geological record must be to some extent deductive and open to corroboration by observation.

[1] Wm. H. Brewer, *Warren's New Physical Geography.*

Playas will be flooded with water partly by means of stream channels, partly by a general wash from the outside over the slopes, partly by a gradual rise of the water level flooding the surface from the inside. In places of inflowing currents, the cracks should fill up with sand and thereby permanently preserve the structure; in places where clay settles in from quiet water, the infiltration may be almost identically the character of the wall materials and the former presence of the crack therefore escape record. The water stands over the flat bottom in periods varying from a few days to a few years, according as to whether it is an evanescent playa or one dry only during an occasional year. The periods of desiccation will vary in inverse order. In general, however, it may be said that the playa bottoms become thoroughly wet for a depth of several feet and undergo some months of desiccation with the formation of deep mud-cracks. Where the deposits are perfectly homogeneous and result in massive saline clays there may be no permanent record of the cracks. As playas are characteristic of typically desert regions there is but little likelihood of the incorporation of an organic record, either of leaves, bones, or tracks. As embodied in the geological record playas should occupy the centers of flat basins in mature desert regions, and in that case their deposits may conceivably attain a thickness of several thousand feet as the mountains are gradually leveled off and their waste accumulated in the tectonic intermontane troughs. Such deposits as seen in cross-section would pass irregularly into marginal waste slopes of coarser material and these in turn end unconformably against the sloping walls of the buried portion of the mountains. Thus their basin nature and limited extent would be evident.

Unless protected, however, by an invasion of the sea or a change to a pluvial climate such deposits as well as the intermediate rocky barriers will gradually be removed by deflation, as Passarge has shown,[1] and the desert will pass into the stages of old age as exemplified by the Kalihari. Throughout this process of erosion shallow playas play an important rôle, since the occasional rains wash the surrounding waste into them and thus tend to maintain a level

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[1] "Rumpfflächen und Inselberg," *Zeitsch. deut. geol. Gesellsch.*, LVI (1904), Protokol., pp. 193–209. Review by W. M. Davis, *Science*, N. S., Vol.XXI, p. 825.

surface. But such deposits must be very shallow since as soon as insolation and deflation have lowered the surrounding tracts these in turn become playa basins and the waste of the former one suffers removal.

Thus ancient playa deposits may be of importance in certain intermontane desert basins of the Tertiary or earlier periods, now suffering stream dissection and exposure, but those of topographically old deserts can be of no importance except possibly as the occasional surface veneer of an ancient continent, such as that of the pre-Cambrian, when it passes unconformably beneath the deposits formed by a marine transgression. In such an event, however, they would doubtless be partly destroyed through marine planation.

MUD-CRACKS MARGINAL TO INTERIOR LAKES

Description.—There are many regions of the world showing all transitions between true salt lakes and fresh-water lakes with perennial outflow.

Where evaporation does not quite balance the inflow of water there may be an occasional discharge, either at the end of the rainy season or only during a series of rainy years. Such lakes without being salt show fluctuating shores, usually very flat, since the water does not stand sufficiently long at one level for the characteristic beach slopes to form. Wide expanses, therefore, may become sun-cracked and thoroughly hardened before the next rise of the lake waters occurs and deposits over them another layer of clay.

Prominent examples of this class of lakes are Titicaca in South America, 80 miles long by 40 broad, and Lakes Tanganyika and Tchad in Africa. Lake Sistan in Persia with a breadth of 60 miles and a length of 100 has been known to go completely dry, while in occasional years during times of heavy flood it sends a stream of water down the Shila.

Nature of the geological record.—In some respects the structures recorded in the formation of the successive laminæ will be similar to playas, but differ in that the exposed area is a transitional belt between a relatively permanent water body and a permanent land surface with its wind and stream-borne detritus. It is more subject to wave-action, building occasional beaches; it may not be salt and may be the seat of a considerable assemblage of living forms. The result is that the lake clays need not be saline, but are likely to be leached of iron or be even carbonaceous and fossiliferous. Footprints may also be common on the shores and the remains of land plants, and animals may become entombed in the deposits. The wash of nearby land waste and the action of waves may fill up the mud-cracks with sand and thus lead to their permanent preservation.

Interior seas are unstable bodies whose shores are ever varying, and which are finally destined to be either dried up into playas, the fate of Lake Lahontan, or to be filled up with sediment, giving rise to river flood-plains, the fate at present overtaking Lake Titicaca, or by becoming fresh to be drained by cutting down an outlet, a change at present in progress in several of the large African lakes.[1] As seen in geological section the mud-cracked margin should be transitional on any one horizon between fine-grained, paper-thin, lake clays, on the one hand, showing no mud-cracks, and the coarser slopes of land waste on the other. In ascending through the formation such mud-cracked shales should oscillate laterally and occupy but a portion of the series. They could hardly, therefore, be a characteristic feature of the sediments in general, nor even of the bodies of shales originating in the lakes of interior basins.

MUD-CRACKS OF RIVER FLOOD-PLAINS

Description of present conditions.—Over all river flood-plains inundations periodically take place, and as the flood waters gradually drain away, a large quantity of fine mud is left upon the surface, perpetually renewing the fertility of the soil. Where the climate is humid, as over the delta of the Mississippi, such regions become seats of luxuriant verdure, while on the contrary in arid or semi-arid regions, an evanescent vegetation may spring up following the flood, but as soon as the water is drained away and the level of the ground water sinks beyond the reach of the plant roots the region becomes a desert until the period of the next inundation. Such regions are abundant over the desert belt of the world, the flood plains of Egypt, of Mesopotamia, and of the Indus River being

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[1] Albrecht Penck, "Climatic Features in the Land Surface, *American Journal Science*, Vol. XIX, p. 171 (1905).

familiar examples.[1] In such regions the conditions of mud-crack formation are at a maximum and may extend to the margin of the littoral zone.[2] Consequently carbonaceous deposits and mud-cracks both mark the land surfaces of aggrading rivers, the one a maximum in pluvial climates, the other in arid. Mud-cracks, as contrasted with coal beds, may thus serve as an index to ancient climates as well as possessing a stratigraphic significance.

In applying this distinction to the earlier geological periods it should be held in mind, however, that there is no evidence of an arboreal or even herbaceous vegetable covering to the land previous to the Silurian, and its surface was presumably devoid of life save possibly that of the lowest cryptogams. Under such circumstances the indications of the presence of former flood-plain surfaces by means of carbonaceous deposits or deoxidizing effects upon the ferric oxide might be entirely absent. Mud-cracks would be the safest remaining indication of the flood-plain nature of the land surface over the regions where the character of the detritus was suitable and periods of desiccation were sufficiently long for the formation of the cracks and hardening of the successive surface layers.

The necessary fineness of deposit is frequently not found on the sandy or gravelly fans of mountain streams, and hence a large per cent. of stream-built deposits could not be expected to show this feature. The necessary conditions are found, however, on all streams of small gradient which broadly overflow their channels, this being characteristically the case of the larger rivers in the lower portions of their courses and especially over the delta, where the argillaceous nature of the deposits is well known. Broadly speaking then, the formation of mud-cracks is non-essential on slopes of piedmont river waste, but is especially characteristic of the larger river plain and delta deposits of arid and subarid climates. That the phenomenon is not strictly confined to even subarid climates is, however, true since humid climates may have their seasons of dryness.

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[1] See for illustration, Daniel Trembly Macdougal, "The Delta of the Rio Colorado" (with map by Godfrey Sykes), *American Geographical Society*, Jan. '06.

[2] Walther, *Das Getz der Wüstenbildung*, 1900, also mentions the occurrence of mud-cracks on arid flood-plains. See *Trockenrissen* in index.

Nature of the geological record.—Flood-plains differ from playas and the shores of interior lakes in important particulars. Playas are formed in local basins or as the ends of desert rivers, usually of limited length. Playas do not fill up valleys from which the rivers escape, but are entirely phenomena of interior drainage. They are not built out against the sea and the deposits are at least brackish from the inclosed salts.

The flood-plain of an aggrading river covers a wide area, in the case of the larger rivers measured by thousands of square miles. It is all periodically subject to inundations which may last for a few days or weeks, but leave the greater part of the surface exposed to the air during much of the year. The invading flood waters frequently sweep sand with them, but after the flood is at its height the waters drain away quietly and much of the fine clay is deposited from suspension. Thus on river flood-plains there is peculiar liability to form well-interstratified deposits of sand and clay: to fill up the last-formed mud-cracks with coarser material, and hence permanently to record them through the varying composition and structure of the formation. Such successive strata of the same nature may be indefinitely accumulated.

Such valleys even in desert regions commonly support considerable life. Drifting vegetation is liable to become buried and animals crossing the half-dried flats in search of fresh water may leave through their foot-prints a record of their visits. The periods of desiccation are seasonal and sufficient to harden this record of cracks, rain-prints, and foot-prints to such an extent that the next invasion of water does not wash it out, but by depositing upon it a new layer of sediment permanently preserves it. As the main streams or their distributaries wander over the plain from century to century they form a network of channels-which cut through the preceding fine-grained layers of the flood-plains, and the channels become filled with sand or even gravel, as they are finally abandoned for new courses. They may be distinguished from the beach sands and gravels of lakes from their linear, treelike arrangement, their occasional cutting-down into the finer-graind layers, and their occurrence far from the margins of the basin.

The mud-cracked strata of flood-plains not only stand excellent chances of temporary preserval until buried, but since the surfaces upon which the fine-grained river waste is deposited are ordinarily near the level of the sea and are also in the case of the greater deposits frequently regions of subsidence, the chances for ultimate preserval of the bulk of the formation is, in such cases, as favorable as that of the true marine shallow-water deposits.

Again, flood-plain surfaces are not of a transitional or temporary geological nature, like the margins of interior lakes, or the borders of the sea, but they are the ultimate physiographic forms toward which both lakes and shallow seas tend by the filling-in of river waste. They are of broad occurrence at all times of continental extension and erosion, and should be looked for in the geological column as only second in importance to the off-shore deposits of the continental shelves and seas. But although flood-plains are most commonly built near the margins of the land and encroaching as deltas upon shallow seas, they are also found to occur over the regions of gräben or troughs of subsidence, such as those of the Rhine, and of other tectonic valleys, and also over interior basins. Murray has estimated the desert areas, that is those which do not drain to the sea, as one-fifth of the continental areas. Doubtless, at least another fifth is possessed of a climate marked by sufficient seasons of drought to allow the broad formation of mud-cracks upon flood-plains, following the subsidence of the flood waters.

This natural condition is, however, largely modified at the present time by the agency of man, since, by regulating the floods and by systems of irrigation, such regions become the seat of populous societies. It has been shown in the previous article that the deposits of flood-plains should enter more largely into the geological record than is usually appreciated. Combining this conclusion with these considerations in regard to climate it is seen that in those past times, which corresponded in general to present conditions, an appreciable fraction of argillaceous deposits should be characterized by mud-cracks formed upon flood-plains, and, on the other hand, in regions where the mud-cracks of the period are missing, another appreciable fraction should by their carbonaceous and organic contents bear witness of the verdure which prevails upon the river plains of pluvial climates.

Besides these general stratigraphical relations which should characterize the mud-cracked deposits of arid flood-plains may be mentioned other associated characteristics, some of which are pointed out by Walther.[1] Such deposits are usually rather barren of fossils of water-living forms; the latter, if present, are apt to be restricted to the lines of sandstone which mark the ancient channels[2] or to the deposits of shallow lagoons. The flood plain proper is more likely to contain the remains of air-breathing forms, but as conditions must have been frequently unfavorable for their life or for their preserval after death the strata are more usually barren.

Further, land deposits on account of the local and annual variations of conditions are apt to show various sorts of deposits—water borne, wind borne, organic, and volcanic, in close association but differentiated from each other. Marine deposits are not subject to this rapid variation and more gradual transitions are observed.

Deposits formed in rivers or in lakes and seas have usually greenish or bluish shades of color as in marine deposits. Those subjected to subaërial exposure, however, under arid or subarid conditions are apt to possess a normal content of iron owing to the absence of carbon and the opportunity for complete oxidation following the subsidence of the ground water. The river muds from which the iron has not been leached by the deoxidizing influence of vegetation may thus be yellow, brown, or red. In well-lithified but still unmetamorphosed formations, in which the iron still exists in the form of a free oxide, reds predominate, whereas in modern muds derived from the erosion of granite lands yellow or brown is observed to be the prevailing color. But Crosby[3] has shown that a gradual dehydration of the ferric oxide serves to transform colors originally yellow and brown into deep red or vermilion.

River deltas normally contain abandoned channels or lower tracts of country not yet built up which are more or less permanently flooded with fresh water. Such are usually the seats of luxuriant vegetable growth and abundant animal life, even under climates where the

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[1] *Einleitung in die Geologie* (1893), pp. 719–26.

[2] J. B. Hatcher, "Origin of the Oligocene and Miocene Deposits of the Great Plains," *American Philosophical Society*, Vol. XLI (1902).

[3] "On the Contrast in Color of the Soils of High and Low Latitudes," *American Geologist*, Vol. VIII (1891), pp. 72–82.

other portions of the delta may be dry and barren during a greater portion of the year. The decaying material of such fresh-water swamps, being preserved by the water covering, will serve to deoxidize the iron to the ferrous state, and even if the carbon is not sufficient in amount to color by its balance the argillaceous strata to brown or black, its former presence will still be indicated by gray or green bands of shales. Thus delta regions of subarid climates are peculiarly liable to be forming deposits which will ultimately become variegated shales, in which maroon, deep red, or vermilion bands will pass, sometimes almost without change of texture, into bands of grayish-white or green. An example of such variegated strata recently made is described by Huntingdon as having formed in the basin of eastern Persia and Sistan.[1]

The seaward portion of the delta surface is also frequently covered between the distributaries by brackish or salt-water lagoons and bays, as in the Nile and Mississippi deltas, protected from the waves and possibly containing considerable life of estuarine types, whose decay will lead in the same manner to variegated shales.

In truly arid climates, however, such river or sea lagoons are the seats of progressive evaporation giving rise to such salt pools as front the northern portion of the Caspian Sea or the recent gypsum deposits of the Isthmus of Suez. The degree of aridity and of the severance of the lagoons from the sea will determine the kind and amount of the chemical precipitation. It would seem, therefore, that the mud-cracked red beds originating on the delta surface of an arid climate should frequently be interstratified with mud-cracked beds holding salt or gypsum, a less arid condition leading more usually to the production of variegated shales.

MUD-CRACKS OF THE LITTORAL ZONE

Discussion as to present origin.—The littoral zone is one of the most sharply delimited of the natural physiographic divisions, forming a narrow belt between the sea and the land and defined here as comprising the zone between the average highest and lowest tides of the month. To form mud-cracks the deposit must be exposed to the sun or air sufficiently long to be dried out to such a depth

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[1] *Carnegie Institution Publications* (1905), pp. 285 ff.

that the underground capillary rise is no longer able to keep the surface wet. This time limit will vary with the climate and the texture of the clay, but there may be immediately excluded all that portion of the littoral which is wet twice per day; in other words, all that portion of the littoral below the upper limit of the neap tides. This may be modified to some extent by strong off-shore winds. In the temperate zone such winds, being usually of a cyclonic nature, are frequently accompanied by rain; but where not, it is possible that by this means the tidal rise may be prevented from reaching its normal level by some feet and mud-cracks formed in the meantime somewhat below the usual level. In the latitudes of monsoon winds such effects might be seasonal, as is noted in the Runn of Cutch on the southeastern side of the Indus delta. Off-shore winds, therefore, will permit a wider development of mud-cracks over the upper portion of the littoral zone, but it is not probable than any appreciable areas below the level of mid-tide should be laid bare, dried, and cracked by such means. Neither has such an effect been described.

In tideless seas the fluctuations of level due to storms are important. Where there is an open reach of water, however, the waves which develop upon its surface break off-shore at a depth which the writer has seen stated somewhere as half the height of the wave below the trough of the same. This action maintains an open sea and an effective working depth, since the waves as soon as they drag on the bottom scour it out and carry the material partly on to the beach, partly into deeper water. In order, then, that any appreciable stretch of bottom normally covered by water should be laid bare, the change of water level between the on-shore and off-shore storms would have to equal at least the height of the waves of the on-shore storms.

As an instance of changes of level under favorable circumstances may be mentioned those of Lake Erie, a narrow body of fresh water 245 miles long lying in a northeast and southwest direction and therefore subject to heavy gales blowing the length of the lake from both directions. As a result Whittlesey has noted a change of level at Buffalo of 15½ feet between flood water and low water.[1] At intermediate points such as Erie and Cleveland there is naturally

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[1] Dana, *Manual of Geology*, p. 202.

but little change of level. Even at the points of extreme change a lowering of eight feet below the normal level lays bare but a narrow margin, insignificant in comparison with the total area of this relatively shallow lake. In addition it is observed that such extreme conditions are never of long continuance. Therefore, until instances are cited to the contrary, it must be considered that in all bodies of open water the normal wave action maintains such a depth that off-shore gales cannot lay bare any broad tracts of bottom. Partly land-locked lagoons may in such cases run dry, but such can only form a broader fringe within the actual limits of the land. The border flood zone of tideless seas is therefore not so much due to off-shore winds as to those which blow on-shore. Such may occasionally flood wide belts of lowland, as is seen to take place around the shores of the Gulf of Mexico. By such means in tideless seas mud-cracks may originate above the normal level of the water and therefore upon the land surface, but not to any appreciable extent below the line of mean water.

In the case of the Mississippi the possibilities for the formation of mud-cracks are doubtless somewhat increased by the presence of the mud lumps described by Hilgard, convex or low conical elevations, sometimes 100 feet or more in diameter, showing their tops at the surface. These occur in the shallow waters within one to three miles of the main channel at the mouth of the Mississippi River. They originate in upheavals of the soft but tough bottom. Once formed they discharge mud from the top, the successive layers being but a fraction of an inch thick.[1] These appear to be exceptional phenomena, however, and could hardly be appealed to to account for the structure of extensively mud-cracked formations.

Returning to the consideration of seas with notable tidal ranges it is doubtful if under any climatic conditions mud-cracks could be made upon surfaces left bare by the tides for less than thirty-six hours; but as offshore winds may succeed for a couple of days or more in preventing flooding above the line of neap-flood tide, that may be taken as the limit below which mud-cracks cannot form. Taking the relative heights of the neap and spring tides above the mid-tide line as 4 to 7, this gives 21.5 per cent. or approximately

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[1] J. D. Dana, *Manual of Geology* (1895), p. 197.

the upper fifth of the littoral zone as the greatest possible limit over which mud-cracks may form. The upper fifth in level may, however, comprise much more than a fifth of the area, since the salt marshes are especially developed near this level. This indicates that the more favorable places for the development of mud-cracks are either those comprising extensive salt marshes, or regions of unusually great tidal range. As an example of the latter may be cited the Bay of Fundy as pointed out by Lyell.[1]

> On the borders of even the smallest estuaries communicating with the bay, in which the tides rise sixty feet and upwards, large areas are laid dry for nearly a fortnight between the spring and neap tides, and the mud is then baked in summer by a hot sun, so that it solidifies and becomes traversed by cracks, caused by shrinkage. Portions of the hardened mud may then be taken up and removed without injury. . . . . When a shower of rain falls, the highest portion of the mud-covered flat is usually too hard to receive any impressions; while that recently uncovered by the tide near the water's edge is too soft. Between these areas a zone occurs, almost as smooth and even as a looking-glass, on which every drop forms a cavity of circular or oval form, and, if the shower be transient, these pits retain their shape permanently, being dried by the sun, and being then too firm to be effaced by the action of the succeeding tide, which deposits upon them a layer of new mud.

In connection with fossil rain-prints this calls attention to another factor in the problem of fossil foot-prints and rain-prints, structures often associated with mud-cracks, and that is the necessity of drying and hardening before the next invasion of waters which would otherwise wash out the newly made record.

Not wishing to draw an artificial distinction, however, as mud-cracks belonging to the littoral zone may be here included those made from tides of abnormal rise, especially where the water is driven upward by powerful storms. But where flooding of erosion slopes takes place the mud deposited will be ultimately washed away. Where flooding of a river flood-plain takes place, the sea temporarily invades a region which is periodically flooded by fresh water, and therefore mud-cracks in such regions are not distinctive marks of the occupancy of the sea.

It is seen then that exceptionally high tides are not important as necessary conditions for the making of mud-cracks.

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[1] "On Recent and Fossil Rains," *Quarterly Journal Geological Society*, Vol. VII (1851), p. 239

As a final exception may be noted the effect of the previously mentioned monsoon winds, as seen on the Runn of Cutch, southeast of the delta of the Indus. In this case winds blowing steadily on-shore for months at a time raise the sea-level sufficiently to flood with sea-water large tracts of marshy country which during another portion of the year become an arid desert. Such conditions are, however, very exceptional and probably are most likely to occur broadly where rivers have previously built up alluvial plains, so that this seasonal extension of the littoral zone may only take place in connection with the continental deposits of rivers.

As the season of off-shore monsoon winds, during which the mud-cracks form, should be normally a season of aridity, it is likely that saline deposits from evaporated sea-water should frequently be associated with the mud-cracks. This is notably the case in the Runn of Cutch. The two features are also associated in the saline beds of New York. If the climate on the contrary is a pluvial one, the rain which would wash off the residual sea-water would also prevent the formation of mud-cracks from the sea-water *as a cause.*

To sum up: it is seen that mud-cracks are confined to an upper fraction of the littoral zone, and where occasionally formed beyond it by inundations of the sea only attain a broad development at the present time in arid regions where continental river deposits have been previously built. In this case the mud-cracked strata should be at least frequently saliferous.

Nature of the geological record.—The nature of the geological record and the features which distinguish mud-cracks of the littoral zone from those made under other conditions may be gathered from the preceding discussion of the conditions of present occurrence. The zone itself marks the transition between a subaërial and a subaqueous surface, in the case of deltas each nearly horizontal but at different levels. When the delta deposits of these three regions are seen in cross-section, the littoral will be a transition belt between continental and marine deposits. As the seashore during the accumulation of the strata was ordinarily a shifting line, as seen in cross-section, it will pass nearly horizontally between the two. If the subsiding land was receiving no river deposits, the lower surface will be an erosive surface represented by an unconformity. If the land surface had been one of river building it may underlie or overlie the littoral and marine deposits according as to whether the delta was retreating owing to subsidence or advancing owing to river building. But in either case the physical conditions of accumulation are so different upon the land and beneath the shallow sea that there is to be expected a marked contrast in the character of the contiguous continental and marine deposits.

Not only will the littoral zone be narrow and transitional in nature compared with the regions which border it on either side, but, as shown in the preceding article, its deposits are liable to suffer much destruction from the planing effect of the waves in the case of a subsiding land and are the first to suffer from subaërial erosion upon an emerging land. Only in the case of a delta building forth into a sea is there a good chance for the preserval of the littoral record. It has been further seen that mud-cracks are not a characteristic feature of the littoral, but can only originate upon its upper fifth or tenth, and in the places most favorable for ultimate preservation there is a grading into the land surface of the delta of which in arid climates the mud-cracks are more characteristic than of the littoral.

From these considerations it is seen that mud-cracks of littoral origin cannot be a characteristic or important feature of geological formations. They are by no means excluded as of occasional occurrence, but it would seem safe, where certain formations are dominated and widely characterized by mud-cracked shaly layers, to assign them to another origin and most probably to one upon a river plain receiving fluvial deposits.

To speak more particularly of the features which will be associated with the occasional mud-cracks of littoral origin may be noted the presence of beach structures of associated sands and muds, frequently fossils characteristic of the littoral zone, leaves and other débris from the land, rain-prints and the foot-prints of such land animals as frequent the shore. These will ordinarily be restricted to animals which seek food native to the littoral or cast up by the sea, as for instance the grubbing of swine for clams upon exposed mud flats, or birds which run over the flats and beaches for annelids or other small organisms.

The mud-cracks should be most frequently developed upon coasts where the tides are high, and in this case the areas of salt marsh should be rather frequently cut up by wide and deep tidal channels filled with coarser material. Yet in most mud-cracked formations such erosion of deep channels across the mud-cracked layers is conspicuously absent.

Under the subject of mud-cracks of fluvial plains the subject of variegated shales was discussed and it was concluded that in those formed under a subarid climate the conditions were especially favorable for their production. Before closing the present topic, therefore, the subject should be again mentioned, in order to find if they may not form equally readily in the littoral zone or even in estuarine or open sea portions of the zone of marine deposits. Along the littoral somewhat the same conditions of variable exposure to the air exist as upon flood plains. Below the line of low tide, however, extensive tracts are never exposed to the air except by broad changes of level, and local variations in the amount of organic matter present, to which variegated shales are presumed to chiefly owe their origin, will depend upon conditions of current and influx of sediment. Variegated colors should therefore be associated more markedly with variations of texture and composition than is necessarily the case with the deposits upon flood plains; changes more analogous with the contrast between channel sands and true flood-plain muds.

That red muds as well as blue muds of the terrigenous zone may form on ocean bottoms is indicated by the red muds chiefly found off the Brazilian coast. "Its red color is thought to be due to the great amount of hydrous peroxide of iron brought to the sea by the rivers and which cannot be reduced by organic matter, as in the case of the blue mud. The area covered by it is, however, small, and is estimated at about 100,000 square miles,"[1] while the blue muds cover some 14,000,000 square miles.

Variegated shales may therefore originate in any zone of sedimentation and under any depth of water, but those of marine origin are due to broad and slow changes upon the land and should not show any of the local variations and partial independence between color and stratification which may mark the deposits of a flood plain. Within limits variegated shales may be considered, therefore, as rather characteristic of continental and littoral deposition.

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[1] W. B. Clark, *Geological Survey of New Jersey, Annual Report*, 1892, p. 223.

CONCLUSIONS ON GEOLOGICAL SIGNIFICANCE OF MUD-CRACKS

From the preceding analysis of the origin of mud-cracks, as observed at the present time and the conditions under which they would be geologically preserved, it would seem that next to coal beds formed *in situ*, or abundance of land fossils belonging to the animal kingdom, that mud-cracks form one of the surest indications of the continental origin of argillaceous deposits. The structure is also seen most commonly to originate under climatic conditions where the other tests are apt to fail.

It may be considered, therefore, that mud-cracked shales predominantly indicate former flood-plain deposits, usually on delta surfaces which have displaced shallow seas. Removed from the vicinity of the sea and occurring in continental basins with older rock rims, they may have originated as playa deposits and indicate a formerly truly desert climate.

More rarely mud-cracked shales may be found as transitional belts separating unlike formations and indicative of the sun dried margins of former lakes or seas. In any case the associated characteristics which have been pointed out should assist in arriving at a conclusion in regard to the particular conditions of origin.

PREVAILING INTERPRETATIONS

The prevailing views upon a subject are exemplified by the statements of the current textbooks and manuals. These not only guide the formation of views of the younger students of the subject, but represent the longer-established and verified opinions of the older body of scientists. While frequently specialists in various lines would regard the presentation of their departments even in the better textbooks as not strictly up to date, this is, on the whole, not without its benefits, since it is necessary for new knowledge to become seasoned with time before its exact place and importance can be assigned among the body of well-established principles.

It will be desirable in summing up the present subject to compare the conclusions just arrived at with those statements concerning the significance of mud-cracks which are given in the standard texts, and which it is believed have been largely influenced by the habit of interpreting all sediments as marine unless there was positive evidence to the contrary. It is in no spirit of adverse criticism that this is done, but in order to call sharper attention to the degree of variance with the present conclusions and the desirability of confirming or modifying the latter by further observation and analysis.

Turning first to the work of the best known of American geologists: J. D. Dana, in his *Manual of Geology*[1] stated that mud-cracks are made on drying mud flats, but with customary insight was evidently careful not to restrict them entirely to the seashore, since on the next page he refers to them as well as rain-prints as made by "exposure above the water level at low tide, or at least a low stage of the waters." Thus Dana recognizes the possible continental origin, but places the emphasis, perhaps unconsciously, upon the sea-beach or estuarine origin.

Chamberlin and Salisbury in their *Geology* (1904), Vol. I, p. 466, state that "sediments are sometimes exposed between tides, or under other circumstances, for periods long enough to permit drying and cracking at the surface."

Sir A. Geikie in his *Text Book of Geology*, 4th ed. (1903), pp. 643, 644, speaks of mud-cracks as vestiges of shores of former seas and lakes, and one of the kinds of evidence showing that a locality was sometimes laid bare of water.

James Geikie, in his *Structural and Field Geology* (1905), p. 116, mentions the present occurrence of mud-cracks around the shores of inland seas and lakes, and states that the same action may take place on low flat beaches which are exposed to a hot sun during the retreat of the tide. Although lake shores are mentioned first, no discussion is given as to the relative geological importance of the two situations in producing mud-cracks.

In none of the preceding books is the possibility mentioned of mud-cracks being formed over flood-plains of rivers and apart from permanent bodies of standing water. Yet these authors are authorities upon the subject of sedimentation and sedimentary structures, and in Sir A. Geikie's *Text Book* especially, an appreciation is constantly shown of the importance of fluviatile formations. It remains a question, therefore, if this difference of view upon the significance

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[1] P. 94; see also pp. 742, 745 (1895).

of mud-cracks is due to an inheritance of expression from the past or if undue importance has been given in the present paper to mud-cracks of continental, and especially of flood-plain, origin in arid and subarid climates.

In both LeConte's and Scott's textbooks no mention is made of mud-cracks originating by any other means save by the laying-bare of tidal flats, and in both it is used as an argument proving the estuarine nature of the Newark basins; and Scott discusses the question whether the basins were parts of one or two "continuous bodies of water," p. 445.

Recently Huntingdon[1] has spoken of sun-cracks and ripple-marks taken in connection with other features as initiating continental sedimentation of the Tertiary in Central Turkestan.

> It appears as though, after the retirement of the sea, the land was covered with great playas, on which water first stood in thin sheets, forming ripple-marks in the mud and then retired or was evaporated, allowing the surface to become sun-cracked. As time went on streams began to flow across the playas, at first slow and broad and able to cut only shallow channels which were afterward filled and covered, assuming the form of very thin lenses of a material slightly different from that of the surrounding playa strata. Then, as the strength of the streams increased, sand was deposited over the whole area, and the channels, now deep and distinct, were filled with gravel. Lastly gravel was deposited almost everywhere.

So far as the writer is aware the only attempt at a discussion of the several methods of origin of mud-cracks and the relative chances of their preserval is by Penck,[2] who points out that they, as well as foot-prints and rain-prints, occur on sea-beaches, over the flood-plains of rivers and the shores of interior seas, but that the surface bearing the markings must to a certain degree have hardened and consequently have remained as a land surface for a certain length of time in order that the impressions should not be washed out by the next invasion of waters. For that to be accomplished he states that the sea-coast is less favorable than the flood-plains of rivers and the margins of lakes. In the latter cases the exposed floor dries for weeks or months and attains a considerable hardness before being again overflowed.

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[1] "Explorations in Turkestan," *Carnegie Institution of Washington* (1905), pp. 164, 165.

[2] *Morphologie der Erdoberfläche* (1894), Vol. II, pp. 25, 26.

ILLUSTRATIVE GEOLOGICAL APPLICATIONS

In the preceding paper under the heading of "The Relations of Continental and Marine Sedimentation through Geological Time," it was concluded, not from a detailed study of the strata, but entirely from the broader relations at present prevailing, that at certain times in the past continental sedimentation should have played an important rôle, especially in the form of fluviatile deposits filling interior basins or displacing epicontinental seas. Having made this present examination of the different methods by which mud-cracks may originate, together with some of their associated characteristics, it will be well to apply it as a test to the conclusions of the preceding paper. If the result is a confirmation, there will thus be two largely independent lines of reasoning which arrive at the same result; a result in which therefore correspondingly more confidence may be placed.

MUD-CRACKED FORMATIONS OF THE PRE-CAMBRIAN

In both northwestern Montana and northwestern Arizona occur a series of predominantly arenaceous and argillaceous formations of great thickness which are distinctly older than the Middle Cambrian, since these lower formations were gently folded and base-leveled before the transgression of the Middle Cambrian sea. Yet these terranes are remarkably free from metamorphism and still retain their original characters. For this reason they are selected for illustration and briefly described. It was suggested in the preceding article that on account of the general nature of the deposits and the fact that the early Cambrian as well as the immediately pre-Cambrian were periods of great continental extension, the hypothesis of subaërial and fluviatile origin for certain formations should be at least entertained until disproved. It is now proposed to describe certain features of these formations in detail in order to arrive at some conclusion in regard to their continental, littoral, or marine origin, the conclusions being drawn after the presentation of the details.

PRE-CAMBRIAN FORMATIONS OF MONTANA

These are described by Walcott under the title of the "Belt Terrane"[1] and by Willis as the "Algonkian of the Lewis and Liv-

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[1] Pre-Cambrian Fossiliferous Formations," *Bulletin Geological Society of America*, Vol. X, pp. 201, 215.

ingston ranges."[1] The two districts described above are about 150 miles apart in a general north-northwest and south-southeast direction; and as the intermediate region has not been studied in detail, Willis does not pretend to correlate closely the several formations described by him in the northwest with those described by Walcott from the district near Helena, but the similarity of sequence is sufficiently striking to warrant placing them in juxtaposition as is done below.

Belt Formation, Helena Region—Walcott	*Thickness in feet*	Algonkian of Northwest Montana, Lewis and Livingston Ranges—Willis	*Thickness in feet*
Marsh shales	300	Kintla argillite Sheppard Quartzite	800+ 700±
Helena limestone	2,400	Siyeh limestone	4,000
Empire shales	600		
Spokane shales	1,500	Grinnell argillite	1,000 to 1,800
Greyson shales	3,000	Appekunny argillite	2,000+
Newland limestone	2,000	Altyn limestone	1,400+
Chamberlain shales	1,500	(Bottom of limestone not exposed)	
Neihart quartzites and sandstone	700		
	12,000		9,900 to 10,700

Brief descriptions of these formations are quoted as follows, those of the equivalent formations of the two localities being placed together:

Neihart quartzite and sandstone Helena region, Little Belt Mountains.—In this formation are included the reddish, coarse sandstones, with interbedded dark greenish layers of fine-grained sandstone and shale, beneath the Chamberlain shales. The lower 400 feet of the formation is a massive, sometimes cross-bedded quartzite, which, in some of its members, where unaltered, is a compact, hard sandstone. The prevailing color is pinkish-gray on the freshly exposed surface, with dark and iron-stained weathered surface. Occasional layers of a fine conglomerate occur in some portions near the contact with the gneiss.[2]

About 300 feet above the base the character of the formation changes. The pink and white pure quartzites are replaced by more thinly bedded rocks, no longer of pure arenaceous material, but containing an admixture of greenish mica, which higher in the group forms the layers of mica shales interbedded with the quartzite. The higher strata are still more impure and the quartzite beds are but six to twelve inches thick, blackened by carbonaceous material that now forms a prominent feature of the intervening shales, becoming increasingly abundant until the latter rocks are true black shales in which the green mica no

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[1] "Stratigraphy and Structure, Lewis and Livingston Ranges, Montana," *ibid.*, Vol. XIII, pp. 316–24.

[2] *Bulletin Geological Society of America*, Vol. X, p. 204.

longer shows. At the same time the quartzite beds decrease in thickness and purity, while the interbedded shale increases in thickness and purity, so that an arbitrary line must be drawn separating the two formations.[1]

Chamberlain shales, Helena region, Little Belt Mountains.—This formation is composed of a series of dark silicious and in places arenaceous shales. Ripple-marks, mud-flows, and sun-cracks were occasionally seen, but no traces of life were observed. The dark shales frequently form low cliffs along the canyon side, near the beds of the streams.[2]

Newland limestone, Helena region, Little Belt Mountains.—At the typical locality on Newland Creek the limestones are thin bedded, the layers averaging from two to six inches, with shaly partings of variable thickness between them. In the section of Sawmill Canyon, near Neihart, the layers are somewhat thicker, more impure, and with a greater number of beds of interbedded shale. The prevailing color of the limestone is dark bluish-gray on fresh fracture, and buff to straw color on the weathered surface.[3]

Altyn limestone, Lewis and Livingston Ranges.—Limestone, of which two members are distinguished; an upper member of argillaceous, ferruginous limestone, yellow, terra-cotta, brown, and garnet-red, very thin-bedded; thickness about 600 feet; . . . . and a lower member of massive limestone, grayish-blue, heavy-bedded, somewhat silicious, with many flattened concretions, rarely but definitely fossiliferous; thickness, about 800 feet.[4]

Greyson shales, Helena region, Little Belt Mountains.—Dark-colored, coarse, silicious, and arenaceous shales, passing above into bluish-gray, almost fissile shale, which, when broken up, weather to a light gray fissile shale, resembling a poor quality of porcelain. These in turn are succeeded by dark gray silicious and arenaceous shales, with interbedded bands of buff-colored sandy shales and occasional layers of hard, compact, greenish-gray and drab silicious rock. At the base of this series, in Deep Creek Canyon, a belt of quartzites occurs, interbedded with shales, the base of the quartzites showing ten feet of interformational conglomerates, composed of sand and pebbles up to eight inches in diameter, and derived from the subjacent Belt rocks.[5]

Appekunny argillite Lewis and Livingston Ranges.—The Appekunny argillite is a mass of highly silicious, argillaceous sediment approximately 2,000 feet in thickness. Being in general of a dark gray color, it is very distinct between the yellow limestones below and the red argillites above. The mass is very thin bedded, the layers varying from a quarter of an inch to two feet in thickness. Variation is frequent from greenish-black argillaceous beds to those which are reddish and whitish. There are several definite horizons of whitish quartzite from fifteen to twenty feet thick. The strata are frequently ripple-marked, and occasionally coarse grained, but nowhere conglomeratic.[6]

[1] W. H. Weed, *Geology of the Little Belt Mountains*, pp. 281, 282.

[2] *Bulletin Geological Society of America*, Vol. X, p. 206.

[3] *Ibid.* [4] *Ibid.*, Vol. XIII, p. 317. [5] *Ibid.*, Vol. X, p. 206.

[6] *Ibid.*, Vol. XIII, p. 322.

Spokane shales, Helena region, fifteen miles east of Helena.—The Spokane shales occur as massive beds of silicious and arenaceous shales of a deep red color. The arenaceous shaly portions frequently thicken up into thin layers of sandstone. The shales break down on exposure, but they are usually sufficiently firm to resist erosion and form strongly marked slopes and cliffs.[1]

The present writer had an opportunity in 1901 of examining the Spokane about 20 miles northwest of Helena and found the shaly layers frequently mud-cracked.

Grinnell argellite, Lewis and Livingston Ranges.—A mass of red rocks of predominantly shaly argillaceous character is termed the Grinnell argillite from its characteristic occurrence with a thickness of about 1,800 feet in Mount Grinnell. These beds are generally ripple-marked, exhibit mud-cracks and the irregular surfaces of shallow water deposits. They appear to vary considerably in thickness, the maximum measurement having been obtained in the typical locality, while elsewhere to the north and northwest not more than 1,000 feet were found. It is possible that more detailed stratigraphic study may develop the fact that the Grinnell and Appeknuny argillites are really phases of one great formation, and that the line of distinction between them is one diagonal to the stratification. The physical characters of the rocks closely resemble those of the Chemung and Catskill of New York, and it is desirable initially to recognize the possibility of their having similar interrelations.[2]

Empire shales, Helena region, twenty miles northwest of Helena.—These are greenish-gray massively bedded, banded, silicious shales.

Helena limestone, Helena region, Helena.—The Helena limestone formation is composed of more or less impure bluish-gray and gray limestone, in thick layers, which weathers to a buff and in many places to a light gray color. Irregular bands of broken oölitic and concretionary limestone occur at various horizons. Bands of dark and gray silicious shale and greenish and purplish argillaceous shale are interbedded in the limestones. These bands are from half an inch to several feet in thickness. There are also beds of thinner bedded limestones, especially toward the top of the formation.[3]

Siyeh limestone, Lewis and Livingston Ranges.—Next above the Grinnell argillite is a conspicuous formation, the Siyeh limestone, which rests upon the red shales with a sharp plane of distinction, but apparently conformably. The Siyeh is in general an exceedingly massive limestone, heavily bedded in courses two to six feet thick like masonry. . . . . Occasionally it assumes slabby forms and contains argillaceous layers. It is dark blue or grayish, weathering buff, and is so jointed as to develop large rectangular blocks and cliffs of extraordinary height and steepness. Its thickness, as determined in the nearly vertical cliff of mount Siyeh, is about 4,000 feet.[4]

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[1] *Bulletin Geological Society of America*, Vol. X, p. 207.

[2] *Ibid.*, Vol. XIII, p. 322.

[3] *Ibid.*, Vol. X, p. 207.

[4] *Ibid.*, Vol. XIII, p. 323.

Sheppard quartzite, Lewis and Livingston Ranges.—A distinctly sandy phase of deposition succeeding the extrusive rhyolitic eruption capping the Siyeh limestone has resulted in a quartzite which is very roughly estimated to have a thickness of 700 feet.[1]

The present writer has observed a basal quartzite to the Marsh shales in a similar stratigraphic relation upon Greenhorn Mountain, sixteen miles northwest of Helena. But the occurrence of the quartzite was lenslike and not persistent for many miles.

Marsh shales, Helena region.—At Helena there is a thickness of about 250 feet of shales and thin-bedded sandstones of the Belt Terrane above the Helena limestone and beneath the Cambrian sandstones. The same bed, on the north side of Mount Helena, is reduced to 75 feet in thickness, but to the northwest the formation increases in thickness to 300 feet or more.[2]

Kintla argillite, Lewis and Livingston Ranges.—Argillite and quartzite, thin-bedded, maroon red, ripple-marked, and sun-cracked, containing casts of salt crystals; also occasional beds of white quartzite and some calcareous; thickness 800 feet; no upper limit seen.[3]

The Kintla formation closely resembles the Grinnell, and represents a recurrence of conditions favorable to deposition of extremely muddy, ferruginous sediment. The presence of casts of salt crystals is apparently significant of aridity, as the red character is of subaërial oxidation. The formation has an observed thickness of 800 feet, but no overlying rocks were found. Its total thickness is not known, and the series remains incomplete.[4]

Discussion.—The very similar general nature of these formations at a distance of 150 miles from each other indicates similar conditions of accumulation over wide areas, though it is possible of course that the stratigraphic cycle was not strictly contemporaneous in the two regions. The volume of material which must have been eroded to supply these sediments was far greater than the volume of the sediments, since the one kind of sediments of any epoch, occurring at *both* localities, represents but a portion and, in the case of the limestones and quartzites, but a small portion, of the rock masses whose erosion supplied the material.

Taking Clarke's figures[5] of the average amounts of the oxides and common minerals in the "primitive crust of the earth" it is seen that an approximately pure dolomite which should contain all of

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[1] *Ibid.*, p. 324.

[2] *Ibid.*, Vol. X, p. 207.

[3] *Ibid.*, p. 316.

[4] *Ibid.*, Vol. XIII, p. 324.

[5] "Analysis of Rocks, Laboratory of the U. S. Geological Survey," *Bulletin U. S. Geological Survey No. 168* (1899), pp. 14, 16.

the lime and magnesia of a primitive rock mass would contain but about one-tenth of the original, and in volume, allowing for the carbon dioxide in combination with bases, would roughly represent about a fifth of the original. In this case, however, since the material has been deposited from solution, it does not signify a necessary origin from contiguous land masses.

The average igneous rock, containing, according to Clarke, 10 per cent. of quartz, a pure quartzite will represent less than one-eighth of the original rock mass, but an argillite, containing variable amounts of the original quartz and additional water and carbon dioxide combined with the bases, represents a far higher, but indefinite, proportion of the original rock mass. Quartzites and argillites, however, since they cannot be transported across deep bodies of water imply contiguous land. The great thickness and similarity of the arenaceous and argillaceous formations over a wide area point to an originally still more widely spread character, since there is no indication that these districts were near the original limits. But their volume indicates deep erosion of a correspondingly extensive contiguous land. The formations do not show the local variations and conglomeratic nature which would indicate the erosion of a nearby mountain range, and therefore the denudation must have taken place from a wide area. The similar formations which are known to exist in British Columbia, Utah, Nevada, California, and Arizona emphasize still further the profound erosion of widespread adjacent land masses of late pre-Cambrian time.

Thus a detailed examination of the composition and texture of these Montana formations allows inferences confirming *for this region* the statements made in the previous article from more general grounds concerning the wide development of the continents in the later pre-Cambrian times.

In regard to the topographic and sedimentary cycles expressed by the succession and character of the formations it is seen that the two great limestones represent long-enduring incursions of the sea, while the quartzites and argillites represent the uplift and erosion of neighboring lands of large area.

The Neihart quartzite.—The cleanness and partially deferrized character of the basal formation, the Neihart quartzite, indicates shallow water off-shore deposit, subject to the prolonged sorting and attrition characteristic of the work of currents and waves or of desert winds resulting in the accumulation of dune sands. The latter idea is perhaps made improbable by the transition into, and alternation with, the deoxidized and carbonaceous lower members of the Chamberlain shales.

The Chamberlain shales grade, on the one hand, into the underlying quartzite and, on the other, into the Newland limestone. These relations, in addition to the dark silicious and occasionally arenaceous character and occasional ripple-marks, suggest a quiet offshore formation. The mud-cracks noted by Walcott may be either of littoral or fluvial origin, but in either case imply a nearby land. The lack of a more arenaceous character may be due, therefore, to a topographic old age and lessened stream gradients of the land, or to the river material having been borne from a great distance.

Newland and Altyn limestones.—The inauguration of the era of the Newland and Altyn limestones may be due as much to the lack of supply of mechanical sediments as to subsidence and incursion of the sea.

Greyson and Appekunny argillites.—Following the limestone came some 2,000 to 3,000 feet of Greyson and Appekunny argillites. The generally dark gray color, thin-bedded lamination, occasional ripple-marks, and quartzitic strata suggest the submarine deposits poured into a sea as a result of the re-elevation of a contiguous land.

The association with the limestone below, the absence of conglomerates and observed mud-cracks, and the contrast in color with the deep-red and mud-cracked formation above all tend to confirm this interpretation.

The Spokane and Grinnell argillites, from 1,000 to 2,000 feet in thickness, on this view represent subaërial delta deposits over a region where sedimentation had gained upon subsidence to such an extent as to fill up and exclude the sea. In contrast to the inferior argillites are to be noted the highly oxidized character indicated by the deep red color, the frequent alternations of sandstone strata, and especially the widespread occurrence of mud-cracks. These are not sparingly present and developed in strata transitional between two distinct types, as would be characteristic of mud-cracks of the littoral zone, but on the contrary are developed in the normal red shales. Furthermore, the exposed sections show throughout a marked sameness in color and a similar repetition of argillaceous and arenaceous beds. The areal extent, the fineness and evenness of grain, combined with the evidences of aridity, bespeak an extensive delta fan, comparable in size and climatic environment to those of certain of the larger Asiatic rivers of the present time.

The lack of knowledge as to the extent and relations of the formation will not allow of a closer comparison, but it is seen that it represents the continental culmination of the sedimentary cycle as the preceding Newland and Altyn limestones represented the opposite or marine phase.

The cycle appears to be less dependent here upon a mere transgression and recession of the sea as the active agent, than upon the wasting-away and the rejuvenation of adjacent land masses, which, upon being re-elevated, supply such a flood of sediment as to crowd back and dispossess the sea, the subsidence of the geosyncline going forward more or less continuously but at a variable rate.

The succeeding formations of this terrane indicate a repetition of this cycle, the Empire shales, showing greens and grays and passing into the upper limestones, doubtless represent the submarine deposits made during the transgression of the sea across the subsiding former delta surface. Then followed several thousand feet of limestone formation. This is largely thin bedded and shaly in the upper portions in the Helena region and various features described elsewhere suggest that it was largely accumulated in a shallow sea. This limestone was succeeded in places by quartzites which suggest wave-sorted deposits, and finally by a deep red mud-cracked series of argillites, somewhat similar to the Spokane-Grinnell formation, suggestive once more of land deposition under conditions of aridity. The thickness of this formation varies widely, the upper surface being a base-level erosion surface upon which is superimposed the Middle Cambrian marine transgression across a far-reaching and topographically ancient land.

THE GRAND CANYON SERIES OF ARIZONA

Leaving the preceding region and passing to the Grand Canyon of Arizona, some 750 miles south of Helena and some 950 miles south of the international boundary, a different series of rocks is found to occur, but one holding a similar stratigraphic position, being embraced between the metamorphic formations of the Vishnu and Archean below and the unconformable Middle-Cambrian above. Walcott gives the series a total thickness of 11,950 feet, divided into two terranes, the upper or Chuar containing 5,120 feet of strata of which 285 feet are limestones and 4,835 feet brown to black or variegated shales and some reddish-brown sandstones. The lower or Unkar terrane attains a total thickness of 6,830 feet of which from 110 to 210 feet are limestones and the balance brown to vermilion sandstones and shaly sandstones with a basal conglomerate 30 feet in thickness. The Unkar is characterized by a great thickness of reddish-brown sandstones. The detailed section of the Unkar as given by Walcott follows, the italics being introduced:[1]

SECTION FROM THE SUMMIT DOWNWARD	FEET
1. *a*) Massive bed of gray to reddish magnesian limestone, passing below into a calciferous sand rock	50–150
b) Light gray, shaly sandstone	25
c) Irregular, massive beds of yellowish-brown sandstone	50
d) Partially crossbedded, fine grained, purplish-brown sandstone.	50
e) Reddish-brown sandstone and sandy shales, ripple-marked.	200
	475
2. Lava beds:	
a) Nine lava flows aggregating	770
b) Interbedded sandstones	30
At Chuar lava hill the lava beds are 1,000 feet thick.	
	800
3. Sandstones (upper)	
a) Shaly, vermilion, rather fine-grained sandstones, with intercalated bands of greenish-gray, followed below by 700 feet of vermilion beds of a uniform character, and massive beds with arenaceous, shaly partings, the massive beds breaking up into shale and sandstone on the talus slopes. *Ripple-marks and shrinkage cracks characterize the upper, shaly beds*	1730
b) The vermilion sandstones of *a*) pass into chocolate colored sandstones, that for 125 feet down unite in the general slope of the beds above. Below, a cliff is formed of five massive bands of chocolate-colored, slightly micaceous sandstone, separated by shaly sandstone partings of a greenish color below and a chocolate color above	925
c) Reddish-brown to chocolate, more or less shaly sandstone, 125 feet, underlain by 300 feet of friable sandstone and arenaceous and micaceous shale	425
d) Irregularly bedded, compact sandstone:	
Curiously twisted and gnarled layers	15
Massive, grayish layer	10
Light gray layer with reddish spots, friable, shaly in places	125
	3230

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[1] "Pre-Cambrian Igneous Rocks of the Unkar Terrane," *Fourteenth Annual Report* (1894) U. S. Geological Survey, Part II, pp. 510–12.

4.		Sandstones (lower):	
	a)	Compact, quartzitic, gray sand rock, 25 feet, with 65 feet of hard, compact sandstone	90
	b)	Massive, compact, cliff-forming, brown, buff, and purplish-brown sandstone	1200
	c)	1. Reddish-brown to vermilion, friable, shaly sandstone	200
		2. Brick-red, shaly sandstone	250
		3. *Brown, friable, shaly sandstone, ripple-marks and shrinkage cracks*	300
		4. Same in more massive layers, with fine, siliceous conglomerate	80
		(10 feet) at the base	80
			2120
5.	*a*)	Light gray limestone with interbedded laminæ of quartzitic shale	8
	b)	Brown sandstone with a bed of silicious conglomerate, 2 feet	30
	c)	Reddish cherty limestone	10
	d)	Reddish-brown limestone	2
	e)	Dark, reddish-brown slate	5
	f)	Light gray, compact shaly limestone	14
			69
6.		Dark, compact basaltic lava in one massive flow	80
7.		Light gray, compact shaly limestone with pinkish tinge between the laminæ; it is a little cherty near the base, or with thin, hard, interbedded layers of sandstone	26
8.		Silicious conglomerate formed largely of pebbles derived from the upturned edges of the pre-Unkar strata, upon which it rests unconformably	30
		Total thickness of the Unkar terrane	6830

Discussion.—The basal silicious conglomerate derived from the upturned edges of the underlying beds and followed by 175 feet of limestones containing a lava bed and some sandstone may be taken as a good indication of the invasion and continued presence of the sea.

It is noticed, however, that beginning 205 feet above the base are 10 feet of a fine silicious conglomerate which suggests a possible origin as a wave-sorted beach sand. Above this follows 370 feet of brown, friable, shaly sandstones showing ripple-marks and shrinkage cracks. These could be explained as of littoral origin by supposing that the subsidence and sedimentation remained exactly balanced so that this zone was the transition between the subaërial and submarine portions of a delta during the entire time of the deposit of the 370 feet. Even assuming a littoral origin, however, the immediate vicinity of a shore is implied and it seems a much simpler hypothesis to suppose that the mud-cracks were of flood-plain origin. Under this assumption the cracks could be more readily accounted for and it is not necessary to postulate an exact balance between the subsidence, the marine planation and the delta building during all the time of accumulation, it being only necessary to assume that sedimentation remained in excess of subsidence and that the shore was a fluctuating line, of which this locality was continually on the landward side. These mud-cracked strata form the basal portion of the lower sandstones. Above them are 1,650 feet of red buff, brown, and vermilion sandstones and shaly sandstones similar in character, but not noted by Walcott as characterized by mud-cracks. The similar characters and especially the color of the iron oxide implying complete subaërial oxidation either before or after deposition suggest a continuance of the continental conditions. If deposited beneath the sea it would be expected that the continued wave action which affects the sandy deposits of shallow seas would, at least, in part, have separated the clay and iron from the grains of sand, producing cleaner gray quartzitic layers. Such a change is, in fact, noted in the compact, quartzitic, gray sand rock which separates the lower from the upper sandstone of the Unkar.

The question arises as to why the mud-cracks should be absent from the 1,650 feet of lower sandstones, if the latter were really of subaërial origin. The answer is that, even if the necessary periods of desiccation were present between the river inundations, mud-cracks need not necessarily arise. A sandy nature is unfavorable for their development, and the strata are much more sandy, on the whole, than in the case of the Spokane and Marsh shales of the Belt terrane. Again, a canyon wall is not a favorable place upon which to observe the bedding surfaces of gently dipping strata. It is furthermore possible that mud-cracked strata which could be observed by careful search were not noted, since Walcott was not conducting the examination with that end in view as a principal object. Finally mud-cracks which were noted were not always recorded in this necessarily brief synopsis of the strata, at least if they were off the line of the section, since on p. 515 of the article cited it is stated that at Chuar Lava Butte numerous ripple-marks and mud-cracks occur among the sandstones and shales covering the uppermost lava flow, yet mud-cracks at this horizon are not mentioned in the synopsis which has been given.

Returning to the description of the Unkar stratigraphic section, the upper sandstones below the lava beds comprise 3,230 feet, nearly all being again vermilion, reddish-brown, or chocolate in color. Occasional partings of a greenish-gray are noted, and the upper shaly beds are characterized by ripple-marks and shrinkage cracks. It would seem from this that if the gray quartzite separating the upper and lower sandstones is, indeed, a beach and marine deposit, that the transgression was but temporary, the beach was pushed back and subaërial deposition continued.

Following this stage occurred a series of outpourings of lava, thin layers of sandstone separating most of the flows. The lava beds aggregate from 770 to 1,000 feet in thickness, varying this much in a distance of about four miles. The partings of shale and sandstone are widely distributed and of uniform thickness over considerable areas (p. 517) and on Chuar Lava Butte it is noted that the upper lava flow is capped by 35 feet of cholocate-brown sandstone and sandy shales with numerous ripple-marks and mud-cracks occurring among the layers (p. 515).

A study of the relations of the traps and interbedded sandstones with respect to the alternative hypotheses of marine or continental origin would probably offer some evidence in support of one view as against the other. The widespread character of the lava flows indicates that they were poured out over a level surface. The subaërial portion of a delta with a slope of normally not more than a foot per mile is more broadly level than the submerged portion, but, on the other hand, is also more cut by stream channels.

The more or less viscous nature of lava would cause the upper surface of the flows to depart from a true plane. If above the sea level the streams would tend to erode the upper surface to some extent and result in thicker deposits of sand and clays in the hollows of the upper surface, leveling it once more to grade. These effects might be less marked if the lava flows were poured out beneath the sea.

In the absence of field study with these points in view it seems best to leave the problem as an open question, but the mud-cracked layers covering the upper lava flow indicate rather strongly the subaërial origin of at least that particular sheet.

Above the last lava flow are found 250 feet of these apparently land-deposited beds followed by 50 feet of irregular massive beds of yellowish-brown sandstone and 25 feet of light gray shaly sandstone. These by their contrast in color presumably represent the off-shore deposits of a transgressing sea and are followed by 50 to 150 feet of massive, gray to reddish magnesian limestone, closing the deposits of the Unkar terrane.

The detailed section of the following Chuar terrane is not quoted in full as the beds are not described by Walcott as mud-cracked, nor do most of them by their other characters strongly suggest subaërial deposition. As previously noted, they embrace 5,120 feet of strata of which 285 feet are limestones. The greater portion of the balance consists of brown to black, gray, or variegated shales, with some reddish-brown sandstones, often shaly. Deposition in off-shore waters beyond the reach of beach action is suggested as the mode of origin of much of the formation by the prevailing difference in color, the more shaly character, and the beds of limestone scattered at intervals through the entire terrane. Occasional transitions to shore deposits of an arid climate are similarly suggested by the variegated shales, and especially masses of white and pink gypsum found in a few localities in one horizon which consists of black argillaceous shale with chocolate and greenish, sandy and argillaceous shales beneath, carrying hard layers of sandstones.

A classification of the Chuar section into appreciably calcareous and arenaceous portions suggests three movements of subsidence with invasions of the sea and four periods of halting or possibly elevation with approach of the littoral to this region, the series ending with 125 feet of massive, reddish-brown sandstone, with irregular layers of similar color and containing numerous fragments of sandstone-shale of lighter color.

The thorough and accurate observations of Walcott have made it possible to give this discussion of continental as opposed to marine origin both for the Belt and Grand Canyon series, although the problem of a possible continental origin is not discussed in the original papers and possibly was not seriously in mind, since such a question had never been raised in regard to them. Since the facts have been freely quoted, however, it is also desirable to give the observer's interpretation, which is throughout that of a marine origin. In regard to the upper lavas of the Unkar terrane Walcott states:

> The first coulée flowed over the level ocean bed, in which 5,000 feet of sediment, that now forms a reddish-brown sandstone, had accumulated on the upturned and eroded edges of the Archean, the few layers of limestone and the one flow of lava, 150 feet in thickness near the base scarcely serving to break the great sandstone series.[1]

Again the author states that

> The wide distribution of thin layers of sandstone, shale, etc., of uniform thickness over considerable areas indicates a relatively smooth sea bed at the time of the spreading of the first sheet of (the upper) lava over it; and that the sea was shallow, is shown by ripple-marks and the filling of sun-cracks.[2]

CONCLUSION ON THE NATURE OF THE PRE-CAMBRIAN SEDIMENTATION

In the absence of personal observation with the particular problem in mind any other interpretation than that given by Walcott should be held with reservation, but it has been shown that in view of the highly oxidized character of the sandstones of the Unkar terrane, and mud-cracks frequently found in the shaly beds, that the presumption is in favor of a continental origin and the burden of proof is rather upon those who would give the marine interpretation.

The discussion of these pre-Cambrian deposits but especially of the Montana occurrences, shows how completely in accord is the hypothesis of the dominant flood-plain origin of mud-cracks with the other marks of subaërial deposition in an arid climate. The mud-cracks are confined to just such formations as from other characteristics suggest a flood-plain origin and these formations are usually separated from the deposits of limestone by transitional formations which differ in color, in character, and in the absence of mud-cracks, suggesting the true submarine deposits originating between the shore and the open sea.

Assuming that a strong case has been made out for the continental origin of certain of these pre-Cambrian formations, it is seen that in the two regions examined the conclusion is justified which was reached from general considerations in the preceding paper—that the late pre-Cambrian being an aeon of wide continental extension should show in its epicontinental deposits a considerable proportion

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[1] P. 504.

[2] P. 517.

of subaërial origin. The two regions are unusually favorable for study in this particular, since, as previously noted, the deposits have been relatively little disturbed by later earth movements and the original sedimentary record has not been obliterated through the processes of metamorphism.

A general conclusion should be founded on a far wider study of occurrences, but such would run beyond the limits of this paper. It may be noted in passing, however, that the Montana region shows an unusual proportion of carbonate rocks, while the pre-Cambrian deposits over the world as a whole apparently are characterized by minor amounts of carbonates, rocks whose presence in notable proportions are usually the surest indication of truly marine conditions. Such a poverty in limestones may in a small measure be accounted for by a possible dominance of disintegration over decomposition in the erosion of those times, the lime thus in part not being set free and the disintegrated products giving rise upon metamorphism to a large proportion of gneisses, graywackes, and feldspathic schists, instead of quartzites, argillites and marbles.

Highly silicious rocks are, however, not uncommon, and the question arises as to where the corresponding quantities of salt, gypsum, and dolomitic limestones are to be found. In the long time elapsing since their origin these might have been completely leached out by subterranean waters, as Rutley has shown,[1] if they had remained near the surface in the zone of circulating waters. But the pre-Cambrian rocks are usually highly metamorphic and have been buried deeply in the zone of anamorphism during a considerable proportion of their existence, so that such an explanation can hardly apply to them in very much greater measure than to the Eopaleozoic limestones which remain in such abundance.

The bulk of the salt is doubtless still in solution in the sea and is a measure of the volume of erosion in those early ages in addition to that of later times. The corresponding dolomites, however, since they are apparently not found in proportionate abundance upon the continents must presumably repose within the limits of the present ocean basins.

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[1] "On the Dwindling and Disappearance of Limestones," *Quarterly Journa Geological Society*, Vol. XLIX (1893), p. 372.

But as carbonate deposits are characteristic of the open sea, so are silicious, feldspathic, and argillaceous deposits dominant upon the land surface, and thus a separate argument is derived for the view that in pre-Cambrian times the continents possessed at least their present extension, an argument, however, which requires further testing in regard to the premises as to the poverty of limestones.

It would seem, therefore, that the 12,000 feet of the Belt terrane, consisting, as it does, of from 37 to 50 per cent. of dolomitic limestones is far from being an occurrence holding an unusual proportion of continental deposits and that the conclusion derived from its study in regard to their presence in important quantity is therefore susceptible of wider application.

Reviews and Book Notices

Miocene Foraminifera from the Monterey Shale of California, with a Few Species from the Tejon Formation. By Rufus M. Bagg, Jr. (U. S. Geological Survey, Bulletin No. 268, 1905.) Pp. 55, 11 plates, 2 figures.

The Monterey Shale is 2,000–2,500 feet thick where the fossils were collected. This was near Asuncion, in San Luis Obispo County. The collecting was done by Professor Branner, of Leland Stanford University, who also wrote an introduction to the *Bulletin.*

The formation as a whole lies in a broad fold, but there are smaller folds and numerous faults. The bulk of the shale is made of diatom skeletons.

Dr. Bagg finds sixty-six species and seventeen genera in the collection. Most of them are common in the North Pacific today, so that conclusions may be drawn as to the temperature and depth of the water where these sediments were deposited. The water was probably less than 500 fathoms deep.

E. W. S.

The Lead, Zinc, and Fluorspar Deposits of Western Kentucky. By E. O. Ulrich and W. S. Tangier Smith. (U. S. Geological Survey, Professional Paper No. 36, 1905.) Pp. 218, 22 plates, 31 figures.

The geology and general relations of the deposits are discussed by Mr. Ulrich and constitute Part I of this paper; the ore deposits and mines are described by Mr. Smith in Part II. The region has been subjected to abundant faulting, and the surface is quite rough and irregular on that account. The deposits are somewhat similar to other deposits of similar ores in the interior of the United States, but there are a number of unique features in lithologic and mineralogic associations. One of these is the presence of basic igneous dikes. Another is the abundance of fluorspar, especially where the lead and zinc ores occur. Thirdly, the ores are found principally in true fissure veins, which have resulted from fracturing and subsequent faulting.

The minerals of economic importance are fluorite, barite, galena, sphalerite, and smithsonsite. In addition, there occur cerussite, pyromorphite, sulphur, hydrozincite, calamine, greenockite, chalcopyrite, malachite, calcite, quartz, kaolinite, and ankerite. Fluorite is the main product of the mines, and lead and zinc might almost be regarded as by-products. Much of the ore must be cleaned before shipping, because the mines are working in the oxidized zone. The mining industry will grow more rapidly when a deeper zone is reached and the ore becomes cleaner, and when transportation facilities improve. E. W. S.

Climatic Features of the Pleistocene Ice Age. By PROFESSOR ALBRECHT PENCK. (Reprint from the *Geographical Journal,* February, 1906, pp. 182–87.)

Professor Penck, in this paper, approaches the problem of the climate of the Pleistocene Ice Age from the data of physio-geographical research. He thinks it likely that the pluvial periods, of which there is evidence in many of the deserts of the world, were contemporaneous with ice-advances, and that desiccation phenomena accompanied interglacial epochs. The world-wide parallelism of such events points to a common origin, which he thinks to be a very slight change of temperature. E. W. S.

The Transvaal Formation in Prieska, Cape Colony. By E. H. L. SCHWARZ. (Reprint from Transactions of the Geological Society of South Africa, Vol. VIII, 1905, pp. 88–103; 1 plate.)

This paper describes the parts of the Transvaal system and sums up what is known of it. A number of suggestions are made as to correlation with other formations in South Africa and formations in other countries. There is a very striking resemblance, both in lithological character and sequence, to the Huronian of the Lake Superior region. E. W. S.

Iron Ore Reserves. By CHARLES KENNETH LEITH. (Reprint from *Economic Geology,* Vol. I, No. 4, February-March, 1906, pp. 360–68.)

The exhaustion of the world's supply of iron ore has been put by many authorities at less than a century hence. Professor Leith holds that these estimates do not take the low grade ores sufficiently into account. Before the high-grade ores are exhausted the price of iron will have so advanced as to make profitable the working of immense bodies of ore which are not worked now. Accompanying this change will be widespread economic changes in matters related to the iron industry. E. W. S.

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NOTES ON THE GEOLOGICAL SECTION OF IOWA

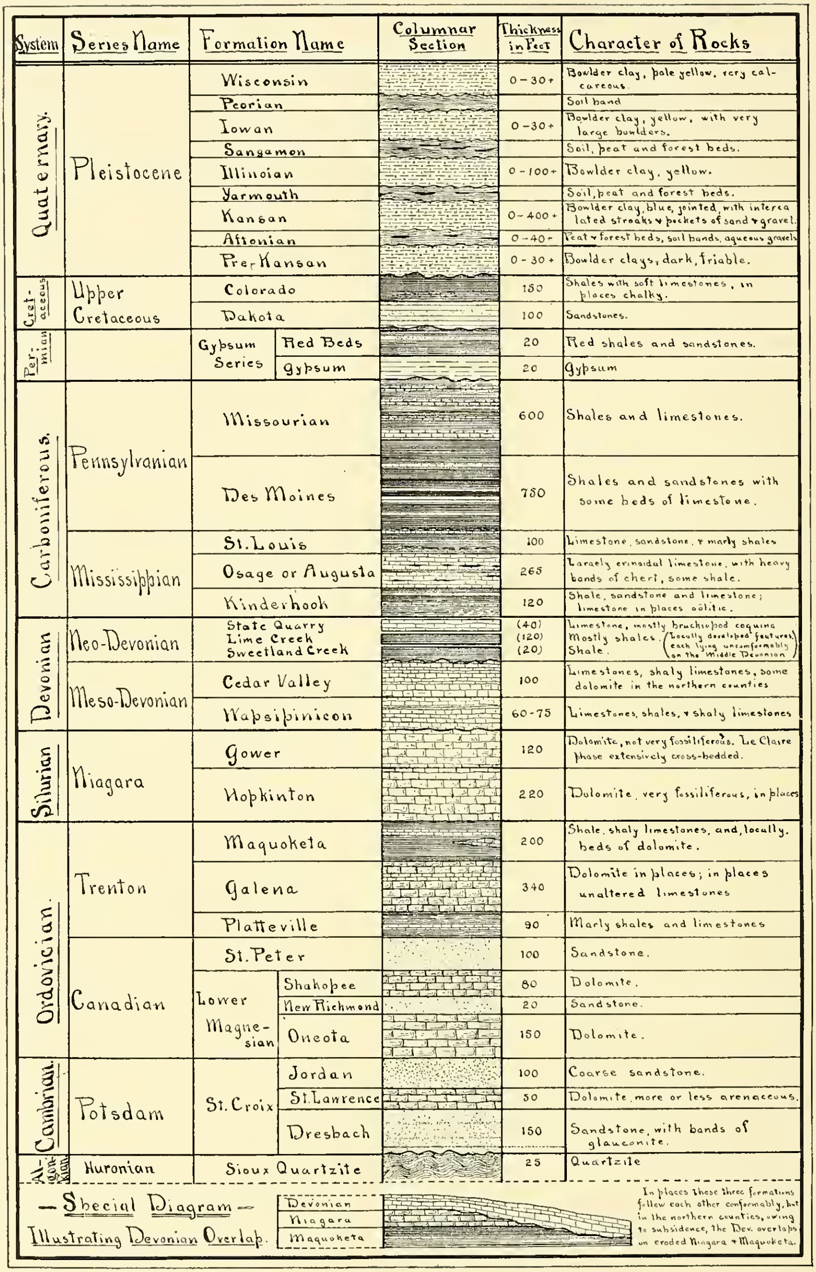
SAMUEL CALVIN
Iowa City, Ia.

The columnar section is not drawn to scale. The approximate average thickness is indicated in the appropriate column.

The Sioux quartzite occupies only a few acres in the northwest corner of the state, and in this locality it is Cretaceous sediments which are found, in place, abutting against it. That it is pre-Cambrian in age admits of no doubt, and that it is the equivalent of the Baraboo quartzite of Wisconsin is equally certain. The 25 feet exposed in Iowa is only a small part of the thickness of this formation.

The Cambrian sandstones are exposed by the erosion of the river valleys in the northeastern part of the state. The basal contact with the Algonkian quartzites is not seen in Iowa; a thickness of fully 700 feet of this formation lies below the level of the Mississippi River at Lansing and New Albin. This sandstone has been referred to the Upper Cambrian, or Potsdam series, in the geological reports of Iowa and Wisconsin. The special formation name, St. Croix, and the names applied to the smaller divisions, have been adopted from the reports on the geology of Minnesota.

Lower Magnesian.—This term is retained tentatively for the sediments lying between the top of the Cambrian, the Jordan sandstone, and the very consistent geologic unit which has been universally recognized under the name of the St. Peter sandstone. The New Richmond sandstone, when present, divides the Lower Mag-



System	Series Name	Formation Name		Columnar Section	Thickness in Feet	Character of Rocks
Quaternary.	Pleistocene	Wisconsin			0-30+	Bowlder clay, pale yellow, very calcareous.
		Peorian				Soil band
		Iowan			0-30+	Bowlder clay, yellow, with very large bowlders.
		Sangamon				Soil, peat and forest beds.
		Illinoian			0-100+	Bowlder clay, yellow.
		Yarmouth				Soil, peat and forest beds.
		Kansan			0-400+	Bowlder clay, blue, jointed, with intercalated streaks & pockets of sand & gravel.
		Aftonian			0-40+	Peat & forest beds, soil bands, aqueous gravels
		Pre-Kansan			0-30+	Bowlder clays, dark, friable.
Cretaceous	Upper Cretaceous	Colorado			150	Shales with soft limestones, in places chalky.
		Dakota			100	Sandstones.
Permian		Gypsum Series	Red Beds		20	Red shales and sandstones.
			Gypsum		20	Gypsum
Carboniferous.	Pennsylvanian	Missourian			600	Shales and limestones.
		Des Moines			750	Shales and sandstones with some beds of limestone.
	Mississippian	St. Louis			100	Limestone, sandstone, & marly shales
		Osage or Augusta			265	Largely crinoidal limestone, with heavy bands of chert, some shale.
		Kinderhook			120	Shale, sandstone and limestone; limestone in places oölitic.
Devonian	Neo-Devonian	State Quarry Lime Creek Sweetland Creek			(40) (120) (20)	Limestone, mostly brachiopod coquina Mostly shales. Shale. (Locally developed features, each lying uncomformably on the Middle Devonian)
	Meso-Devonian	Cedar Valley			100	Limestones, shaly limestones, some dolomite in the northern counties
		Wapsipinicon			60-75	Limestones, shales, & shaly limestones
Silurian	Niagara	Gower			120	Dolomite, not very fossiliferous. Le Claire phase extensively cross-bedded.
		Hopkinton			220	Dolomite, very fossiliferous, in places
Ordovician.	Trenton	Maquoketa			200	Shale, shaly limestones, and, locally, beds of dolomite.
		Galena			340	Dolomite in places; in places unaltered limestones
		Platteville			90	Marly shales and limestones
	Canadian	St. Peter			100	Sandstone.
		Lower Magnesian	Shakopee		80	Dolomite.
			New Richmond		20	Sandstone.
			Oneota		150	Dolomite.
Cambrian.	Potsdam	St. Croix	Jordan		100	Coarse sandstone.
			St. Lawrence		50	Dolomite, more or less arenaceous.
			Dresbach		150	Sandstone, with bands of glauconite.
Algonkian	Huronian	Sioux Quartzite			25	Quartzite

— Special Diagram —
Illustrating Devonian Overlap.

In places these three formations follow each other conformably, but in the northern counties, owing to subsidence, the Dev. overlaps on eroded Niagara & Maquoketa.

nesian of Owen into three units, here named respectively the Oneota, New Richmond, and Shakopee. In the earlier reports of the Iowa Survey the term "Oneota" was used as the full equivalent of the Lower Magnesian of Owen.

The St. Peter sandstone needs little comment further than to say that McGee, in his *Pleistocene History of Northeastern Iowa*, extended the application of the term downward so as to make it include the Shakopee and New Richmond of the Lower Magnesian stage. It was assumed that the two sandstones are related, and the intervening Shakopee limestone is only an incident. Apart from the fact that they are made of quartz grains, the two sandstones have nothing in common. The New Richmond lies in thin beds; the surface of the beds is often ripple-marked; the individual grains, in the most perfect way imaginable, show secondary enlargement; some parts of the formation have been converted into a fair quality of quartzite. None of these things characterize the St. Peter.

The Platteville and Galena limestones.—The confusion which has arisen in connection with the use of the terms "Trenton" and "Galena" as applied to certain Ordovician limestones of the midwestern states, and the probable causes of such confusion, are discussed in the "Geology of Dubuque County," in Volume X of the *Iowa Geological Reports*. The assemblage of strata covered by the two names conjoined is divided by a persistent band of shale and shaly limestone carrying *Orthis subaequata* and *O. tricenaria* of Conrad as characteristic fossils. This band has been called the "Green Shales" in some Minnesota and Iowa reports. All the beds above the "Green Shales" are dolomitic at Dubuque, and, so far as concerns this locality, they have been consistently known as the Galena limestone ever since the publication of the report on the *Geology of Iowa* by James Hall in 1858. In localities where these beds are unaltered limestones, they have usually been spoken of as Trenton. Lithology, and not stratigraphy, was the basis of the classification. It is now proposed to use the term "Galena" for all the strata above the "Green Shales," whether they are dolomitic, as at Dubuque, or are non-dolomitic, as along the river at and above Decorah. Bain's name, "Platteville," is acceptable for the beds below the top of the "Green Shales."

The Maquoketa shales were so named by White in his report on the *Geology of Iowa*, published in 1870. The beds are, in part only, the equivalent of the Cincinnati shales of Meek and Worthen, of the Hudson River shales of the New York geologists.

The Niagara limestone.—Lithologically, the Niagara series of Iowa is wholly unlike that of New York. There are no sandstones, no shales, practically no unaltered limestones. In the mid-west the Silurian is represented by a great body of dolomite in which there is more or less commingling of the Clinton and Niagara faunas of the region farther east. In some cases a number of life zones may be recognized. *Syringopora tenella* characterizes one of these; *Pentamerus oblongus*, another; another has *Caryocrinus*, *Eucalyptocrinus*, and related forms as diagnostic types; and others, like that carrying *Dinobolus Conradi*, are marked by still different species. But these zones are not well set off one from the other, and in many localities there is more or less of intermingling of forms from adjacent zones. The lower part of the Niagara limestone, including the zones between the base of the formation and the top of the Pentamerus-bearing beds, is quite distinct from the upper portion which includes what have been called the Le Claire and the Anamosa limestones. In the earlier volumes of the current series of *Iowa Reports* the lower phase was designated the Delaware stage, and the upper has been called by Norton the Gower stage. The term "Delaware," however, as the name of a geological unit, was used by Orton for a phase of the Ohio Devonian as early as 1878, and it is proposed in the Winneskiek County report, now in press, to use "Hopkinton" in place of the preoccupied term "Delaware" for the lower phase of the western Niagara. All the characteristics of this stage are well displayed in the quarries and ravines within a radius of two or three miles around Hopkinton in Delaware County, Iowa.

The Devonian system.—The Devonian is represented in Iowa by an assemblage of sediments carrying characteristic Devonian faunas. It is not possible, however, definitely to correlate any part of the western Devonian with any part of the sediments referred to the same system in New York. There is certainly nothing west of the Mississippi which can be said to represent the Helderberg or Oriskany of the East, and the New York Corniferous, or Onondago, is but doubtfully indicated by a few species. The faunal relations of our Devonian, so far as it is possible to recognize such relations, are with the divisions generally known as Hamilton and Chemung. The conditions of sedimentation were different in the two areas, mechanical sediments and turbid waters prevailing in one, clear seas and organic deposits characterizing the other; geographically the basins were separate; a very large proportion of the species are quite distinct and are useless for purposes of correlation. Of the species which are common the order in which they arrived in the respective basins is not the same, some of the upper Devonian forms of New York appearing early in Iowa, while some of the earlier ones came late. In a general way, therefore, but not in any way definite or specific, the Middle and Upper Devonian may be recognized; but not even in the most general way can we point to anything corresponding to the Lower Devonian of the New York section. Indeed, the remarkable lung fish, Dipterus, which elsewhere is found only in the Upper Devonian, occurs in Iowa in formations which have been tentatively referred to both the middle and upper divisions of this system. The system has been divided in Iowa on the basis of a marked unconformity; faunally the two divisions are not very distinct. The intimate faunal relations between the Independence shales, near the base of our Devonian, and the Lime Creek shales, above the unconformity near the top, are noted in the reports on Cerro Gordo and Buchanan Counties. The three units referred to the Upper Devonian—the Sweetland Creek shales, Lime Creek shales, and State Quarry limestone—do not lie one above the other, but each is locally developed and lies unconformably on the Cedar Valley limestones.

In Cedar, Linn, and Scott Counties the Devonian follows the Silurian conformably, but in the northern counties, Howard, Winneshiek, and Fayette, there is a record of subsidence due to crustal warping after the Devonian was fairly well advanced, and the rocks of this later system overlap the whole Niagara, and, in the counties named, their eastern edge rests on deeply eroded Maquoketa. An attempt is made to show these relations in the special diagram at the foot of the columnar section sheet.

The Lower Carboniferous-Mississippian.—It is possible, indeed probable, that there is an unconformity between the Devonian and Lower Carboniferous, but it has not been positively demonstrated. The actual contact of Devonian and Kinderhook has not been observed. The faunal break is not exceptionally great. The stromatopores, favosites, and most of the other corals characteristic of the Devonian do not appear in the Kinderhook, and the same is true of the Stropheodontas, Strophonellas, and Atrypas; but the Orthothetes, Rhipidomellas, Spirifers, and Cyrtinas have pronounced Devonian relationships. *Productella pyxidata* and *Ptyctodus calceolus*, collected in the Kinderhook of Missouri, furnish other points of affinity between the Kinderhook and Devonian faunas. On the other hand, leaving out Productella, the Productidae of the Kinderhook are decidedly Carboniferous, and the fish fauna in general points unmistakably in the same direction. The Burlington limestone and the Keokuk limestones of the earlier geologists of Iowa and Illinois have been united under the term "Osage" or "Augusta." While the two alternative names are not quite synonymous, it is probable that geologists will unite on the term "Osage" for the assemblage of limestones, cherts, and shales under consideration. The St. Louis limestone brings the Iowa Mississippian to a close, and this formation remains as originally defined. When the later Mississippian, the Kaskaskia or Chester, was deposited, the shore lines, so far as now known, lay outside the limits of our state. That the greater part of the Mississippian was characterized by comparatively arid climate is supported by many lines of evidence.

The Pennsylvania series includes the productive coal-measures and presents the usual characteristics, biologic and lithologic, of equivalent deposits in other parts of the world. One of the most pronounced unconformities in the Mississippi valley occurs between the Upper Carboniferous and the older formations. When the Pennsylvanian series began, the shore-line was probably as far south as Arkansas. There are indications that, at that time, Iowa stood higher with respect to tide level than it does at present, and deep erosion trenches were cut in the Silurian, Devonian, and Lower Carboniferous formations. When subsidence allowed the sea to return, it advanced upon a scarred and eroded surface, depositing shales and sandstones of the Des Moines stage in old drainage channels, and over the surface generally, as far to the northeast as Delaware and Jackson Counties. In the counties last named remnants of coal-measure strata are found in troughs cut in Silurian, and even Ordovician, beds, and similar remnants occur in old river channels cut in the Devonian limestones of Muscatine, Linn, and Johnson Counties. The extreme advance of the coal-measure sea was of comparatively short duration. For the greater part of the Des Moines stage, so far as it is represented in Iowa, the shore-line oscillated back and forth over the area now occupied by the valleys of the Des Moines and the Skunk Rivers. Within this area there are records of numerous slight movements of elevation and subsidence.

The sediments referred to the Missourian stage follow those of the Des Moines without break. The crustal oscillations seem to have been less numerous; the waters were clearer; the climate was less humid; arenaceous deposits are scarce; limestones and shales make up the bulk of the deposits of this stage; progress was made toward the more arid conditions of the Permian.

The Permian.—The gypsum beds in Webster County, together with the associated red shales and sandstones, have been referred by Professor Wilder to the Permian system. By some writers they have been referred to the Triassic, by some to the Cretaceous. These beds contain no fossils, and their stratigraphic relations are such as to lend no aid in determining their exact position in the geological column. They lie unconformably on deposits of the Des Moines stage; in some places they rest on St. Louis limestone, for erosion had cut through the whole thickness of the Des Moines sediments before conditions favoring the deposition of gypsum began.

The Cretaceous system.—The Dakota and Colorado stages of the Upper Cretaceous are represented in northwestern Iowa by a series of sandstones, shales, and chalky limestones. In his report on the *Geology of Iowa*, published in 1870, White divides the Iowa Cretaceous into the "Nishnabotany sandstone," the "Woodbury sandstones and shales," and the "Inoceramus beds." The sandstones along the Nishnabotna River, as well as those at Sergeants Bluff and Sioux City in Woodbury County, together with some interbedded shales, are referable to the Dakota stage; while the main body of shale and the calcareous Inoceramus beds represent the Fort Benton division of the Colorado. It is not certain that there is any true Niobrara in Iowa. During the long interval between the Upper Carboniferous and the Upper Cretaceous the surface of Iowa was deeply eroded, and it was on such a surface that the Cretaceous sediments of the state were unconformably deposited. Since the Cretaceous, these sediments, which were comparatively thin at the most and imperfectly consolidated, have been extensively removed by erosion, and now occur in more or less isolated patches. On the geological map of Iowa the Cretaceous is indicated over the entire area upon which it was originally spread.

The Pleistocene deposits.—Iowa was exceptionally fortunate in its location with reference to the movements and marginal limits of the successive ice-invasions of the Glacial epoch. The state, therefore, offers unusual facilities for the study of the relative age and differential characters of the several sheets of drift which make up the great body of mantle rock within the limits of the glaciated area. The succession of the glacial and interglacial stages which have been recognized by members of the national and state surveys is indicated in the columnar section, and the subject will be found discussed in the national and state reports.

THE DEVONIAN SECTION OF ITHACA, N. Y.[1]

HENRY SHALER WILLIAMS
Ithaca, N. Y.

At a meeting of the American Association for the Advancement of Science, June 29, 1906, the following chart was exhibited before Section E with explanations (an abstract of which is given below), under the title "Revision of the Geological Section Running through Ithaca, N. Y."

REVISED CLASSIFICATION AND NOMENCLATURE OF THE SECTION PASSING THROUGH ITHACA, N. Y.

SERIES	FORMATIONS	MEMBERS AND LENTILS	
ERIE DIVISION OR SERIES OF VANUXEM	Chemung (shale and sandstone) formation	Fall Creek conglomerate lentil	0–10′
		Wellsburg sandstone member	600–650′
		Cayuta shale member	600′
	Nunda (shale and flagstone) formation	Enfield shale member	550–800′
		Ithaca shale member	80–460′*
		Sherburne flagstone member	188–260′
	Genesee shale formation		125′
	Tully limestone formation		10–30′
	Hamilton shale formation		1035′
	Marcellus shale formation		125′
	Onondago limestone formation		125′
	Oriskany sandstone formation		0–4′

* In the chart as published in *Science* (Vol. XXIV, p. 366) this figure is 300′; see beyond remark on thickness of Ithaca.

ABSTRACT

The accompanying chart expresses the result in classification and nomenclature of the resurvey of the section of the Devonian passing through Cayuga Lake valley and Ithaca, between the Third and Fourth Districts of the original geological survey of the state

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[1] Published by permission of the Director of the United States Geological Survey.

of New York made by Messrs. Vanuxem and Hall, and regarded by them as the standard section of the portion of the Devonian there represented. The revision was based upon a critical study of the composition, sequence, and range of the fossil faunas gathered in constructing the folio map of the Watkins and Catatonk quadrangles now in progress. The classification into taxonomic categories (i. e., series, formations, members, and lentils) is in accordance with the rules of classification and nomenclature of the United States Geological Survey as published in the *Twenty-fourth Annual Report* for 1902–3.

The *Nunda* (*shale and flagstone*) *formation* is the stratigraphic equivalent of the Portage or Nunda group of Hall, the standard section of which is in the Genesee valley; the term "Portage" having been dropped from the name because it was already specifically applied to the upper sandstone member of the Nunda formation of the Genesee valley. The lithologically discriminated members (Cashaqua, Gardeau, and Portage) there recognized are not distinguishable in the Ithaca section, which is divided into the *Sherburne flagstone*, the *Ithaca shale*, and the *Enfield shale members*. The term "Enfield" is applied to the latter member for the town of Enfield, where its typical exposures are found.

The boundary between the Nunda and Chemung formations is established on the generic change in fossils taking place at the horizon indicated. The more prominent of the new genera first appearing in the Chemung of this section are Dalmanella, Douvillina, and the species *Spirifer disjunctus*.

The *Cayuta shale member* contains the typical Chemung fauna of Chemung Narrows; and the name "Cayuta" is applied for Cayuta Creek along the sides of which, from Cayuta Lake to its discharge into the Susquehanna River, the typical exposures are met with. The upper boundary of the Cayuta member is marked by the fourth (above the Hamilton), and highest at present known, zone of *Tropidoleptus carinatus*, called the *Swartwood Tropidoleptus zone* for its conspicuous outcrop southwest of Swartwood at about 1,600 feet altitude above sea-level.

The second member of the Chemung formation is named the "Wellsburg sandstone member" for its outcrop from Wellsburg upward into the high hills of Ashland, near the top of which the member is terminated by a thin conglomerate lentil called the *Fall Creek conglomerate lentil.* Immediately below this conglomerate the horizon is indicated by a band of thin-bedded sandstone, often calcareous, containing a great number of shells of *Leptostrophia nervosa* and *Orthothetes chemungensis*, to which the name *Ashland Leptostrophia zone* is applied.

It was noted that the formations of this section, extending from the top of the Onondaga limestone formation to the top of the section, belong to the Erie division of Vanuxem and Hall. This constitutes a natural *series* according to the rules of the Survey; the upper boundary of which, according to the original definition, should be the Catskill division (or series). Although the Wellsburg sandstone member appears to be the upper member of the Chemung formation of this particular section, the author expressed the conviction that the stratigraphic horizon of the Fall Creek conglomerate does not mark the termination, chronologically, of the Chemung fauna.

DISCUSSION

The original definition of the section.—This geological section of the Devonian rocks running through Ithaca was constructed along the boundary line between the Third and Fourth Districts of the state. Lardner Vanuxem wrote the *Final Report on the Third District* (1842), and James Hall the *Final Report on the Fourth District* (1843). The adopted classification and nomenclature of the Paleozoic rocks, up to the base of the Carboniferous, for North America has been constructed on the general lines which were announced chiefly by Vanuxem and Hall, and published in these two reports.

The significance of this particular section was expressed by Vanuxem in his report (1842), in the following passage:

> The Erie division embraces the rocks above those of the Helderberg division, extending to the Catskill group. It presents through several counties on both sides of the boundary of the Third and Fourth Districts two well-defined parts, separated by the Tully limestone and the Genesee slate; these latter are boundary masses of the two parts, being comparatively very thin, and of no great extent of range. The lower part of the division consists of the Marcellus shales and the

> Hamilton group; and the upper portion contains the different sandstones and shales below the rocks at Ithaca, subsequently to be mentioned, and the Ithaca and Chemung groups. The distribution of the rocks of the upper part of the Erie division, under the heads of Sherburne flags, Ithaca group, and Chemung group, was founded upon observations made with Mr. Hall, commencing along Cayuga Lake, going south from Ludlowville by Ithaca, and from thence to the Pennsylvania line. The rocks, therefore, along that section, especially the upper ones, are the standard of reference, or types of those of their name. (P. 170.)

From this quotation it is evident that this section was adopted by Vanuxem and Hall as the standard section, and its subdivisions as the standard subdivisions, of that portion of the geological column which was then called the Erie division of the New York system. The nomenclature applied by Vanuxem to this standard section, expressed in tabular form and in natural order of sequence, is as follows:

Catskill division	28 Catskill group
Erie division	27 Chemung group
	26 Ithaca group
	25 Portage or Nunda group
	24 Genesee slate
	23 Tully limestone
	22 Hamilton group
	21 Marcellus shales
Helderberg division	20 Corniferous limestone, etc.

The rocks considered in the present paper are the upper four subdivisions of the Erie division of the New York system.

Original application of the term "member."—The term "member" was used in the text, both by Vanuxem and Hall, to designate a subdivision of a group which offered some local distinguishable characters, but was not regarded as of sufficient importance to incorporate in the nomenclature of the general classification proposed. Thus, in describing the Hamilton group, Vanuxem says: "This group takes its name from the town of Hamilton, in Madison County, which contains no other rocks, and where the best opportunity exists for examining some of the important members of which it is composed;"[1] and Hall, in describing the fossils of the Cashaqua shale, says: "In the Cashaqua shale, or lower member of this group, there are several species of shells which have not been seen in any

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[1] *Geology of the Third District*, p. 150.

other rock, and at the same time there are no fossils found in them which are known in other rocks beyond the group."[1]

The taxonomic rank of the original subdivisions of the section.—In geological literature subsequent to the publication of these reports the geographic terms above mentioned have been applied in a technical sense to subdivisions of the geologic column of varying taxonomic value. Thus we find "Chemung group, period, series, beds, and formations;" and in the latest edition of Dana's *Manual of Geology* we find "Hamilton period" described as consisting of the Marcellus and Hamilton epochs (p. 576), and again the "Hamilton group as composed of the Marcellus shale, Goniatite limestone, Hamilton beds, and Tully limestone (p. 593).

Rules of classification and nomenclature.—Confusion of this kind has made it necessary to construct definite rules for nomenclature and classification in which the taxonomic rank of the subdivisions is indicated.

Two well-known examples of such rules are in use. The one was proposed by the Congrès géologique international; the substance of which was published as a report of the *Commission pour l'uniformité de la nomenclature*, made to the Berlin congress in 1885 by M. G. Dewalque, secretary of the commission. The other, as finally perfected, was published in the *Twenty-fourth Annual Report* of the Director of the United States Geological Survey in a passage headed "Nomenclature and Classification for the Geological Atlas of the United States" (pp. 21–27). The first may be said to be the set of rules for the construction of the geologic map of Europe; the second, rules for the construction of the geologic map of the United States.

No attempt will be made in this place to describe either of these sets of rules; suffice here to explain a fundamental difference between the two schemes. Dewalque's scheme was an attempt to unify the nomenclatures of the various nations of Europe by first establishing a set of names to distinguish the order of rank of the divisions to which they were to apply. Thus, to divisions of the first rank (i. e., the largest named divisions of the rock column) the term "group" (French *groupe*) was applied; second, *système* was the

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[1] *Geology of the Fourth District*, p. 243.

name proposed for divisions of the second rank (i. e., subdivisions of groups); third, *séries* was the name for the third-rank divisions; fourth, *étage*, for the fourth rank; and, fifth, *assise* for the fifth rank. The terms, *ère*, *période*, *époque*, *âge* were proposed for the time divisions corresponding to the respective stratigraphic divisions of the first list. In this scheme "systems" were the systems in common use. Agreement as to which of the system names should be retained was settled by the congress. Finally it was proposed that all the names of each particular rank should receive the same ending: *-aire*, *-ique*, *-ian;* and thus names show by their endings the rank of the division to which they are applied.

The fundamental difference from all this, seen in the rules of the United States Geological Survey, is the adoption of a cartographic unit and calling it "formation."

The formation the unit in American classification.—In rule 2 it is stated: "In all classes of rocks the cartographic units shall be called 'formations.'"[1] A "sedimentary formation" is defined, viz.: "Each formation shall contain between its upper and lower limits either rocks of uniform character or rocks more or less uniformly varied in character." In other words, the unit division of stratigraphic rocks recognized for mapping, and hence for classification purposes, is a mass exhibiting unity of composition. Provision is made further in the rules for recognizing and mapping "especially developed parts of a varied formation" and calling them members, "*if they have considerable geographic extent*," and and lentils "*if their distribution is more limited.*"[2]

The units of the time scale, however, are, by the United States rules, said to be "periods"—the time equivalent of the standard geologic systems (rules 14 and 15, p. 25), and "for purposes of general correlation formations shall be referred to the standard systems," principally by paleontology. Thus, in classifying and correlating formations with each other, the physical units in the United States are "formations," which may be gathered into aggregates on the basis of correlation of their fossils with standard systems, all of which are in fact represented typically in Europe; but they

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[1] *Twenty-third Annual Report*, p. 23.

[2] *Ibid.*, p. 24.

(the formations) are subdivided on the basis of differences in composition locally expressed.

Systems the European units of classification.—In Europe, practically, the "systems" are the primary units found already defined, named and in common use; and subdivisions of the systems are called respectively, according to their order of rank, *séries*, *étages*, and *assises* (these are the French terms).

Terms "group" and "series."—The terms "group" and "series" are also adopted in the United States Geological Survey rules, but they are there used for aggregates of formations, subordinate to systems and determined by local structure rather than simple correlation. Rule 20 sets forth this practice.

> Within the system smaller aggregates of formations may be recognized which shall be called "series," and these may be divided into subordinate groups of formations . . . . These minor aggregates should be formed so as to express the natural relations of the formations of the particular province rather than to conform with divisions recognized elsewhere.

The fundamental difference is exhibited in this rule 20: "Systems" are subdivided in Europe into *séries*, *étages*, *assises;* in America "formations" are aggregated into "groups," "series," and "systems."

In practice American geologists, unless actually working on the survey under the rules of the United States Geological Survey, are more accustomed to adopt the principles of the European rules than those of the United States Geological Survey. This result is perhaps because the European system lends itself better to the use of textbooks and colleges.

Uncertainty as to the definition of "formation."—In the present revision particular attention has been given to meeting the requirements of the rules of the United States Geological Survey. To do so, one of the first, and certainly an important, task required of the investigator is to determine which of the subdivisions of the section proposed by Vanuxem is a "formation" under the rules. Vanuxem realized the nature of the problem when he wrote:

> There are difficulties in the beginning of most, if not all, subjects. Those in the three groups under consideration arise from the little difference in their mineral characters, which, for distant points, cannot be relied upon. The change,

> too, in the fossil characters is not so marked as to be at this time available. . . . What has caused geology to advance with rapid strides has been a knowledge of fossils, and when those of the upper part of the Erie division shall have been fully examined, and the kind determined which are limited to a group, and those which are not, then the difficulties will be at an end. (P. 172.)

Vanuxem in 1842 may have estimated too highly the results to be attained by a study of the fossils, but of the nature of the results he had a clear conception.

Neither of the sets of rules above referred to has given an intimation of the way by which we are to distinguish the size (in thickness of strata) of the geological unit, either of classification or for mapping purposes. How thick may a "system" or an *étage* of Dewalque's report be? or, How may a "formation" of the United States rules be distinguished from a "member" or a "group"? The raising of these questions will doubtless call forth scarcely two replies alike. In new work as in the old, the individual is left to draw the limits or boundaries of his "formation" as he will. The literature indicates that usage has been as diverse as is the modern practice.

The fact remains that it is all-important to discover if there may be some means of discriminating between the major and the minor divisions of the geological column.

The taxonomic rank of the subdivisions of the first New York survey.—The specific problem now before us is regarding the rank to be assigned the subdivisions originally recognized by Vanuxem in the Ithaca section.

The Portage or Nunda group.—Vanuxem described the first subdivision above the Genesee (no. 25) as the Portage or Nunda group. It is evident that it is only by correlation that this name is applicable to a part of the Ithaca section. The typical section of the Portage or Nunda group is found in the Genesee valley and is defined in Hall's *Report of the Fourth District.* In that region the "group" is composed of three subdivisions, viz., Cashaqua shales, Gardeau shale and flagstone, and Portage sandstones. It is fair to assume that the taxonomic rank of these subdivisions be tested in the original section, and that the application of the terms to the section at Ithaca rests upon correctly correlating its rocks with those of the original section in the Genesee valley.

Rule 3 of the United States Geological Survey *Rules of Nomenclature and Classification* contains the following provision for discriminating a "formation":

> Lines of separation are drawn at points in the stratigraphic column where lithologic characters change, or where there are breaks in the continuity of sedimentation or other evidence of important geologic events.

In the original definition the line at the base was drawn where the "soft argillaceous rock of a green color" of the Cashaqua shale succeeds the "fissile black shale" of the "Genesee black shale." The upper boundary, although marked by the "thick-bedded sandstones" (Portage sandstones) was distinctly drawn on paleontological evidence. Hall stated:

> Still it must be acknowledged that in lithological characters there is no abrupt change, or evidence of very different conditions in the ocean from which they were deposited, from the termination of the Tully limestone, to the final deposition of the Chemung group (p. 229).

After stating that there are some general differences noted on passing upward by which the Portage and Chemung rocks can be distinguished as masses, he adds:

> When we apply the test of organic remains, we find an equally or even more strongly marked difference in the two groups, and upon this alone a distinction between the two should be made.

Later studies have confirmed both of these points, and upon purely lithologic grounds it would be necessary to go down to the Tully limestone to find a sharply defined lithologic lower limit for the rocks in question. There is no satisfactory upper limit of a purely lithologic nature—not till we reach a definite pebbly conglomerate or a red sandstone such as has been supposed to mark the upper boundary of the Chemung formation. Nevertheless, the rule defines more clearly what is intended by "unity of constitution" by stating that in determining the unity of constitution, which is to characterize a formation, "all available lines of evidence, including paleontology, shall be considered" and "when two formations of closely similar lithologic character are in contact, it will sometimes be necessary to depend almost entirely on the contained fossils in separating them."

These statements distinctly apply to the case in hand. The unity of the fossil fauna of the three subdivisions of the original Portage or Nunda group, the definite change in faunal composition passing on downward into the Genesee, and that observed on passing upward into the Chemung in the region of the original section, together give ample reasons for regarding this subdivision as a "formation" in the technical sense of the rules. Each of the parts, Cashaqua, Gardeau, and Portage, naturally falls into the nomenclature of "member" as defined in rule 5.

The name of the formation.—There is thus a formation composed of three members already described in the section of the Fourth District of New York to which a definite name was applied by Hall, but to the final adoption of the names of the subdivisions of the Ithaca section rule 7 applies. Rule 7 reads:

> In the application of names to members, formations, and larger aggregates of strata the law of priority shall generally be observed, but a name that has become well established in use shall not be displaced merely on account of priority.

It is well known that the name "Portage" has been largely used for the Portage or Nunda group; there is therefore some question as to the proper name to apply to the formation. Hence, the rule of common-sense must be called into use. Since the rules contemplate the application of distinctive terms to formations, as well as to members and larger aggregates of strata, it is clear that the same geographic part of the name cannot be applied distinctively to two separate subdivisions. The law of priority applies to Portage as the distinctive name for the upper sandstone member of the Portage or Nunda group; this excludes the use of the abbreviation of the group name to Portage by dropping from it the words "or Nunda." It is therefore proposed to rectify the usage by taking the second of the synonymous geographic terms, and omitting "Portage or," from the original name, to leave Nunda as the geographic part of the formation name. Thus the revised nomenclature for Hall's "Portage or Nunda group" is "Nunda formation," composed, in the Genesee section, of the Cashaqua shale, Gardeau flagstone, and Portage sandstone members.

The Nunda formation in the Ithaca section.—A critical examination of the *Final Reports* of the Third and Fourth Districts indicates that Hall and Vanuxem were not in perfect agreement regarding the correlation of the Genesee and Ithaca sections. Hall evidently believed that the Ithaca group of the annual reports was not distinct from, but a lower portion of, the Chemung group. The equivalent of the Portage or Nunda group according to that view would be found below the Ithaca. Vanuxem, on the other hand, originally intended "to unite the Sherburne and the Ithaca masses, not having discovered in the district those leading characters by which they could be readily distinguished."[1] Both authors evidently expected the fossils, when fully studied, would solve the perplexity.

In the final reports on the paleontology, which was chiefly prepared by Hall, the Ithaca fossils were described as from the Chemung group, thus perpetuating the view held by Hall in 1843.

A review of the section and contained fossils was made by the writer, and published in 1883 as *Bulletin No. 3* of the United States Geological Survey.[2] In that paper it was shown that the fauna of the Sherburne portion of the section below the Ithaca group was present also above the latter; that there are 600 feet or more of strata separating the Ithaca from the base of the Chemung; and that the Ithaca and Chemung faunas are distinct.

The investigations recently undertaken, in preparing the areal map of the Watkins Glen quadrangle, have confirmed the correctness of these points and have demonstrated more clearly the true correlation of the two sections. It has been shown that, upon passing westward from the Ithaca section, the molluscan fauna characteristic of the Nunda formation prevails throughout the whole 1,300 feet of strata following the Genesee shale, with (at the head of Seneca Lake) only a sparse representation of the Ithaca fauna appearing in a few narrow beds in the lower portion of the section. West of Seneca Lake scarce a trace of the Ithaca fauna is discovered, but, when present, it is always below the first appearance of the Chemung fauna. The fauna in the Grimes sandstone of the Naples section reported by Clarke and Luther appears to contain a trace of the Ithaca fauna.[3]

[1] *Report of Third District*, p. 171.

[2] Henry S. Williams, "On the Fossil Faunas of the Upper Devonian along the Meridian of 76° 30′ from Tompkins County, N. Y., to Bradford County, Pa."

[3] New York State Museum, *Bulletin No. 63*, p. 63.

Peculiarities of the formation east of Ithaca.—On passing east of the Ithaca section, into the Dryden and Harford quadrangles, the beginning of the Chemung fauna is found at the same stratigraphic horizon; but the Nunda fauna becomes rare and limited in range in the Enfield member. The upper limit of the Ithaca fauna proper rises higher in the strata, and a successor of the Ithaca fauna appears in the upper portion of the Enfield, below the Nunda Chemung boundary. In the Chenango valley section there is little, if any, trace of the Nunda fauna above the Sherburne sandstone, which there represents, as shown by Prosser,[1] the portion of the Nunda lying below the Ithaca at Ithaca rather than the whole Nunda of the Genesee valley section. In this eastward extension of the portion of the section called "Nunda formation" in the Genesee valley the species of the Nunda fauna are very rarely discovered, but in place of them an increasing number of species of the Hamilton formation appear, mingled with others of the Ithaca fauna.

In these strata there are representatives of three faunas, viz., those typically expressed in the Hamilton, the Nunda, and the Chemung formations. In single sections they appear in the order named; but this order of succession can not be interpreted into an assumption that the time range of each is separate. The faunas undoubtedly lap over in time. In stratigraphy this fact is expressed by saying that the stratigraphic horizon at which one fauna is succeeded by the next in a particular section does not represent the same moment of time at which the like succession occurs in some other section. As has been explained elsewhere,[2] the principle involved is the geographic shifting of two contemporaneous faunas over the same ground. The fact of this gradual replacement of the Nunda fauna on passing eastward by representatives of the Hamilton fauna is indicated in the Ithaca section by the appearance in the midst of the normal faunas lying above the Hamilton formation of thin beds four times repeated, holding a nearly pure Hamilton fauna. Discussion of this subject will be taken up later.

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[1] See *Fifteenth Annual Report* of the State (New York) Geologist, pp. 112, 113, 119, 134, and 221.

[2] Henry S. Williams, "Shifting of Faunas, etc.;" *Bulletin of the Geological Society of America*, Vol. XIV (1903), pp. 177–90.

The members of the Nunda formation at Ithaca.—From these facts the conclusion is drawn that the stratigraphic equivalent of the Nunda formation of the Genesee valley is represented in the Ithaca section by three subdivisions or members, viz., *Sherburne flagstone member*, which is the westward extension of Vanuxem's Sherburne flagstones of the Chenango Valley; *Ithaca shale member*, the equivalent of Vanuxem's Ithaca group; and *Enfield shale member*, a member not recognized by Vanuxem or Hall, but first reported by Williams in *Bulletin No. 3* of the United States Geological Survey (p. 30) in 1884 as "Upper Portage." The name "Enfield" is proposed for its outcrop in the town of Enfield, west of Ithaca. The rocks of the Enfield are shales, flags, and thin sandstones as in the Sherburne; the fauna is similar to that of the Sherburne flags below; and the thickness in the Ithaca section is from 600 to 800 feet.

Two reasons may be given for not recognizing the original subdivisions of the Nunda in the Ithaca section. (1) Though the lithologic characters upon which these three members (i. e., Cashaqua, Gardeau, and Portage) were founded become more pronounced going westward, on passing eastward before reaching Ithaca they fail to be distinctive of the lower, middle, and upper portions of the formation. (2) The fauna which was recognized by Hall in 1843 as characteristic of the Cashaqua member prevails throughout the Nunda formation of the Ithaca section. Hence the subdivisions of Hall's original Portage or Nunda group are discarded in the definition of the Ithaca section.

Discrimination of the members.—The Ithaca member is recognized on the basis of its fauna; the portion of the Nunda lying below the Ithaca member is correlated lithologically and stratigraphically with the Sherburne flagstone member of Vanuxem, and the upper portion, lying between the Ithaca member and the base of the Chemung formation, is for the first time given a distinctive name, i. e., the Enfield member. Lithologically and paleontologically the Sherburne flagstone and the Enfield shale or flagstone are very similar; stratigraphically they are separated by the shaly member bearing the characteristic Ithaca fauna. The range of this Ithaca fauna is restricted to a zone of about 80 feet in the Watkins exposure; this range is increased on passing eastward, and at the Ithaca meridian is some 300 feet. The thickness of the Ithaca member, estimating it from the upper Reticularia lævis zone of the Sherburne to the upper Ithaca Reticularia lævis zone is approximately 460 feet at Ithaca.

Lithologic definition of the Nunda formation.—Thus is established a definite stratigraphic subdivision of the Devonian system of formational rank of which the technical name is "Nunda formation," composed of the members Cashaqua, Gardeau, and Portage in its typical outcrop in the Genesee valley, and of the Sherburne, Ithaca, and Enfield members in the Ithaca section.

Lithologically it is defined as an irregular combination of fine fissile shales, either light or dark in color, with, generally, thin-bedded and occasionally thicker beds of sandstone. The shales, in general, are more conspicuous in the lower half; the thicker sandstones are more frequent in the upper part. The light-greenish-colored shales seen in the western part of the state are inconspicuous in the eastern sections. The tough, thin-bedded, often wave-marked sandstone, called "flagstone" from its common use in paving sidewalks, is more frequent in the eastern than in the western outcrops.

THE BLACK SHALE BANDS

The fissile black shales, similar lithologically to the Genesee black shales below, appear throughout the vertical thickness of the formation at various horizons, sometimes of 20 to 50 feet thickness, presenting locally great uniformity. These fissile black shale masses rapidly change their appearance laterally by the intrusion of sandstone bands interrupting the shales, and altering the aspect of exposures to that of the ordinary type of shale and thin-bedded sandstone so characteristic of the whole mass. A typical example of this type of shale is seen at the base of the Ithaca group, near the foot of the hillsides at Ithaca. Locally it seems conspicuous, and I defined and indicated it as the "Ithaca Lingula shales" in the *Bulletin No. 3* of the United States Geological Survey in 1884.

Clarke has defined other local expressions of it under the names *Middlesex black band*, *Rhinestreet black band*, and *Dunkirk black* *band.* When the resurvey of the Watkins Glen quadrangle was begun, I expected that these black bands would prove of value in tracing and classifying the rock horizons from one quadrangle to another. It was discovered, however, in the course of the survey, that any particular mass of this fissile black shale does not retain its peculiarities with sufficient uniformity to serve as a reliable mark of a definite horizon.

The same may be said of local thick-bedded sandstones; they are also, so far as thickness is concerned, confined to narrow local distribution. The mode of change in the structure is through a breaking-up of the thick sandstone bed, by increase of shaly bands in its midst, reducing it to a mass of thin-bedded sandstone and shales. When for a considerable thickness no sandstone bands are present, the section appears as a mass of fissile shales; when the shale layers diminish, the sandstone bands run together, and become beds of sandstone separated irregularly by shale bands in which case the sandstones become the conspicuous features in the outcrops.

It was also discovered that the faunas are associated with particular classes of sediments; hence, where similar types of strata appear the fossils are also alike—irrespective of stratigraphic position within the formation through which the same fauna ranges. These are some of the reasons for discarding from the systematic nomenclature all such subdivisions of the strata as are of local narrow distribution.

Subdivisions of the Nunda formation not recognized in the Watkins Glen and Ithaca quadrangles.—Other names have been applied to subdivisions of the formation elsewhere where they are considered to be of member or lentil value. They have been discarded whenever the definitions given them, lithologic or paleontologic, fail to apply to any recognizable portions of the section in the Ithaca region.

According to the United States Geological Survey rules, it has been considered illegitimate to continue to apply member and lentil names to corresponding stratigraphic portions of a formation, when the section ceases to exhibit the lithologic or paleontologic characters upon which discrimination of the members was based. The formation name should be applied, according to rule 4, "as far as the formation can be traced and identified by means of its lithologic character, its stratigraphic association, and its contained fossils." But the member or lentil is a "specially developed part" of a formation; it is therefore considered inappropriate to apply the member or lentil name in absence of the characters distinguishing it.

For these reasons the terms "West River shale," "Cashaqua shale," "Parrish limestone," "Rhinestreet black shale," "Hatch shale and flags," used by Clarke and Luther,[1] are not deemed appropriate names to apply to portions of the Nunda formation of the Watkins or Ithaca quadrangles, however appropriate they may be for the sections of Canandaigua Lake or in the Genesee Valley.

Paleontological definition of the Nunda.—Paleontologically the Nunda formation is well characterized by the fauna ascribed to it by Hall in the Fourth District report of 1843 (pp. 241–47). The species named by him are (giving the original names): *Fucoides graphica*, *Fucoides verticalis*, *Avicula speciosa*, *Ungulina suborbicularis*, *Bellerophon expansus*, *Orthoceras aciculum*, *Clymenia complanta*, *Goniatites sinuosus*, *Pinnopsis acutirostra*, *Pinnopsis ornatus*, *Delthyris lævis*, *Cardium? vetustum*, *Orthis tenuistriata*, *Lucina retusa*, *Nucula lineolata*, *Astarte subtextilis*, *Bellerophon striatus* (Bronn, Phillips), *Goniatites bicostatus*, and *Cyathocrinus ornatissimus*. These nineteen species have been more definitely defined and named, and a great number of other species have been added to them since 1843, but they clearly indicate the fauna. There are in Hall's list eight Pelecypoda, two Gastropoda, four Cephalopoda, two Brachiopoda, one Echinodermata, and two of uncertain classification. About 75 per cent. are Mollusca. Later study of the fauna shows the same dominance of this class. The Brachopods are conspicuous by their absence; and it is the dominance of Brachipods in the Ithaca fauna which distinguishes the zone in which they occur as a well-marked member of the formation. Lithologically the Ithaca rocks are not clearly distinguishable from the other rocks of the Nunda formation of this section, though they are paleontologically. This Nunda fauna was definitely recognized

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[1] "Geology of the Watkins and Elmira Quadrangle," by John M. Clarke and A. Dana Luther, New York State Museum., *Bulletin No. 81*, 1905.

by me in 1884,[1] and it was then shown to range "through approximately 1300" feet, including the "Ithaca group." It was then spoken of as the *Cardiola speciosa fauna.* In 1886[2] this general fauna was differentiated into the several stages, *Lingula fauna*, characteristic of the black shales; *Cephalopod fauna*, found more frequently in the green shales; and the special *Cardiola speciosa fauna* also occurring in the greenish shales, but often disassociated from the Cephalopods. In 1887[3] these faunal distinctions were more fully elaborated and defined for the Genesee section. In 1885[4] J. M. Clarke described the fauna and flora of the Naples beds of Ontario county, there proposing the term "Naples beds" to include the Cashaqua and Gardeau members of the Portage or Nunda group of Hall; and in 1898 and 1904[5] the fauna was more fully elaborated by him under the name of the "Naples fauna," and its intimate relations to the European Intumescens fauna was also indicated.

ALTERNATION OF DISTINCT FAUNA

In the paper of 1887[6] the Nunda fauna was shown to run up in the strata at Hornellsville high enough to be mingled with species of the distinctive Chemung fauna.[7] This fact of the alternation of the representatives of two distinct faunas in the zone of transition from one fauna to another has been repeatedly observed in later studies. It led me to the necessity of assuming that two faunas normally appearing one above the other in direct succession owe their order of succession to shifting of their local habitat in the same oceanic basin (i. e., marine faunas), rather than to any absolute

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[1] *Bulletin No. 3*, U. S. Geological Survey (1884).

[2] "On the Classification of the Upper Devonian," *Proceedings of the American Association for the Advancement of Science*, Vol. XXXIV (1886).

[3] Henry S. Williams, "On the Fossil Faunas of the Upper Devonian–the Genesee Section, New York," *Bulletin No. 41*, U. S. Geological Survey (1887).

[4] John M. Clarke, "On the Higher Devonian Faunas of Ontario County, New York," *Bulletin No. 16*, U. S. Geological Survey (1885).

[5] *Memoir No. 6*, New York State Museum, "Naples Fauna in Western New York," Parts 1 and 2 (1898 and 1904).

[6] *Bulletin No. 41*, U. S. Geological Survey.

[7] *Ibid.*, p. 80.

extinction of one and replacement by the other.[1] On such assumption the correlation of formations by fossils becomes a complex problem, for we cannot say that the last stage of the fauna of one locality occurs at the same stratigraphic horizon as at another locality. The range of this Nunda fauna (i. e., "Cardiola," "Portage," "Naples," "Manticoceras" fauna) has been shown to pass above the Ithaca fauna in the Ithaca section; at Hornellsville it is seen in contact, so to speak, with the Chemung, and traces of it also occur well up in the zone dominated by Chemung fossils. The result is that to be accurate in drawing formation lines on a paleontologic basis there must be recognized a zone of transition of greater or less extent in which either or both faunas may appear. The drawing of formational boundaries on lithologic basis is not more accurate; but the error is more difficult to detect. The actual number of feet thickness assigned to a particular formation in a local section often depends more upon the positiveness of the assumption as to the actual boundary stratum than upon the definiteness of the evidence of the correlation.

The passage from the Nunda fauna to the Ithaca fauna, from Ithaca back to Nunda, and from Nunda to Chemung can generally be detected within passage of a few feet of strata, the chief reason being that the faunas thus brought into direct sequence are different in their generic and, often, class composition. In the Nunda frail-shelled Pelecypods, Gasterpods, Cephalopods, and Arthropods of its lower orders dominate. In the faunas of both the Ithaca and Chemung formations, Brachiopods, Bryozoa, and Lamellibranchs of the Pectinoid type are the conspicuous forms. The assumption is made that this difference between the Nunda fauna and either the Ithaca or Chemung is intimately associated with environmental conditions of their habitats, hence the contrasted faunas are described as heterotopic in relation to each other.

Difficulty in separating the Ithaca from the Chemung fauna.—When the successive faunas are homeotopic, the difficulty of dis-

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[1] Henry S. Williams, "Shifting of Faunas as a Problem of Stratigraphic Geology," *Bulletin of the Geological Society of America*, Vol. XIV, pp. 177–90; "The Correlation of Geological Faunas: A Contribution to Devonian Paleontology," and *Bulletin No. 210*, U. S. Geological Survey, (1903).

tinguishing their characteristics is greater. Clarke has recognized this difficulty in saying that

> it is extraordinarily difficult to fix on a division plane between the Ithaca and the overlying Chemung faunas, as the one passes into the other by easy gradation, and we are still somewhat at a loss in determining specific values indicial of the early stages of Chemung time.[1]

This difficulty has been met in the present revision by recognizing the reasons for the difficulty and drawing the lines accordingly. The reason why it is difficult to draw a stratigraphic horizon plane, separating two faunas in which a large part of the genera are identical and many of the species the same, is because of the evident similarity in composition of the two faunas. This similarity, I have assumed, is due to adjustment of the species of the faunas to like conditions of environment, but in different areas of distribution. The fact that the two faunas contain some distinctive species, associated with a second fact that in the New York province at least the one (Chemung) is always found higher in any single section than the other (Ithaca) fauna, together prove that distinguishing characters are of long standing, From this fact it is inferred that the two faunas developed their peculiarities in different areal centers. The differences are like those distinguishing the Arctic from the Florida faunas of the western Atlantic, or the faunas of the east coast of the United States of America from those of the coast of Europe. If these interpretations are correct, two kinds of differences should be capable of discovery, viz.: (1) differences in the evolution of the species of a common race, and (2) differences in the original stock of the two faunas, i. e., survivals of old races which have become extinct in one and have continued to live in the other.

If we attempt to draw the line of boundary between the two faunas, stratigraphically, it is necessary to assume that the later fauna is not the strict genetic successor of the earlier one, in spite of the close similarity in its species. Either barriers have been removed opening to a common basin the waters of separate basins, or general shifting of temperature by currents or by depth has produced such changes of general temperature that the two faunas have been forced

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[1] "Naples Fauna of Western New York," New York State Museum, *Memoir No. 6*, Part 2, p. 213 (1903).

to shift their *locus habitans.* One fauna (the Ithaca) has either become partially destroyed or forced to migrate, while the other (Chemung) has entered for the first time into the region where the New York state rocks were being deposited.

In some particular section the change of occupation may take place suddenly so that the last of the Ithaca species will be brought into close contact with the first appearance of the Chemung, but this state of facts cannot be expected without some violent revolution, of which no evidence is here given. In some cases, particularly east of Ithaca, it is difficult to distinguish the passage, but for the reason that there the Ithaca fauna is in a later state of its evolution than at Ithaca, and thus the transition of species between the two homeotopic faunas is less conspicuous. This is due to the fact that such species as are present in both faunas are then in nearly the same stage of evolution; and, second, because the diagnostic species of both faunas are less in evidence where the Chemung fauna immediately follows the later stages of the Ithaca fauna than, farther west, where a long interval of time separated the period of the occupation by the Ithaca from the period of the income of the Chemung fauna.

[*To be continued*]

PANGONG: A GLACIAL LAKE IN THE TIBETAN PLATEAU

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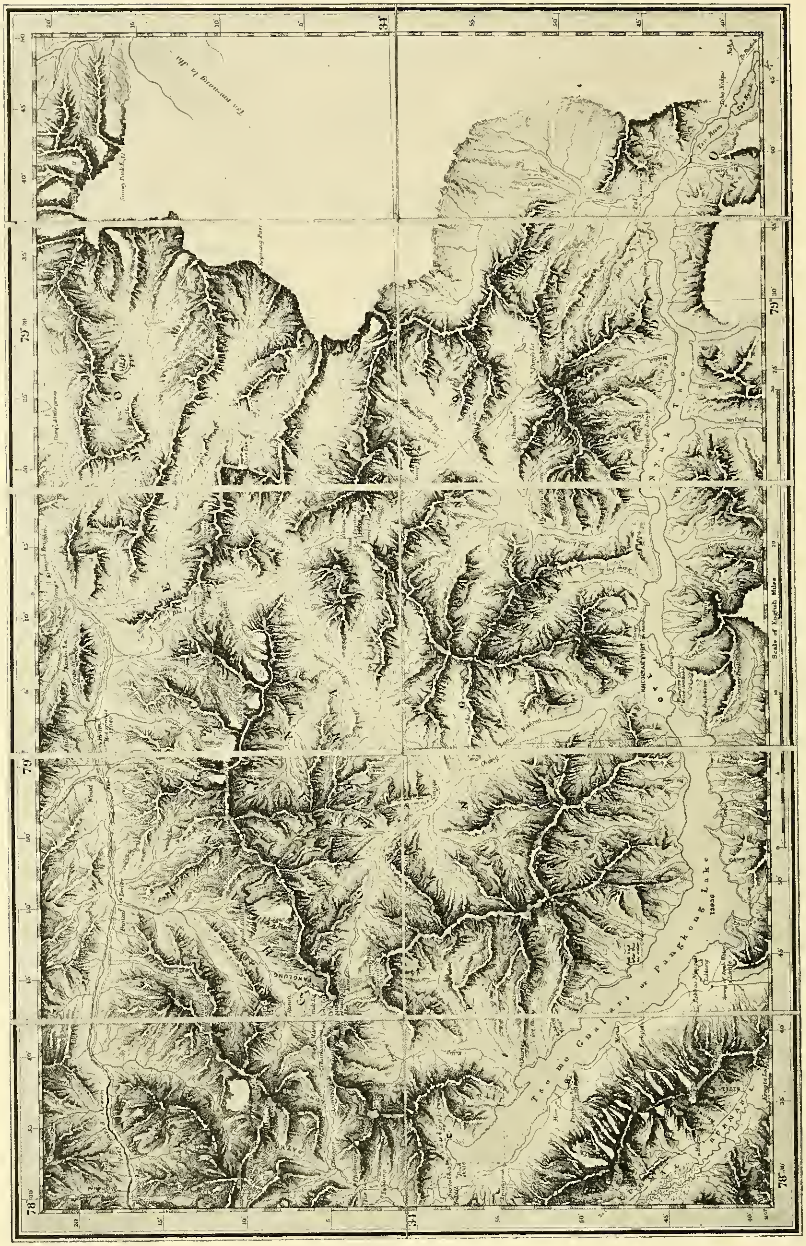
At the western end of Tibet the Tso-mo-gualari, a series of five connected lakes, lies at an elevation of 14,000 feet in a narrow valley winding for over 100 miles from east to west, among magnificent snowy mountains. The upper lakes, which drain from one to the other and are fresh, lie in Tibetan territory and are but imperfectly known; the lowest and largest lake, Pangong, which has no outlet and is saline, lies in the Indian province of Ladakh or Little Tibet, and is visited almost yearly by British sportsmen. As the two main lakes, Pangong and Nyak Tso, with a combined length of 75 miles, and apparently the others also, lie at nearly the same level and are separated from one another only by an alluvial fan or delta like that at Interlaken in Switzerland, the whole series may be regarded as occupying a single basin with a length of 105 miles, a maximum width of 4 miles, and an average width of only 1.8 miles where covered with water. The basin appears to be due to glacial erosion, and the lakes, as their scenery indicates, belong to the same type as the famous valley lakes of Switzerland. Old moraines show that previous to the formation of the present lake the basin was once or twice filled with ice; while lacustrine deposits and elevated beaches show that in later times the lake-level has fluctuated in response to changes of climate less severe than those which caused the invasion of the basin by glaciers. Thus a record of various phases of the glacial period is preserved in a region where it is especially valuable for purposes of comparison.

While on the way to Chinese Turkestan as a member of the Barrett Expedition to central Asia, I visited Pangong, remaining there from May 1 to May 6, 1905. The lake is exquisitely beautiful, a sparkling sheet of the clearest, deepest blue, shading delicately to purple in the shadows and to pure, pearly green in the shallow rim



MAP OF THE TSO-MO-GUALARI LAKES

near shore. Dark, rugged mountains, especially in the eastern part, spring steeply from smiling blue bays to a height of 1,000 or 2,000 feet (Fig. 1, *A*), and then, at gentler angles, rise 3,000 to 4,000 feet more to a chain of peaks, 20,000 feet high, snow-capped and full of glacier tongues (Fig. 2). Verdure alone is needed to make Pangong rival, or even excel, the most famous lakes of Italy or Switzerland.

In early May, at the time of my visit, the snow had disappeared up to a height of 16,000 feet, and two inches which fell at the level of the lake May 6 melted rapidly. The minimum night temperature ranged from 21° to 29° F. The mornings were sunny and warm, but every afternoon between one and three o'clock a strong west or northwest wind arose, chilly and disagreeable, and sometimes accompanied by squalls of sleet. The scanty bushes and still rarer willow trees had not begun to bud, and the few hardy Buddhists of Tibetan stock (Fig. 3) inhabiting the western shores of the lake were just beginning to sow barley, the only crop which will ripen. Sown in the frosts and snow of May, it is reaped in the frosts and snow of September. At the lake level, 14,000 feet, the barley usually ripens, but at Phobrang, a few hundred feet higher, six miles north of the west end of the lake, the crop often fails, and the upper

Fig. 1.—Panorama of Lake Pangong from the middle of the south side, May 3, 1905. The west end of the lake had been freed from ice by the wind the previous night, but the narrower and less exposed eastern part remained closed a few days longer.

limit of cultivation is reached not only for this region, but probably for the world.

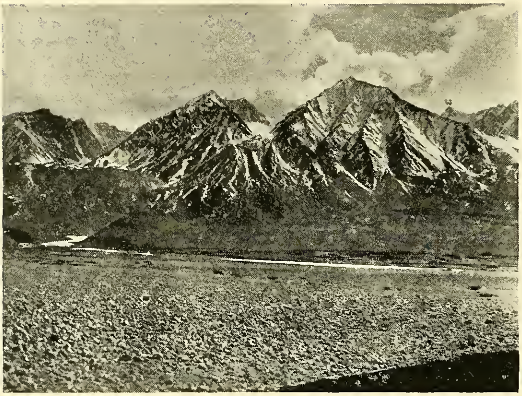


FIG. 2.—A little glacier southwest of Lake Pangong, above the village of Man. The latter can be seen on the right lying on an old moraine at the foot of the mountain.

On May 1 and 2 the lake was entirely covered with pale-green or steel-blue ice, the only exception being some large cracks and a marginal strip 20 to 200 feet wide, where ducks, geese, and gulls fished merrily most of the day, though obliged to sit disconsolate for the first hour or two each morning, when even the open strip was frozen. On the night of May 2 a violent wind blew from the northwest. Next morning, though the temperature was 22° F., the ice had entirely disappeared from the center of the lake for 8 or 10 miles, although the ends were still closed. Part of the ice lay piled along the shore in a ridge 8 or 10 feet high and 30 or 40 wide (Fig. 4). Elsewhere it had been shoved upon the gently sloping beach in large sheets, one of which, from 2 to 4 inches thick, remained unbroken to a size of 15 by 40 feet (Fig. 5). Later I saw a thinner sheet in the act of coming ashore. Un-

FIG. 3.—A family of Ladakhis living in the outlet valley about 10 miles below Lake Pangong.

der the influence of the usual strong afternoon wind from the northwest, it moved diagonally across the strand at the rate of 3 feet per minute, with as steady a motion as though pushed by an invisible machine. The sandy beach was shoved into a ridge, as appears in the foreground of Fig. 4, and flatstones 8 inches in diameter were easily moved.

FIG. 4.—Ice piled up to a height of 13 feet by the northwest wind on the south shore of Pangong during the night of May 2, 1905. Notice the ridge of gravel shoved up in the foreground.

The quantity of ice thrust upon the beaches did not seem sufficient to account for all of the sudden disappearance. Thinking that a change in the lake's circulation must have been taken place, I resolved to test it by the degree of saltness of the water. On May 1 and 2 I had tasted the latter in the bay east of Mun and elsewhere, and could scarcely detect the least salinity; on May 4 and 5 I tasted it again in the same places, and found it so salt as to be undrinkable. Apparently with the breaking up of the ice under the influence of the wind, currents

FIG. 5.—Ice on the south shore of Pangong, showing sheets 4 inches thick and 40 feet in diameter shoved up entire.

came into play by which a cold film of fresh surface water, due to melting ice, was displaced by warmer, more saline water from below, and thus the remaining ice was quickly melted.

Glacial origin of the basin.—It has been stated by Drew[1] and others that the basin of Pangong is due to the damming of an old outlet by fans from tributary torrents. The old outlet is evident, a broad U-shaped valley extending northwestward from the western end of the lake; and so, too, is the supposed dam, a large fan, 1,500 feet in radius, having its lowest point 90 feet above the lake, and located a mile from the latter at the mouth of a small tributary from the south. The fan forms the divide between the Indus River and Pangong Lake, but it does not appear to have been the cause of the formation of the latter, but rather to have been able to grow up because the former stream from the Pangong region ceased to flow. The cross-sections of the valley shown in Fig. 6 illustrate the matter. The line *A–B* shows the conditions at the divide, and so far as it alone is concerned, the valley might have been dammed by the fan. The lower section, *C–D*, however, half-way from the divide to the lake, shows quite a different state of affairs. At this point the flat bottom of the broad, steep-sided valley which once served as an outlet is over 600 feet wide; more than 500 feet consists of solid rock, *Ls*, 20 of soft lacrustrine material, *Lc*, and the remaining 90 of gravel, *Gr*, deposited by the insignificant wet-weather tributary flowing from the divide to the lake. Thus the Pangong basin appears to be

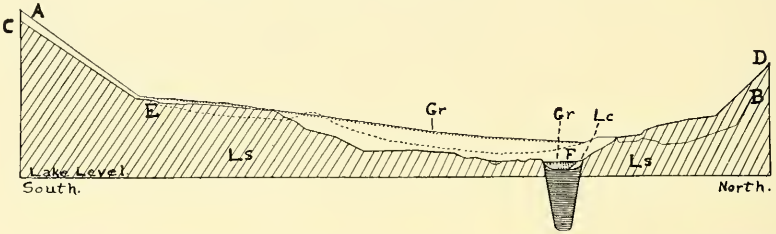


FIG. 6.—Cross-sections of the outlet valley of Lake Pangong drawn to true scale.

A–B=section at the fan, at the divide between Lake Pangong and the Indus.
C–D=section where the rock lip is most plainly visible.
E–F=probable section of the rock below the fan, including a glacial knob.
Gr=gravel.
Lc=lacustrine deposits.
Ls=bed-rock, chiefly marble.

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[1] F. Drew, *The Jummoo and Kashmir Territories.*

terminated by a rock-lip rising well above the present lake-level. Otherwise there must exist at this point a gorge like that shown in the heavily shaded portion of the section. Its depth must be equal to at least the height of the lowest point of the section above the lake, 35 feet, plus the depth of the lake which Drew (p. 323) gives as 142 feet, that is a total of 177 feet. Its width at the top cannot be over 110 feet. Such a gorge is quite out of harmony with the topography of the outlet valley and of the other valleys of the region, and there is no reason to suppose that it exists.

Furthermore, supposing for the moment that such a gorge existed, it could scarcely have been dammed by the fan of the insignificant little wet-weather stream at the divide. If there were no lake, the outlet stream would be large and swift, for it would consist of (1) the Lamle and Lukung brooks, each of which was large, even in May before the flood season; (2) the stream at Ote from the upper lakes, described by Rawling[1] as a river 60 feet wide and 15 feet deep, with a current of 1½ miles per hour; and (3) a host of minor streams. It is almost safe to say categorically that, even if the climate were drier than now, the floods from the whole Pangong basin, when united into a single stream at the bottom of such an extremely deep, narrow gorge, could not be dammed by the fan of a single tributary, one of the smallest. This is shown by the condition of the old outlet valley below the divide. On either side numerous tributary torrents have formed fans as large as those at the divide; yet even the small wet-weather torrent which here occupies the valley has succeeded in keeping its channel open. To be sure, the stream has been caused to aggrade behind each fan, and at Tso Tsear, 3 miles from the divide, a small lake has actually been formed which overflows with every flood. This, however, is where no water flows permanently and where the drainage area is measured by tens instead of thousands of square miles. Three miles below Tso Tsear, just above Muglib, the permanent stream begins. Though small at first, probably not a tenth as large as the supposed Pangong stream, it has had no difficulty in keeping open a broad channel through fans as large as that at the divide. In view of all the facts, it seems extremely improbable

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[1] C. G. Rawling, "Exploration of Western Tibet and Rudok," *Geographical Journal*, Vol. XXV, p. 428.

that there is any narrow inner gorge at the divide, and still more improbable that one of the smallest tributaries, joining the main stream in the gorge where the latter would be most powerful, could completely dam it, especially as the fans of other larger tributaries have produced no such effect. If it be supposed that the outlet has been dammed by a moraine instead of by a fan, it is still necessary to assume the existence of the same improbable gorge, and to explain how such a gorge could ever come to exist. It is further necessary to assume the existence of a completely concealed moraine, for in this part of the outlet valley there is no trace of any such thing, although glacial knobs show that ice once filled it, depositing moraines lower down. The theory of a dam, whether due to a fan or to a moraine, seems untenable. The only alternative is that the Pangong basin is closed by a rock-lip.

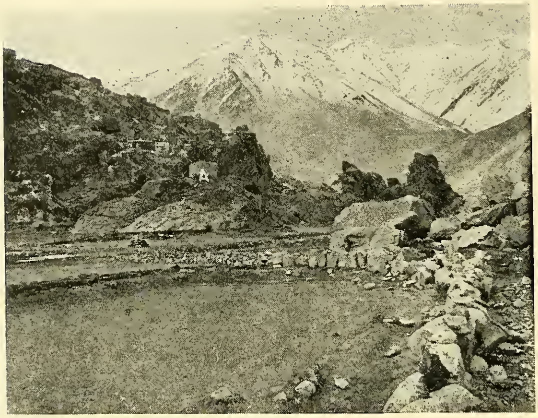

FIG. 7.—Glacial knobs in the mouth of the Pangong outlet valley near Tonktse. Glacial smoothing is clearly seen on the left where the fort *A* stands on a completely isolated, well-striated knob.

The most satisfactory explanation of the formation of the lip seems to be that the basin behind it has been glacially eroded. Another possibility is that the lip is due to warping or faulting, but this may be dismissed for lack of evidence. There is no sign of recent faulting in this region, nor of warping of the kind demanded. As is evident from the map, the long, winding basin occupied by Pangong and the other lakes is distinctly a river valley, with no affinity to the type of basin due to crustal movements. Of glacial action, on the other hand, there is abundant evidence, not only near the lake, but down-stream in the outlet valley. Below Tanktse, 20 miles from the lake, an old moraine from 500 to 1,000 feet thick extends 5 miles down-stream. The characteristic topography has been destroyed and the moraine is smoothed and terraced, but the typical structure remains. Above Tanktse, in the mouth of the outlet valley, finely polished knobs of schist and gneiss (*A*, Fig. 7) show that a glacier came down the valley from Pangong and doubtless deposited part of the moraine, though more may have come from the broader Chumik valley on the south. The knobs and the smoothly glaciated valley bottom are covered in part by a deposit of cobbles and huge bowlders, apparently a moraine laid down in the presence of running water. From analogy with other regions, it is probable that the deposit represents a second advance of the ice, but it may represent merely a stage in the retreat of the first glacier. Farther up the valley, at the tiny lake of Tso Tsear, other glacial knobs appear, and the irregularities in the valley floor shown in the cross-sections of the divide and of the rock-lip in Fig. 6 are of the same sort. It is clear that for 30 miles from Pangong to Dugrukh the outlet valley has been occupied once or twice by glaciers descending below the level of the lake.

Fig. 8.—A deep re-entrant at the northwest end of Lake Pangong. View from an elevation of 1,000 feet looking southeast across the lake at the line of glaciers and moraines on the farther side.

Around the lake itself there are further evidences of glacial action. In the Lukung valley, at the west end of Pangong, a large moraine lies 2 or 3 miles north of the mouth of the outlet valley. Along the southwest shore of the lake something like twenty small glaciers peep out from the tops of the mountains (Figs. 2 and 8), and formerly at times of greater extension deposited moraines well down toward the lake. All these, however, belong to comparatively recent times when, apparently, no moraines reached the basin floor and it was occupied by a lake. The proof of an earlier, more extensive glaciation lies first in the oversteepened lower slopes of the mountains already referred to in describing the appearance of the lake, and second in numerous erratic bowlders of granite perched on slopes and ridges of schist or of metamorphic sedimentary rocks (Fig. 9). The bowlders vary in size from 1 to 25 feet in diameter, and are found at all elevations up to at least 600 feet above the lake. They occur on both sides of the latter, and on almost every slope facing toward it or toward the outlet. The greatest accumulations are found in small protected valleys such as those marked *A*, *B*, and *C* on the map. The granite bowlders can have been brought to their present position on the schist only by a glacier large enough to fill the whole Pangong basin.

The glacier did not come to an end at the rock-lip, as might be expected, but, as we have already seen, continued on for 20 or 30 miles as a comparatively narrow tongue giving rise to the U-shape of the outlet valley, and to the glacial knobs already described, and leaving at least one hanging valley with its mouth 200 feet above the flat valley floor on the south side near the little lake of Tso Tsear. If the Pangong basin is due to glacial erosion, it is necessary to explain why in what once was a single uniform valley the part above the lip has been widened ten times as much as the part below, and deepened correspondingly. Rock structure and texture have something to do with the matter, for there is a hard stratum of marble at the lip; but, except for this, the difference between the schists and metamorphic sedimentaries above and below the lip seem insufficient to account for so marked a contrast. It is possible that the Lukung glacier from the north meeting the Pangong glacier from the southeast acted as a check upon the latter, causing it to broaden and deepen its channel up-stream instead of down. Another possibility is that a glacier or glaciers of smaller size previous to the maximum glacier may have reached only to the lip, broadening the valley above, but not below. When the maximum glacier advanced, the constriction of the valley at the lip would allow only a narrow tongue to extend forward and would cause broadening and deepening of the channel upward.

There is still doubt as to the possibility of the excavation of basins by glaciers. The Pangong basin offers nothing new by which the question can be answered, but it is significant because it adds another to the examples where a peculiar type of basin is associated with glaciation among lofty mountains. The essential features of the Pangong basin agree with those of the fiords of Norway and the valley lakes of Switzerland and other places. The finding of so perfect an example of the type on the edge of the Tibetan plateau, where the theory of glacial erosion would lead us to expect it, lends probability to the theory. The rarity of such lakes among the Himalayas seems to be due to the fact that most of the valleys slope steeply and uniformly and have no portions of gentle grade where the glaciers would be checked and caused to deepen their beds.

Pangong during later glacial epochs.—The history of Pangong after the completion of the rock basin is recorded chiefly in lacustrine deposits and shore-lines, which, together with numerous old moraines, indicate two extremes of moisture, or at least of lake and glacier expansion intervening between extremes of aridity or of lake and glacier contraction. At the mouth of the little tributary whose fan has been wrongly supposed to be the cause of the accumulation of the waters of Pangong, there are some narrow terraces, remnants of an older, larger fan. The latter must have been formed after the retreat of the last great basin-scouring glacier, and at a time so arid that the main stream was not large enough to carry away the débris brought in by the tributary. If the fan were to be reconstructed from its fragments, it would fill the outlet valley to a depth of 200 feet, more or less; that is, to approximately the level of the highest of the strands presently to be described. As the deposits associated with these strands are saline, it appears that at the time of the accumulation of the fan the lake had no outlet, and hence that the epoch was arid, perhaps as arid as the present.

On the approach of the next glacial epoch the glaciers on the sides of the Pangong basin descended several thousand feet, as is evident from the moraines which they deposited a few hundred or a thousand feet above the lake. The latter must have expanded and finally overflowed, for it cut away the fan across the lip, as may be inferred from the terraced remnants. Before overflowing, however, it must, while still saline, have stood at a level of nearly 200 feet long enough to deposit a thin layer of calcareous sinter. The latter occurs on an isolated hill of schist east of Tukkung in the middle of the south side of the lake (Fig 9 *A*), and again on a marble spur in the outlet valley close to the lip. It forms a thin coating on the surface of rocks which had been well smoothed and rounded by the previous glaciation. At the same level there are other evidences of the high stand of the lake. In a general view from almost any point a distinct line can be seen at a height of about 200 feet above the present strand wherever the lake shores consist of solid rock, as appears at the right of Fig. 1. In most places it is a mere scratch, indistinguishable close at hand, though visible in a general view; elsewhere it forms a slight notch, or even a very insignificant bench and bluff. Below it, in favorable locations, two or three still fainter lines appear upon the steep rocky shores. The parallelism of the lines to one another and to the present strand, their continuity around the lake, and their utter disregard of the structure of the rocks on which they lie, make it practically certain that they are strands marking former short-lived high levels of the lake.

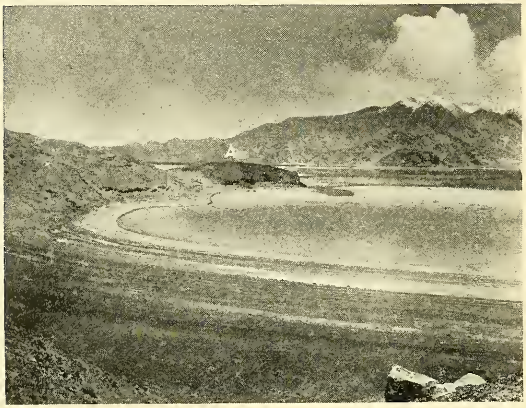

Fig. 9.—The lower set of beaches in a cove in the middle of the south side of Lake Pangong. The bowlder in the foreground, 12 feet in diameter, consists of granite. It was brought by a glacier to its present position on a slope of schist 200 feet above the lake.

When the lines are followed into some of the minor ravines where erosion proceeds slowly, this conclusion is supported. Here, at a height of about 200 feet, there are a number of little fans hung upon the side of the mountain as though they had been deposited when the water stood much higher than now, and nipped off into terraces in front as though the water had retired step by step. Such terraced fans, like the one at *B* on the extreme right of Fig. 1, may be seen along the southwest side of the lake on the steep shores between Spangmik and the outlet, on the promontory east of Man, and in the first deep bay east of Tukkung. An allied phenomenon is found in certain well-defined benches contouring around the isolated hills or knobs which lie in the vicinity of Tukkung, and probably represent the line of weak erosion between the main Pangong glacier and the large Lamle tributary. The panorama of the lake (Fig. 1) was taken from one of the knobs which itself is seen in Fig. 9 (*A*) as a flat-topped promontory. In the panorama two knobs may be seen (*C* and *D*), both of which were islands when the lake stood at the higher levels. The benches are best developed on the sides of the farther and larger knob (*C*), which lies about a mile west of the mouth of the Lamle brook. They are cut in the soft, thick talus of the schistose rock, and, as appears in Fig. 10, have clearly the form of strands. In the photograph five benches appear. In reality there are six or possibly seven, lying at subequal intervals between 90 and 210 feet above the lake. Below them, in the right-hand portion of the photograph, still other strands appear, which, however, are much younger and will be considered later. Putting together the evidence of the dissected fan at the outlet, the deposits of sinter up to a height of 200 feet, the faint strand-lines cut in the solid rock, the fragmentary terraced fans, and the benches about the isolated knobs, the history of the lake at this time seems fairly well defined. After the retirement of the last of the basin-making

FIG. 10.—View to the north from an isolated glacier knob near Tukkung, showing the older and the younger set of beaches.

glaciers a dry epoch ensued, during which a salt lake filled the basin, standing at a low level long enough to allow the accumulation of a fan above the rock-lip. Then, presumably upon the advent of a glacial epoch, the lake rose until at a height of 200 feet above the present level it began to overflow across the fan. From that time onward the water fell, pausing but a short time at each of the levels where the six or seven faint strands appear. One reason for the fall in the lake-level was doubtless the cutting away of the fan at the outlet, but as the latter appears to have been of uniform texture, this will not account for the fluctuations in the rate of fall as indicated by the strands. Another reason was the gradual desiccation which, as is shown below, finally reduced the lake to its last low level previous to that of today. The desiccation probably proceeded at a fluctuating rate, as we shall see to have been the case in a still later epoch, and the terraces and strands may be attributed to this.

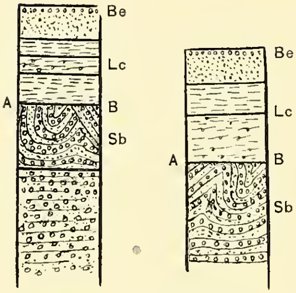

Fig. 11.—Sections of the fan at Tukkung.
A, *B*=Unconformity.
Be=Gravel beach.
Lc=Lacustrine deposits.
Sb=Subaerial (fluvial) deposits.

Evidence of the low level reached by the lake after the formation of the strands just described is found in the present fan at the outlet and in the deposits exposed in cuttings made by streams in other fans along the lake shore. In the outlet valley, as we have already seen, the older fan was cut away during a glacial epoch. The present fan could not have accumulated unless the outlet stream was greatly reduced in size or ceased to flow; that is, unless the climate became somewhat arid. More conclusive evidence of the low strand of the lake is found at Tukkung, along the Lamle brook, where the two sections illustrated in Fig. 11 lie about 100 yards apart, their tops being about 20 feet above the present lake-level. The deposits above the unconformity (*A–B*) consist of lacustrine marls, more or less saline, containing fossil shells and plants; while those below are fluviatile deposits of sand and gravel like that which the stream now carries. The folding and crumpling to which the gravels have been subjected is like that which is today produced on the beach when ice is blown ashore. The lake deposits continue for long distances and clearly belong to the time of the lake's latest expansion. Farther west on the side of a small stream between Man and Meruk the same features are exposed even more clearly in the section of which Fig. 12 is a photograph. The top of the section stands 30 feet above the lake, which lies several hundred yards to the right or north of the observer. The succession of strata from the top downward is as follows:

FIG. 12.—Photograph of the bank of a stream near Man, showing features like those of Fig. 11, especially beach gravels broken and tilted by ice and later covered by the deposits of a rising lake.

Be 2 feet, fine beach-gravel, and cobbles deposited by the lake in its last retreat.

4 feet, sandy clay, presumably a shore deposit.

1 foot, fine gravel, presumably a shore deposit.

Lc 3 feet, finely banded lacrustine clay.

1 foot, white saline marl with lacustrine shells.

Unconformity.

Sb 10 feet, subaerial sands and gravels crumpled by ice.

Apparently after the fall in the lake indicated by the strands described in the preceding paragraph, the water reached a level so low that subaerial fans were deposited only 20 or 30 feet above the strand of today and possibly still lower. Then the lake rose. At first its ice crumpled the sub-aerial deposits on the lake shore, but later, as the water rose higher, it planed off their surface and deposited upon them locustrine clays and marls.

If the stream whose banks are illustrated in Fig. 12 be followed upward, a section is found like that shown in Fig. 13, which is typical of the southwest side of the lake. The large moraines (3) belonging to the first glacial epoch after the retreat of the ice from the main Pangong basin form a ridge from 100 to 1,000 feet above the lake. In one of them a valley has been dissected and has been filled with ordinary schistose talus (*T*) from a ridge near by. The talus passes gradually into the subaerial sands and gravels (*Sb*) of the lower parts of the sections described in the preceding paragraph. The next deposit is a layer of lacustrine clays (*Lc*), lying on a smooth, wave-swept surface. On top of all lies a series of beaches (*B*) formed by the lake in the course of its last contraction. Moraine 3 appears to be synchronous with the 200-foot lake, and to have been dissected during the succeeding interglacial epoch when the lake stood as low or lower than at present. The moraines 4 and 4′, intermediate in size and age between the present moraine, 5, and the older moraine, 3, are apparently synchronous with the last expansion of the lake, when it rose 60 feet above the present level, crumpling the beach by means of drifting ice and depositing the lacustrine strata *Lc* of the last three sections.

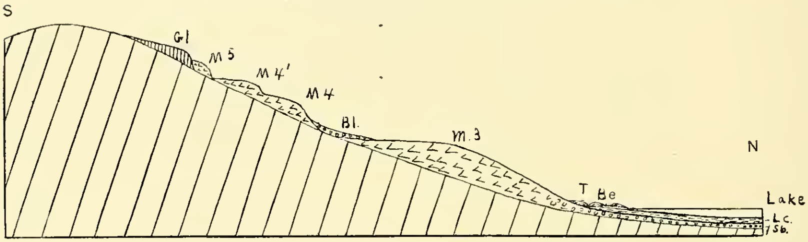

FIG. 13.—Cross-section from Lake Pangong to the summit of the mountains on the south shore of the lake near Man.

Be=Beaches.
Bl=Bowlders.
Gl=Glacier.
Lc=Lacustrine deposits.
M3, 4, 5=Moraines.
Sb=Subaerial fluvial deposits.
T=Talus.

The evidence of this last rise and fall of the lake is very abundant, and has been described by Drew and others. From a height of

60 feet downward the entire lake is bordered by a succession of old strands (see Figs. 9, and 10). The mean levels of the most important strands, as measured in eight sections distributed for 25 miles along the southwest, west, and north shores, were at the following heights above the level of the water in May, 1905, when it was said to be about 3 feet below flood-level: namely, 7, 14, 22, 33, 43, and 61 feet. The strands vary in character in the normal fashion, being marked by beaches in the bays and by cliffs and benches along the headlands. They appear to be of very recent date, this being especially noticeable where they are cut in soft, young fans and are still preserved almost unmarred, even though talus is being poured rapidly upon them. Along the headlands the upper benches are usually cut in a rather hard conglomerate or breccia composed of beach pebbles and talus cemented by white saline, or calcareous sinter, the deposit of the enlarged lake. In a few especially exposed situations the benches have been cut in solid rock, as illustrated in Fig. 14. The lake seems to have stood longest at the higher levels, since at these it did the greatest amount of cutting. It appears to have had no outlet at any time during its last expansion, for the fan at the lip shows no sign of having been recently dissected (see Fig. 6 *A*, *B*), and its lowest part stands 30 feet above the highest strand. Apparently the fall of the lake and all the accompanying irregularities whereby the beaches were formed are due entirely to desiccation.

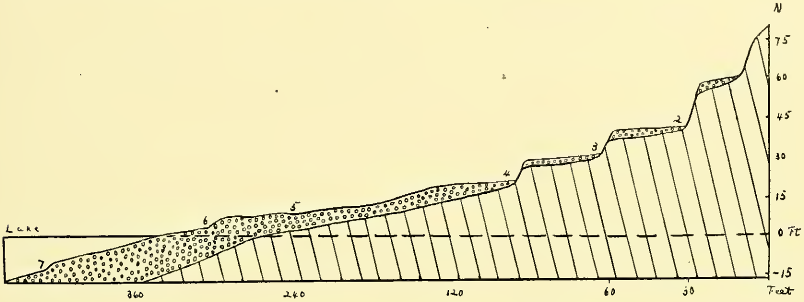

FIG. 14.—Recent lake beaches at the northwest end of Lake Pangong. Drawn to true scale.

Some light on the nature of the process of desiccation may be gained from Fig. 15, which illustrates a section exposed in the same fan where Figs. 11 and 12 were seen. From below upward along the line *xy* the section is as follows:

A. ½ foot of fine gravel with sand beneath it, the two forming parts of an old subaerial fan or of a beach.

B. 1 foot of lacustrine clay deposited by the lake during its expansion to the 60-foot level and continuing as an uninterrupted band to a height of 50 feet above the lake.

C. 3 feet of shingle deposited on a beach at a time when the lake must have retired.

D. 1 foot of lacustrine clay soon thinning out away from the lake, but thickening toward it and joining *B.*

E. 5 feet of shingle deposited on a beach.

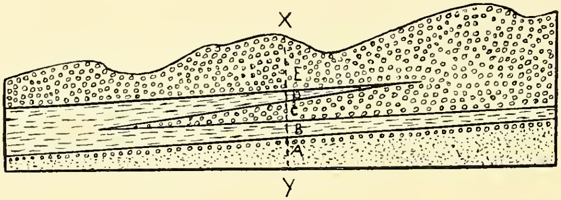

FIG. 15.—Section of lacustrine and shore deposits showing alternating rise and fall of the lake.

The section can be interpreted only on the supposition that in its fall from the 60-foot level the lake fell while *C* was being deposited, remaining at a level of less than 40 feet long enough for the formation of a shingle beach 3 or more feet thick. It then rose 10 feet or more, remaining high until a foot of fine clay had been deposited, and finally fell again, forming the beaches which now lie on the surface. A similar oscillation has occurred still more recently on a smaller scale. At several points along the lake-shore, especially at the northwest corner, three or four little beaches can be seen in the water down to a depth of 12 feet, more or less. The head man of the village of Spangmik said that when he was a boy, some 20 or 30 years ago, the water was 10 or 12 feet lower than now, although in his grandfather's time it stood higher than now. Possibly the submerged beaches, which are very slight, were formed at this time of low water not more than thirty years ago. Whatever their date may be, it is evident that the beaches, like the deposits of Fig. 15, indicate that the lake is subject to constant oscillations due to variations either in rainfall or evaporation. Apparently the process of desiccation has not been continuous in the fashion illustrated by the line *A*, Fig. 16, nor has it been interrupted merely by periods of rest, as shown in *B*, but rather it has been oscillatory, like *C*, now drier, now wetter, but the tendency to aridity generally greater than its opponent. The changes appear to be of precisely the same nature as the much larger changes which characterize the glacial period with its alternating glacial and interglacial epochs. If the oscillations are merely local, their study is of comparatively small importance; but if, as there is reason to believe, corresponding variations are taking place simultaneously over vast areas, they demand the closest study. There seems to be nothing except size to differentiate them from glacial epochs, and as they are even now in progress, their study can be carried on at close hand, and may perhaps be helpful, not only in solving the secret of the cause of the glacial period, but of the part played by climate throughout the whole course of geological history.

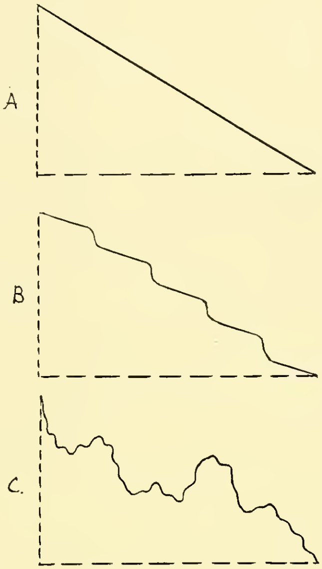

FIG. 16.—Diagram to illustrate the course of dessication at Pangong. The horizontal ordinate represents time, and the vertical the condition of climate, wetter or colder upward, drier or warmer downward.

THE DEVONIAN SECTION NEAR ALTOONA, PENNSYLVANIA[1]

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STRATIGRAPHY

Introduction.—This joint article has grown out of work done in connection with the geologic survey of the Ebensburg quadrangle, which is about 5 miles west of Altoona. Fig. 1 shows the location of the section of the state, and Fig. 2 shows in greater detail the area studied and the location of the profile section, Fig. 2. The rocks of the greater part of the Devonian section of the region are very well exposed along the Pennsylvania Railroad west of Altoona, and along the New Portage branch of the same west of Hollidaysburg. They strike about N. 40° E., and dip regularly to the northwest with a uniformly diminishing degree. Only one fault of any consequence is known. It is shown in the profile section, Fig. 2. The downthrow is apparently 100 feet to the east.

In previous surveys of this region it was recognized that the mass of shale and thin sandstones between the Oriskany sandstone below and the bottom of the Catskill above represents the Marcellus, Hamilton, Genesee, Nunda (Portage), and Chemung formations; yet, on account of the generally homogeneous character of the mass as a whole, no effort was made to discriminate and map the individual formations. It has been found possible, however, by taking careful note of the lithologic and paleontologic characters of the rocks, to identify the main formations recognized in New York state, and to establish and map the limits of the same with a fair degree of precision, as will appear in the following description. The section described in this paper then consists of the Oriskany sandstone, the Marcellus shale, the Hamilton formation, the Genesee shale, and the Nunda, Chemung, and Catskill formations. With the exception of the Marcellus, which is not certainly known at Altoona, the above mentioned formations are shown in the profile section, Fig. 2. The section begins at the intersection of Seventeenth Street

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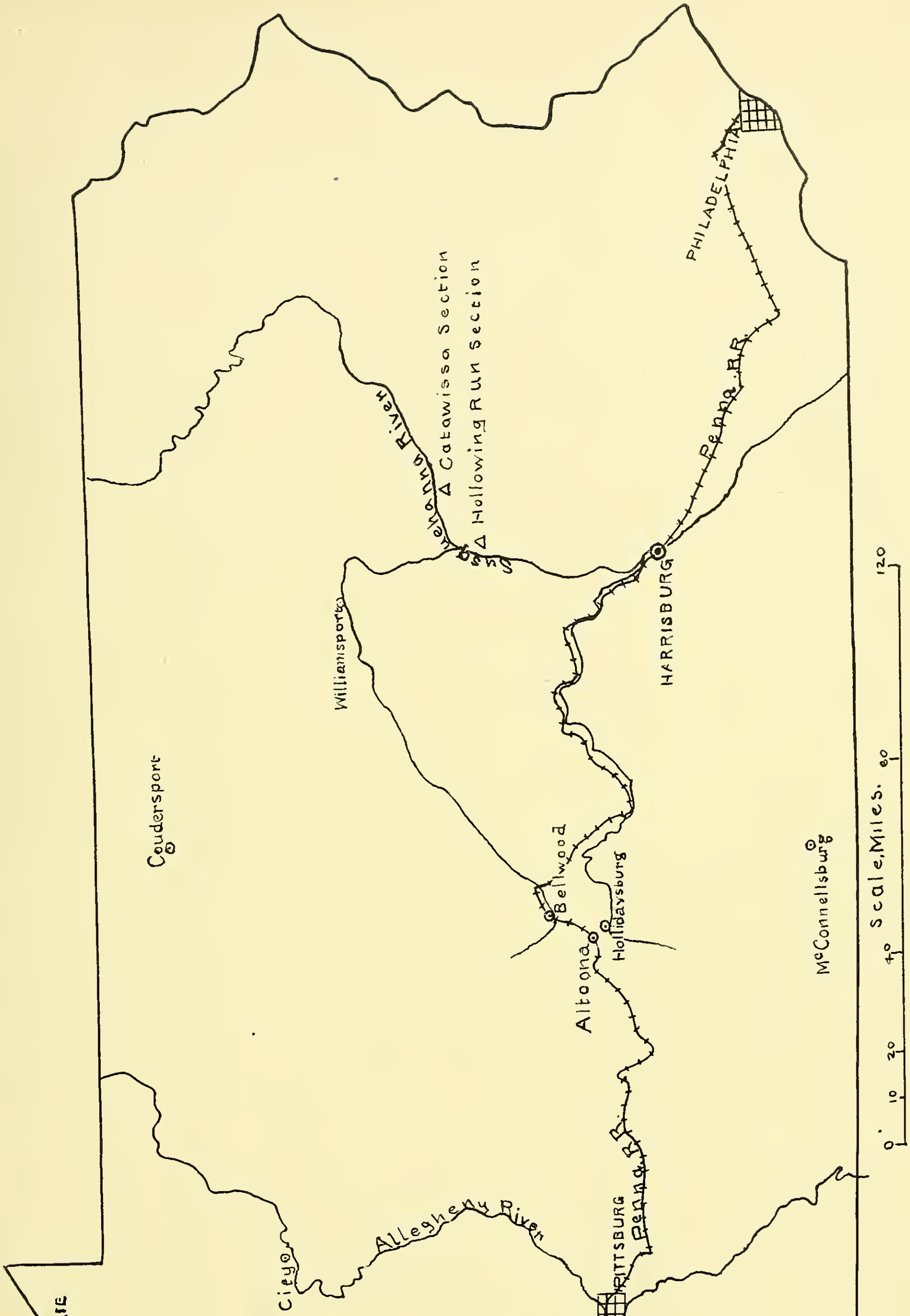
Erie
Oil City
Allegheny River
Pittsburg
Penna. R.R.
Altoona
Hollidaysburg
Bellwood
Coudersport
Williamsport
Susquehanna River
△ Catawissa Section
△ Hollowing Run Section
Harrisburg
Penna. R.R.
Philadelphia
McConnellsburg
Scale, Miles.
0
10
20
40
80
120

FIG. 1

and Second Avenue, Altoona, extends thence northwestward to the Pennsylvania Railroad at a point 1,425 feet west of the Logan House and then follows the track to Kittanning Point. (See Fig. 3.) At the base of the section the Lewistown limestone of the Second Geological Survey of Pennsylvania[1] is exposed.

Oriskany sandstone.—This is thick bedded, generally coarse-grained, gray or buff siliceous rock. The thickness seen did not exceed 20 feet, and apparently it is not over 50 feet thick anywhere in the region. Bowlders of this sandstone lie along the Pennsylvania Railroad track about 1 mile southwest of Bellwood, having slid down from the outcrop on the hillside above. From these bowlders the fossils given in the first list on a succeeding page were collected.

In Altoona an outcrop of Oriskany was observed in an alley just east of Fourteenth Street and between Third and Fourth Avenues. At this outcrop, which is shown on the profile section, the weathered rock is buff, fine-grained, and apparently argillaceous. It contains the fauna of the second list beyond.

At Duncansville, southwest of Altoona, the Oriskany is exposed in a railroad cut and is thick-bedded and siliceous. (See Fig. 4.)

Marcellus shale.—The Marcellus shale follows the Oriskany sandstone directly in this section, the Onondaga limestone of the New York sections being absent as in all of the Allegheny sections south of New York. So far as it can be identified, it is a black, highly fissile, clay shale. It is certainly known only in a railroad cut about 1 mile southwest of Bellwood. At that point about 20 feet of the formation are exposed. Here the Marcellus shale apparently underlies the Oriskany sandstones, since the rocks are overturned and dip to the southeast. In Altoona, shale showing in a thin outcrop on Seventeenth Street near Third Avenue, and dipping 55° to the southeast may be Marcellus, but there is no positive evidence that it is.

Hamilton formation.—The Hamilton formation is predominatingly a very dark green clay shale, which weathers to a dull brown or blackish color, and breaks up in weathering or under the hammer obliquely to the bedding planes into very irregularly shaped pieces. In addition to such rock, there is more or less shale approaching olive-green and gray tints, and also dark green sandy and slightly

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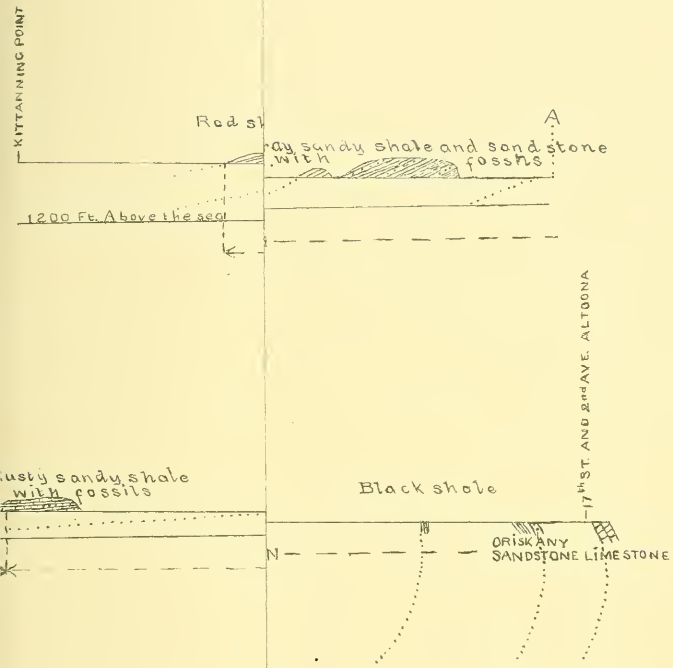
[1] Report T on Blair County, by Franklin Pratt.


KITTANNING POINT
Red sh
A
ray sandy shale and sandstone with fossils
1200 Ft. Above the sea
17th ST. AND 2nd AVE. ALTOONA
usty sandy shale with fossils
Black shale
N
ORISKANY SANDSTONE
LIMESTONE

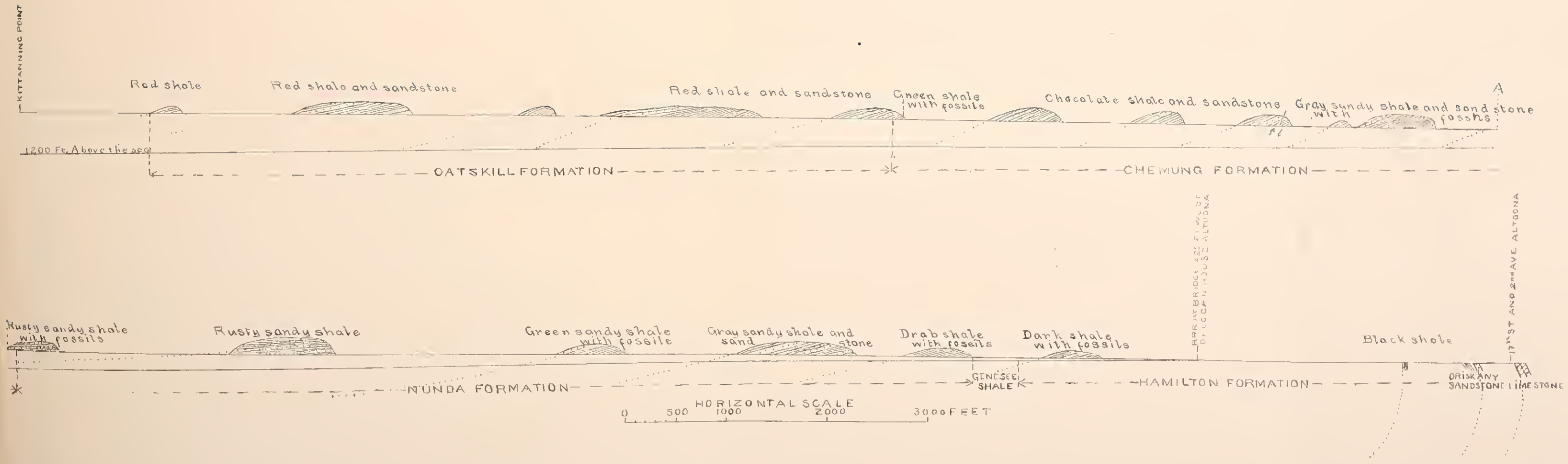

KITTANNING POINT
Red shole
Red shalo and sandstone
Red shale and sandstone
Green shale with fossils
Chocolate shale and sandstone
Gray sandy shale and sand stone with fossils
A
1200 Ft. Above the sea
OATSKILL FORMATION
CHEMUNG FORMATION
RRR AT BRIDGE 425 FT WEST OF LOGAN HOUSE ALTOONA
17th ST AND 2nd AVE ALTOONA
Rusty sandy shale with fossils
Rusty sandy shale
Green sandy shale with fossils
Gray sandy shale and sand stone
Drab shale with fossils
Dark shale with fossils
Black shale
NUNDA FORMATION
GENESEE SHALE
HAMILTON FORMATION
ORISKANY SANDSTONE
LIMESTONE
HORIZONTAL SCALE
0
500
1000
2000
3000 FEET

FIG. 2

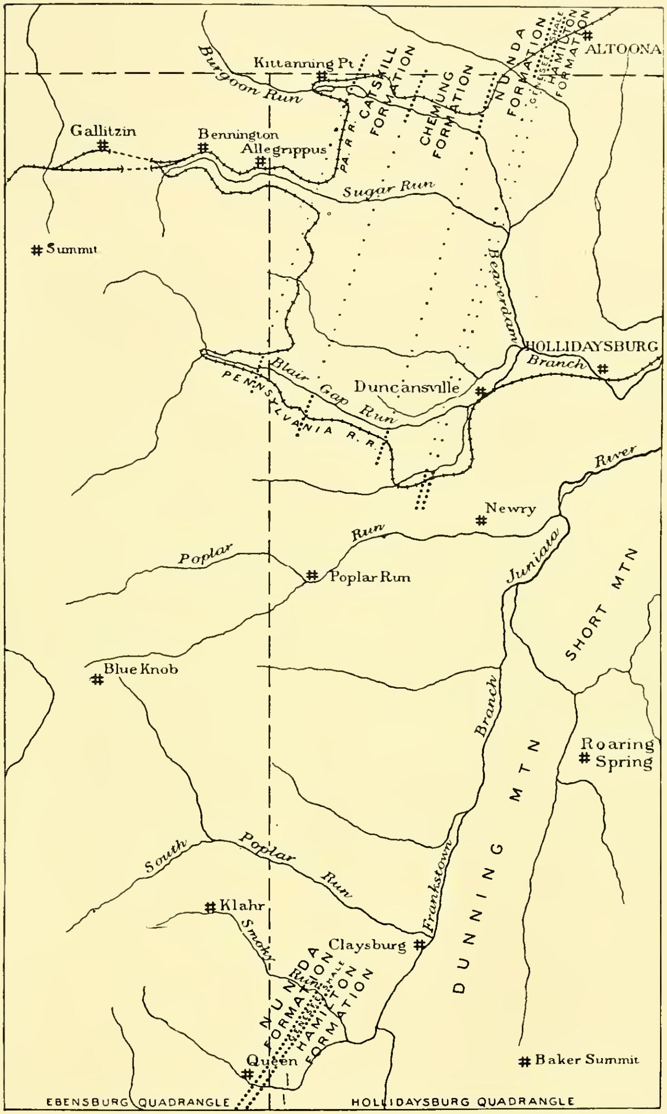


FIG. 3

micaceous shale. Bands of fine-grained, bluish sandstone occur, but they are infrequent and rarely a foot thick. These sandstone layers are often very uniform in thickness, and are divided by jointing into regular prismatic blocks of very characteristic appearance. The bottom of the formation has not been definitely determined in the region; the top is well marked by the Genesee shale, and has been located within narrow limits from the vicinity of Bellwood, on the Pennsylvania Railroad, 6 miles northeast of Altoona, to Queen, about 20 miles southwest of Altoona. In a railroad cut at a point 1 mile southwest of Bellwood, where the present main tracks of the Pennsylvania Railroad diverge from the old tracks, the contact between the Hamilton and Genesee is well exposed. The topmost layer of the Hamilton is an impure limestone, 2 to 4 feet thick, crowded with Hamilton fossils, and immediately overlying it is the characteristic black Genesee shale. At Altoona the contact is not exposed, but its position can be closely determined. On the Pennsylvania Railroad track, beginning about 2,375 feet west of the Logan Hotel and just west of the underground crossing of the electric road to Hollidaysburg, is an exposure extending along the track westward for 540 feet, as shown in Fig. 2. Hamilton fossils were found in

Fig. 4

these rocks practically to the top. Fig. 5 is a photograph of the shale in this exposure. West of the above-mentioned exposure is a concealed space of 630 feet, to the point where Twenty-first Street intersects the track. At this point is the beginning of an outcrop of rocks bearing a Nunda fanua throughout. At the intersection of Fourteenth Street and Thirteenth Avenue in Altoona the Genesee shale is exposed with overlying shale identical in character and fossils with that at the base of the outcrop beginning on the railroad track at Twenty-first Street, as mentioned above. At the above-described street intersection the Genesee shale is at least 80 feet thick, and the strike of the rocks is such as to carry it through the concealed space along the railroad already described. The thickness of rocks in this space is about 140 feet, and deducting 80 feet leaves 50 feet of Hamilton rocks at the bottom of the concealed space. This would extend the Hamilton formation 230 feet beyond the western end of the first cut west of Altoona Station, so that its top would lie about 2,600 feet west of the Logan Hotel along the track.

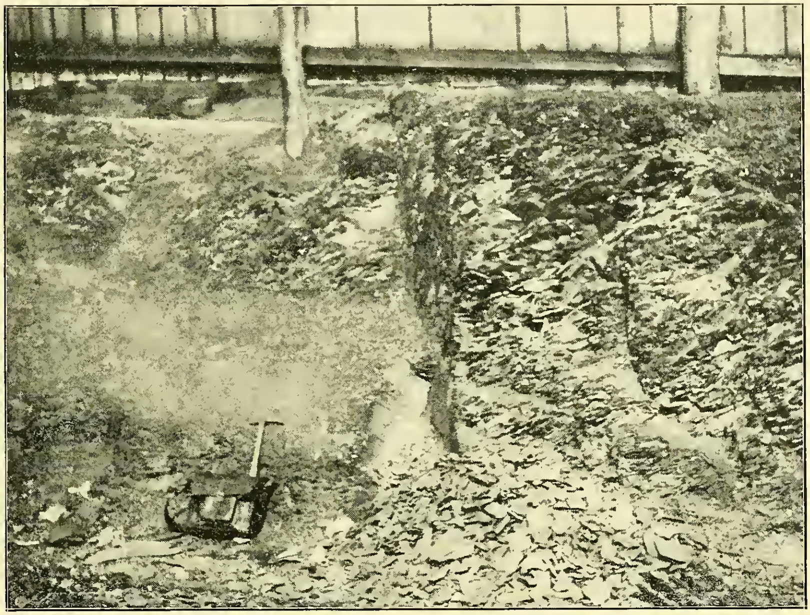


Fig. 5

On the New Portage Branch of the Pennsylvania Railroad the contact of the Hamilton and Genesee shale can be closely located about 1 mile northwest of Newry, where fragments of limestone full of Hamilton fossils were found at the base of an outcrop of the Genesee black shale. The same contact is well exposed in the road between Claysburg and Queen on the crest of a spur ½ mile northeast of Smoky Run. At this point also a thin, impure limestone with Hamilton fossils occurs at the base of the black shale. The thickness of the Hamilton can be determined only approximately, since in none of the sections studied could the bottom be determined, nor were there a sufficient number of exposures to afford a reliable determination of the average dip. In Altoona the upper part of the formation is exposed, as already described. The dip of this part is 52° to the northwest. At the corner of Fifteenth Street and Sixth Avenue the black shale of the formation was exposed in excavating for the foundation of a schoolhouse. The shale at this point is vertical, as shown on the profile section. It is possible that nearer the bottom of the formation in Altoona the shale is overturned. From the meager date at hand it seems that the average dip of 70° to the northwest would be a probable estimate for the formation, assuming that there are no faults or strong variations of dip. The distance between the Oriskany sandstone in the southeast part of Altoona and the bottom of the Genesee shale at Fourteenth Street and Thirteenth Avenue, described above, is, by the city map, about 3,300 feet, normal to the strike of the rocks. This space is occupied by the Hamilton and Marcellus formations in which the broad Logan Valley has been eroded. Calculating from the width of the outcrop and the assumed dip of 70°, the result is 3,100 feet for the thickness of the Hamilton and Marcellus in the Altoona section.

Genesee shale.—This is a well-defined stratum of black clay shale lying conformably between the Hamilton formation below and the Nunda formation above, and on account of its distinctive character it is important as a horizon-marker in the region. The shale is very fissile, cleaving easily into thin plates and flakes. Its black color is probably due to the presence of carbonaceous matter, as in the type region of western New York. As in the type region, it also contains rather plentiful calcareous concretions. Indeed, the formation preserves to a remarkable degree the characteristics by which it is distinguished in western New York. As already stated in the description of the Hamilton formation, the Genesee shale has been seen between Bellwood and Altoona, at the intersection of Fourteenth Street and Thirteenth Avenue in the latter place, on the New Portage Railroad 1 mile northwest of Newry, on the road midway between Claysburg and Queen, and near Queen. It crosses the Pennsylvania Railroad in the concealed space between a point 2,375 feet west of the Logan Hotel and Twenty-first Street. At the above mentioned street intersection in Altoona a thickness of 80 feet was measured, and, as the base of the shale was apparently not exposed, its thickness may be greater. The upper part of the formation is exposed in the bank of Beaverdam Creek, ¼ mile southeast of Queen, and its full thickness at this point is about 75 feet.

Nunda formation.—This formation has been known in the previous reports on the geology of Pennsylvania as the Portage. According to the usage of the U. S. Geological Survey, however, the term "Portage" should be restricted to the Portage sandstone of the Genesee River section in New York, and the term "Nunda," which was introduced in the early New York reports, applied to the rocks generally designated the Portage group or beds.

The basal 100 or 200 feet of the Nunda formation are composed of soft pale brown clay shale, which weathers to a dove color and has a very perfect cleavage, splitting easily into large, thin, smooth plates. In this shale *Paracadium doris* and *Pterochaenia fragilis* are relatively abundant and come in immediately above the Genesee shale. In passing upward through the formation, the rocks gradually change from the shale above described to a pale greenish-gray sandy shale which makes up the greater part of the formation. This shale generally cleaves easily into thin laminæ, but there are beds of coarser character and less perfect cleavage. Evenly bedded layers of hard, bluish, fine-grained sandstone occur, and some thin irregular layers. These layers are generally from 1 to 6 inches thick, and rarely 1 foot. They are especially abundant through the 100 feet of strata beginning about 350 feet above the base of the formation, and are well exhibited on the Pennsylvania Railroad in the third cut about 1 mile west of the station at Altoona. (See Figs. 6 and 7.)

The peculiar dimpling of the bedding surfaces shown in Fig. 7 is said to be characteristic of the Nunda beds in New York. In the fourth cut, 7,750 feet west of the station, a few bands up to 1 foot thick of compact or shaly, chocolate-colored rock occur, and similar rock is exposed in a cut along the incline No. 10 on the old Portage Railroad. These layers may be the attenuated representatives of the Oneonta phase of sedimentation in eastern New York. The thickness of the formation measured along the Pennsylvania Railroad appears to be about 1,400 feet.

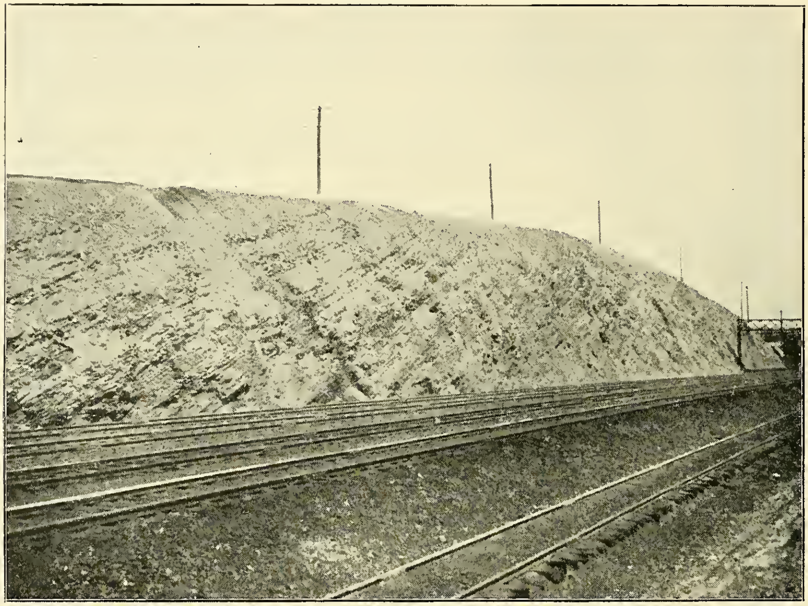


Fig. 6

In Blair County the bottom of the Nunda formation is sharply marked by the top of the Genesee shale. The top of the formation is, however, very indefinite. No persistent and easily recognized stratum separates the Nunda from the succeeding Chemung formation, nor is there any distinct lithologic change to mark the boundary. The rocks of the one merge into those the other by imperceptible stages. The boundary, as established by the writers, rests on a paleontologic basis. All the beds above the Genesee, and below the horizon at which the lowest Chemung fossils are found, are here considered to be Nunda. On the Pennsylvania Railroad this point is about 2½ miles west of the Logan House, Altoona, in a cut near the beginning of the curve at which, in going westward, the track turns into the

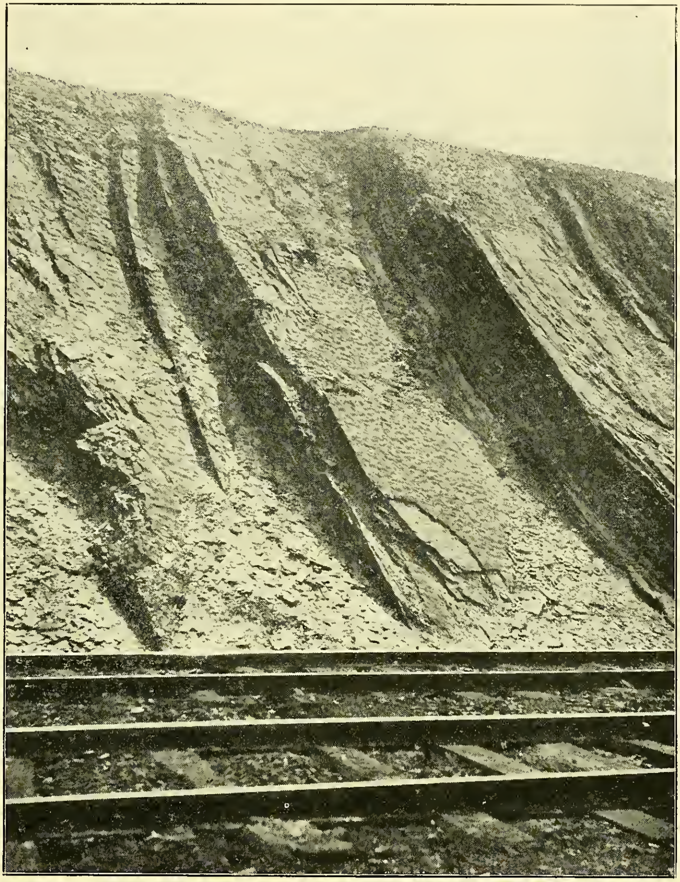


FIG. 7

valley of Burgoon Run. In this cut is a thin band of sandstone, full of *Leiorhynchus Mesacostale* and *Productella lachrymosa*, or a closely allied form. Under the fossil-bearing band nearly 100 feet of rocks are exposed, but no fossils could be found in them. On the New Portage Railroad the lowest Chemung fossils found were the same as mentioned above, and these occur in a cut about 1½ miles southwest of Duncansville where the recently constructed branch of the Pennsylvania Railroad diverges from the course of the old Portage Road. (See Fig. 3.) East of this point also are almost continuous exposures of the underlying rock for a thickness of many hundred feet, but no Chemung fossils could be found. No effort was made to trace this boundary farther to the southwest.

Chemung formation.—The Chemung formation follows conformably upon the Nunda to which it is, in its lower part, very similar in lithologic character, but from which it is sharply distinguished throughout by paleontologic characteristics. As stated in the description of the railroad section above, the lower limit of this formation is placed at the lowest horizon at which Chemung fossils are found. Its upper limit is the bottom of the distinctly differentiated rocks of the Catskill formation. As shown on the profile section, the formation outcrops for 1 mile along the Pennsylyania Railroad, its bottom being about 2½ miles and its top 3½ miles west of Altoona. Fig. 8

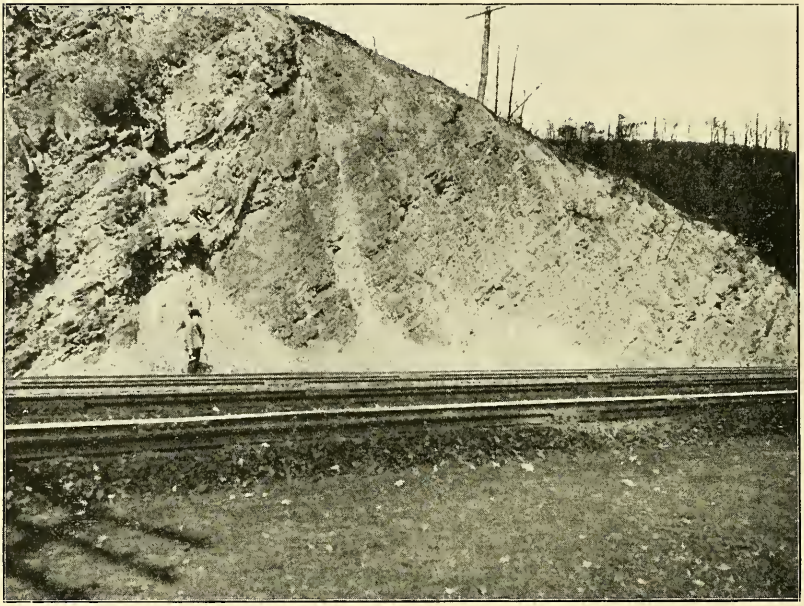


Fig. 8

shows the character of the Chemung rocks about 3 miles west of Altoona, and also the fault mentioned on p 624.

The total thickness of this formation in the section just described is over 2,500 feet. In the lower 1,400 feet the rocks are gray or green, sandy or clay shale, with a small proportion of gray sandstone, generally in thin layers in the shale, but occasionally in a stratum 50 feet thick; in the upper 1,000 feet the rocks are characterized by a large proportion of chocolate shale and by thin layers of chocolate sandstone.

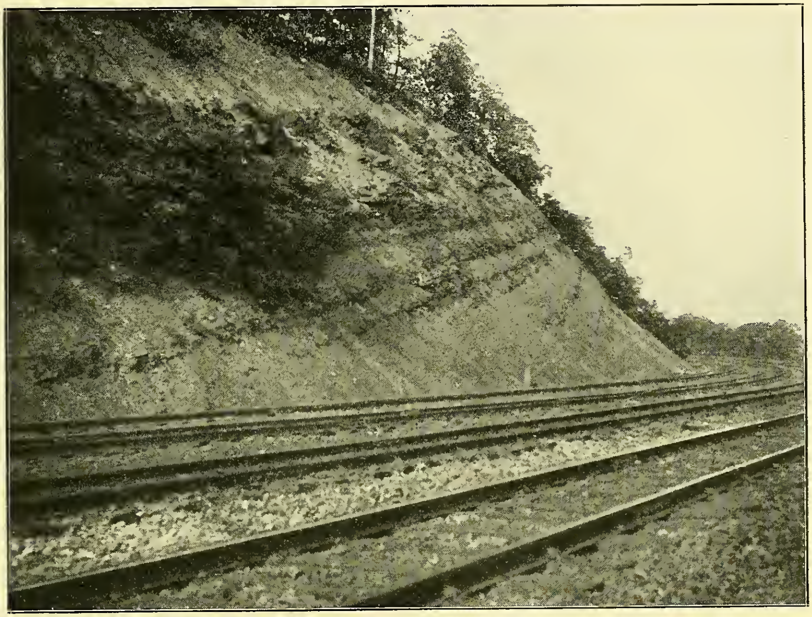


FIG. 9

Fossils occur in the topmost layers of the Chemung within a few feet of the bright red shale and sandstone of the Catskill formation.

Catskill formation.—This formation overlies the Chemung conformably. The top of the Catskill cannot be very definitely determined in the railroad section. The red shale shown in the profile section about 1,400 feet east of Kittanning Point probably is not far from the top, since it is apparently followed above by prevailingly gray shale and sandstone of the Pocono formation at the base of the

Carboniferous System. The Catskill formation is about 2,000 feet thick. Probably 80 per cent. of its rocks are red shale and red or brown sandstone, the rest of the formation being gray or green shale or sandstone. The red shale predominates. It is mainly argillaceous and is bright red in outcrop; the red sandstone generally weathers to a gray or dull brown color, and shows its true color only on a newly broken surface. The sandstone is medium- to fine-grained, and may be thick- or thin-bedded or even laminated. It generally occurs in thin layers or strata interbedded with shale, but may occur in thick-bedded strata having a thickness of 50 feet. No fossils were found in the formation, and their absence as well as the red coloration sharply distinguishes it from the Chemung. Fig. 9 is a photograph showing the contact of the Catskill red shale with the overlying Pocono sandstone at the curve about 1 mile south of Kittanning Point, where the Pennsylvania Railroad turns westward into the gorge of Sugar Run. (See Fig. 3.)

FAUNAS OF THE DEVONIAN SECTION NEAR ALTOONA, PA.

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It is the purpose of this paper to present only the more salient faunal features of the section. The data presented are the incidental results of studies and collections made primarily for the elucidation of the areal geology of the region.

The collections on which the faunal lists are based represent only a small fraction of the species which might be obtained by exhaustive collecting. They are sufficiently full, however, to indicate quite clearly the relationship of the several faunas which they represent to those of the standard Devonian section of New York. It is a well-known fact that the Devonian section, as developed in New York suffers great changes, both lithologic and faunal, in the Allegheny region to the southward. But the precise nature of these changes why and where they occur, are not so well known. At present the published data, which can be utilized in the study of the larger problems of Devonian stratigraphic paleontology of the Allegheny region, relate to a very few and widely scattered sections. Until the results of many more carefully studied sections are available, many fundamental questions of stratigraphic paleontology can be answered only hypothetically. The bearing of such local studies on wider problems seems to justify the present paper.

Base of section.—Several hundred feet of gray shaly to heavy-bedded limestones lie at the base of the section which is here described. This portion of the section lay outside of the area under investigation, and no attempt was made to recognize the several members of the New York section which are probably represented.

Oriskany fauna.—A coarse-grained, buff sandstone generally represents the Oriskany horizon. At the east side of the Pennsylvania Railroad, southwest of Bellwood, the Oriskany sandstone contains the following species:

Spirifercumberlandias	a
Rensselaeria sp.	r
Beachi suessana	c
Dalmanella cf. perelegans	r
Gypidula pseudogaleata	r

Southwest of Altoona the Oriskany shows about the same lithologic and faunal characteristics as near Bellwood.

The Oriskany, as seen in the Altoona section in the eastern part of the town of Altoona, represents a facies differing both lithologically and faunally somewhat from the same horizon as it generally appears elsewhere. The rock, which is an extremely fine-grained, soft, buff sandstone, contains one or more species of *Beyrichia* in great abundance. Other common species are the following:

Chonetes sp.
Anoplotheca dichotoma
Rhipidomella cf. oblata
Spirifer sp.
Pterinopecten sp.
Dalmanites sp.
Conularia sp.

Marcellus fauna.—Only three species have been recognized in the Marcellus shales. These are characteristic Marcellus forms, and are as follows:

Strophalosia truncata	r
Leiorhynchus limitare	a
Styliolina fissurella	a

Exposures which probably represent the Marcellus in excavations in East Altoona yielded no fossils.

Hamilton.—The shales and sandstones of the Hamilton have afforded the following species:

Tropidoleptus carinatus
Anoplotheca camilla
Chonetes scitula
Chonetes vicinus
Spirifer tullius
Spirifer mucronatus
Martinia subumbona
Stropheodonta perplana
Reticularia fimbriata
Palaeoneilo cf. bellistriata
Orthonota cf. parvula
Grammysia arcuata
Grammysia bisulcata
Aviculopecten cf. princeps
Coleolus aciculum
Pleurotomaria sp.
Phacops rana

These are all well-known species in the New York Hamilton. *Spirifer tullius* is common in the upper part of the section, and appears to be confined to this portion of the section, as it is reported to be in the New York sections.[1] *Martinia subumbona* has been observed at only one locality, several miles to the southwest of Altoona. It occurs abundantly in an outcrop in the wagon road about 1 mile northeast of Queen.

The Hamilton appears to be generally less richly fossiliferous than it is in the central New York sections.

Genesee fauna.—The Tully limestone is absent from the section and the dark sandy shales of the Hamilton are followed by the fissile black shale of the Genesee. The Genesee shale of this section is identical in lithologic features with the Genesee of the Finger Lake region. Like the Genesee of the Cayuga Lake section, fossils are very scarce in it. Only two species have been observed. These are:

Styliolina fissurella
Sandbergeroceras sp. undt.

Nunda fauna.—The Genesee is succeeded by the grayish sandy shales and flags of the Nunda. The fauna which this series of beds has afforded comprises the following species:

Cladochonus sp.
Palaeoneilo petila
Pterochaenia fragilis
Pterochaenia cashaquae
Paracardium doris
Paracardium delicatulum
Buchiola retriostriata
Ontaria cf. accinta
Phragmosoma natator
Probeloceras lutheri
Styliolina fissurella
Coleolus aciculum

This fauna is typical of the Nunda of western New York. All of the species in it are found in the western New York fauna, while none of the forms characteristic of the Ithaca facies occur in it.

During the interval represented by the shales and sandstones of the Nunda two marine faunas, entirely distinct in origin and composition, occupied that portion of the Devonian sea which extended over the present area of central and western New York, central Pennsylvania, and western Maryland. The habitat of these faunas extends southward into Virginia and West Virginia to a point not yet determined. In New York, where these contemporary faunas have been very thoroughly studied, one of them, usually called the Ithaca fauna, is found occupying an area lying in general to the eastward of that held by the other. The eastern fanua was the in-shore fauna while the western facies was the more pelagic and proba-

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[1] Sixteenth Annual Report, State Geologist of New York, 1898, p. 273; *Bulletin No. 206, U. S. Geological Survey*, p. 47.

bly lived in deeper waters. That the two faunas were limited to their respective areas solely by marine conditions, such as ocean currents, or differences in depth or temperature, is indicated by the frequent interleaving and intermingling of the faunas in sections located near the general boundary between the two faunal provinces. The two Nunda sections nearest the Altoona section which have been studied in Pennsylvania are the Catawissa and Hollowing Run sections, located at the Susquehanna River, to the northeast of Altoona. Comparison of the Nunda faunas of the Susquehanna and the Altoona sections shows that they represent respectively the eastern and western facies of the formation. The dominance of the Ithaca fauna is as complete in the Susquehanna sections[1] as is that of the western fauna in the Altoona section. That the Altoona section is more remote from the old shore-line of the Nunda sea than the Susquehanna sections is indicated by their respective geographic positions as well as by their faunas. The Altoona section is located just at the Allegheny front, while the Susquehanna sections lie well to the southeast of it.

Chemung fauna.—No very sharp line can be drawn on a lithologic basis between the Nunda and the Chemung. The faunas, however, are very distinct, as the following list of the Chemung species indicates:

Orbiculoidea doria
Stropheodonta mucronata
Spirifer disjunctus
Schizophoria striatula
Orthothetes (Schuchertella) chemungensis
Atrypa hystrix
Atrypa reticularis
Delthyris mesacostalis
Dalmanella tioga
Productella lachrymosa
Productella cf. speciosa
Spirifer mesastrialis
Camarotoechia contractavar.
Camarotoechia sappho
Ambocoelia gregaria
Leiorhyncus mesacostale
Stropheodonta cf. demissa
Strohpeodonta perplana var. nervosa
Chonetes scitula
Productella cf. hallana
Leptodesma protextum
Leptodesma lichas
Leptodesma sp.
Pterinea cf. dispanda
Loxonema terebra
Edmondia sp.
Schizodus pauper
Modiomorpha subalata var. chemungensis
Stenaster sp.

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[1] The faunas of these sections are listed in *Bulletin No. 244*, U. S. Geological Survey, pp. 78, 91.

This assemblage of species is a representative Chemung fauna, and does not differ notably from the Chemung facies as developed at the type locality on the Chemung River. Like the latter, it includes *Spirifer mesastrialis*, and some other forms which come up from lower horizons, in association with such characteristic Chemung forms as *Spirifer disjunctus*, *Dalmanella tioga*, and *Stropheodonta mucronata*. These three species may be considered pre-eminently characteristic of the Chemung. Their appearance in the sections is coincident with the advent of the Chemung fauna in the Allegheny province, and they remain throughout its stay in the region. In a recent publication[1] it is stated that *Spirifer disjunctus* does not appear in the sections till the "period of Chemung deposition was well-nigh over." The writer, however, has collected this species in one of the sections included in the above-mentioned report, 200 feet below the base of the Chemung, as drawn on the map which accompanies it. It occurs also very near the base of the Chemung fauna to the northeast of the area discussed in the paper. The faunas, therefore, appear very clearly to controvert the statement in question Although *Spirifer disjunctus* is frequently a rare species in the lower part of the Chemung, as it often is in the upper part, the writer's observations indicate that it is generally present at or near the base of the Chemung in some of the sections of any given area, and that the earliest appearance of the Chemung fauna is generally coincident with the advent of *Spirifer disjunctus* southwest of Altoona. In a section near Queen, southwest of the Altoona section, this species occurs near the base of the Chemung. In the Virginia sections it occurs inthe lower Chemung, as it does in New York.

[1] *Bulletin No. 81*, New York State Museum, p. 21.

THE GRAND ERUPTION OF VESUVIUS IN 1906[1]

WILLIAM HERBERT HOBBS

Historical.—From the writings of Plutarch and Strabo we know that previous to the Christian era where now is the complex cone of Vesuvius, with its Atrium and Somma, the latter alone existed, though in the form of a complete ring. This Strabo believed to be a volcanic crater, though extinct. From the time of the earliest Greek colonization no records have been preserved of any eruption in this crater previous to the eventful year of 79 A. D.; though attention has been drawn to the fact that wall-paintings recovered from the buried cities of Pompei and Herculaneum represent the Somma of those days with a somewhat broken wall as though from an eruption. The careful studies of Johnston-Lavis have shown, however, that in the composition and structure of Somma there is the record of no less than fourteen periods of eruption, and of two long intervals of repose not unlike that which immediately preceded the Christian era.[2]

The eruption in the year 79, the greatest of Vesuvius within historic times, was of the explosive type, producing no streams of lava, but supplying such a vast quantity of lapilli and ash that, carried by the *tramontana* then blowing, it was distributed over the cities at the southern base of the mountain and along the slopes of the Sorrentine peninsula. Pompei was covered in places to a depth of 25–30 feet by this material; while the populous city of Herculaneum, situated at the bottom of a steep slope, was overtaken by a flood of mud and ash and buried beneath 60 feet of débris, now augmented by lava streams from later eruptions. The vast quantity of ejected material transferred the coast line from the former port of Pompei to near its present position, reduced the ancient crater

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[1] This article was dispatched from Rome a fortnight after the eruption. Various causes have prevented its earlier publication.

[2] H. J. Johnston-Lavis, *Eruptive Phenomena and Geology of Monte Somma and Vesuvius in Explanation of the Great Geological Map of That Volcano* (London, 1891; pp. 21).

of Somma to its present fragmentary form, and laid the foundations of the inner cone—Vesuvius proper. The letters of Pliny the Younger to Tacitus describe the cloud above the crater during this eruption as resembling a great pine (from which the canopy form of the stone pine must be understood), and this simile has ever since served for illustration.

Of the eight eruptions which are recorded between 79 and 1631 we know but little,[1] and the chief interest attaches to the long period of repose which, except for a slight ash eruption (1500), extended over nearly 500 years (1139 to 1631). During this time the crater was forested and overgrown with vines, as it had been for a long time previous to 79; and it is of considerable interest to note that the activity of Vesuvius was in this interim apparently transferred to the Phlegraean Fields west of Naples, where the Solfatara erupted in 1198 and in 1538 a new volcano (Monte Nuovo) formed on the shore of the Lake Lucrinus. Monte Epomeo on the island of Ischia also erupted in 1302.

The greatest Vesuvian eruption of which we have full accounts was that of December 15–19, 1631; which serves as type of the paroxysmal, as does that of 79 for the explosive eruption. This outburst of 1631 began with rumblings within the crater, followed by the opening of a cleft upon the east side of the mountain and the emission of steam and ash. On the following day another fissure opened upon the south side and sent up the characteristic "pine cloud" of steam and ash to overwhelm Nola, Palma, Lauro, and Ottaiano; thus indicating that a southwest wind was blowing as at the time of the present eruption. The climax of this eruption was reached upon the 18th, when lava poured from the crater in four great streams: one of which overran Bosco and Torre Annunziata; a second Torre del Greco; a third Portici and Resina, with the loss of some 3,000 persons; and a fourth Massa di Somma, San Sebastiano, and Sant' Anastasio upon the northwest slope. All streams save the last mentioned precipitated themselves into the sea, where they produced ebullition over a considerable area. It is stated that the cone of Vesuvius was reduced in height by some 170 meters at this time.

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[1] The best edited account of these eruptions will be found in the work by Justus Roth, *Der Vesuv und die Umgebung von Neapel* (Berlin, 1857).

The greatest of the subsequent eruptions have occurred in 1737, 1794, and 1822; in all of which outbursts the cone suffered considerable reductions in altitude. In 1855 also it is said to have lost almost 60 meters. In the eruption of 1737 Portici, Resina, and Torre del Greco were all again invaded by lava, as was the latter city in 1794. Of the eruptions which have taken place in 1822, 1839, 1850, 1855, 1861, 1872, 1899, and 1903, much the most important have been those of 1822 and 1872. The last mentioned was of considerable interest because of its rapid development, and because of the favorable conditions which it offered for observing and photographing the mountain. Great quantities of steam were given off; and the lava, which flowed in the direction of San Sebastiano, was typical of the "ropy" surface sometimes assumed by volcanic magmas. In recent years small quantities of lava have for quite long periods oozed from elevated *bocche*.

No volcano has received the same amount of study as Vesuvius, and the greatest amount of accurate knowledge of it has been brought together upon the map of Dr. Johnston-Lavis.[1]

Chronicle of events during the eruption of 1906.—During late September and early October, 1904, Vesuvius was in almost absolute repose. The eruption of lava began May 27, 1905. The charts kept at the Osservatorio Vesuviano to indicate the grade of activity show absolutely no change at the time of the great Calabrian earthquake of 1905 (September 8), the curve of activity for days before and after that disturbance being almost horizontal. In October and November, 1905, lava was dribbling from an outlet high up upon the central cone and near the funicular railway. At night it showed from Naples as a bright red line, which later forked near the Atrio del Cavallo. This stage with the gradual augmentation of activity continued until the first days of April, 1906.

On the 5th of April there was a very decided increase in the violence of the explosions, and an ash cloud mounted high above the crater (see Fig. 6). The climax was reached on the evening of the 7th (Fig. 7), when three earthquakes were felt in Naples of sufficient

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[1] Geological map of Monte Somma and Vesuvius constructed by H. J. Johnston-Lavis during the years 1880–88. Scale 1:10,000 (6.33 inches to the mile). In six sheets.

violence to produce considerable panic, but no damage. To this accompaniment of shocks a new mouth or *bocca* opened near the shoulder of the mountain (the *piano*) above Torre Annunziata (see Fig. 1), from which lava issued and descended in the direction of Boscotrecase and Torre Annunziata. Either before, at the same time, or shortly thereafter, two other large streams issued within the same general region and descended the near-lying slopes, the one toward Trecase and the other toward Terzigno. On the morning of the 8th the greatest of the lava streams was making its way through Boscotrecase, and before nightfall it had enveloped the city and was on its way down the *vallone* to Torre Annunziata. It came to a halt at the *camposanto* in the outskirts of that city.

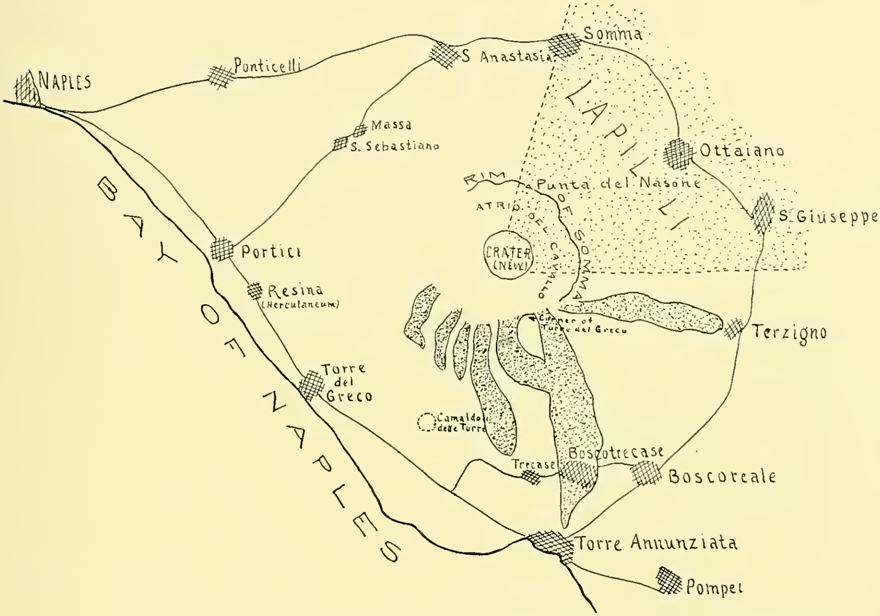

FIG. 1.—Sketch map of Vesuvius and surroundings (areas of lava streams and of lapilli distribution, approximate only).

Apparently simultaneously with the emission of lava from the new *bocche* a series of violent explosions partly destroyed the central crater, and sent small fragments of lava, lapilli, and ash high into the air, to be carried by a westerly wind over the towns east and northeast of the mountain. Ottaiano, San Giuseppe and Somma, which hug the northeastern and eastern base of the volcano, suffered most, being in part buried under some three feet of ejectamenta. Nola and Terzigno also suffered heavily, while a leaden sky and a fall of fine cinder were almost universal throughout a fan-shaped area extending at least to the Adriatic and roughly limited to the north by Campobasso and to the south by Avellino and Bari (see Fig. 2).

Fig. 2.—Sketch map to show the distribution of lapilli and ash from the principal explosions of the eruption.

The principal loss of life was in San Giuseppe, where in their terror the people crowded into the little church to prostrate themselves before the altar, just before the roof fell from the burden of ash upon it. Many others of the weak house-roofs of heavy tiling (wholly unfitted for such a neighborhood) also collapsed, and in some cases with resultant loss of life. The Circumvesuvian Railway and the line from Naples to Salerno were blocked by the accumulation of ash; though upon the last-mentioned traffic was resumed within twenty-four hours. With the outflow of the great lava streams the violence of the explosions within the crater began to wane (see Fig. 8).

Conditions in Naples.—The shifting winds carried the later and finer ash-fall for much of the time in the direction of Naples. On the morning of the 11th trains entered Naples from Caserta through a cloud so dense that the impression of a tunnel was produced, though the sun was high in an otherwise clear sky. On this day workmen were dismissed from the shops along the water front on account of the darkness; and business in the city, already almost paralyzed, practically ceased through the closing of the shops along the main streets. The exodus of the great body of tourists had been accomplished largely on the 8th, though with much confusion and a greatly augmented train service, the result being that on the following morning many of the grand hotels dismissed their servants. Large bodies of troops, increased by levies from other cities, armed with shovels, were promptly sent to all the afflicted cities east of the mountain, and with fire companies, *carabinieri*, and the numerous refugees did excellent work in rescuing the wounded and in digging out the railway. Artillery wagons loaded with bread supplied the homeless who still remained in the partly buried cities. By the 15th railway communications had been established between Naples and Ottaiano.

In Naples the roof of the market of Monte Oliveto and a few other poorly constructed houses collapsed from the weight of ash, in the first mentioned instance with considerable loss of life. The principal inconvenience to the people from the falling cinder was to the eyes, which had to be protected with glasses, celluloid plates, or some other device; and of people of the better class upon the streets the greater number carried extended umbrellas for better protection. For a number of days, and until a shifting wind again brought the bright sunlight, the streets were occupied by religious processions following effigies or pictures of San Gennaro, the patron of the city.

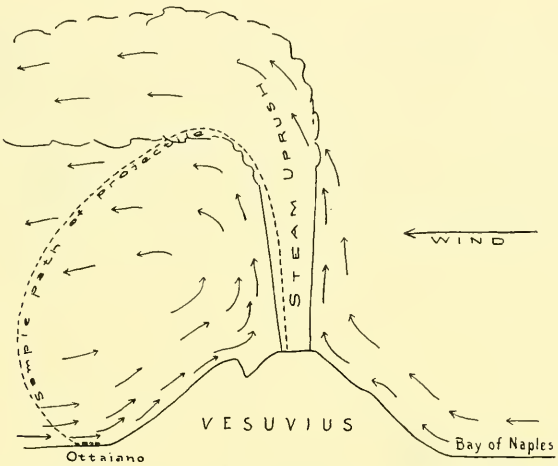

FIG. 3.—Diagram to illustrate the courses of air currents and of projectiles near Vesuvius during the grand stage of the recent eruption.

In contrast with the eruption of 1872, the late outburst offered little opportunity for observing its developments. The constantly shifting light winds kept Naples and nearly the whole western and northern circumvesuvian country shrouded in ash for most of the time; and no such excellent photographs as were taken in 1872 appear to have been secured.

FIG. 4.—View of Vesuvius from the south, before the eruption of 1906.

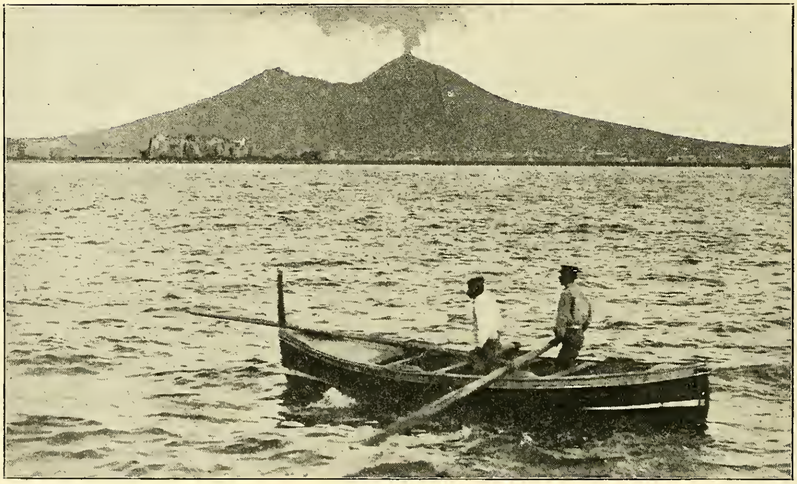

FIG. 5.—View of Vesuvius from the west, before the eruption of 1906.

The electrical phenomena.—An English acquaintance, in whose statements the writer reposes confidence, reported to him that on the morning of the 8th, when the large lava stream was overrunning Boscotrecase, he followed the margin of the stream a considerable distance in the direction of the crater. Almost continuous flashes of lightning seemed to pass from the overhanging cloud nearly straight downward toward the lava; and, if appearances were to be relied upon, at no great distance.[1] On the 15th, when the writer attempted to reach the new *bocca* by following up the stream of lava from Boscotrecase, changes in the direction of the wind left him for considerable periods enveloped in the ash cloud with surrounding darkness too great for following the bad footing over the scoriaceous surface, thus necessitating long delays. At elevations in excess of 1,400 feet above Torre Annunziata heavy rumblings were heard at intervals of from six to nine minutes, and in apparent correspondence with the rhythmic uprush of steam and ash from the main crater. Before the envelopment by the ash cloud the direction of the crater had been ascertained to be in close correspondence with the steepest slopes. The *boati* always began in this direction as low continuous rumblings, like the rolling of heavy wagons over hard and irregular pavements; but they soon moved away to the southward and were transformed into reverberating crashes of thunder so resembling those of a heavy electrical storm as to be unmistakable. In a favorable shift of the wind an altitude of 2,200 feet was reached, when a quick change again brought the black ash cloud and a patter of lapilli, so that further progress (now wholly over fresh lava) was impracticable.

Pliny mentions that in 79 almost incessant lightning flashes accompanied the eruption. The rhythmic *boati* of Vulcano during its great eruption of 1888–89 lacked these striking electrical features, at least at the time the volcano was visited by the writer in April, 1889; and apparently a smaller proportion of water vapor was characteristic of the eruption. Professor Palmieri, the former director of the Vesuvian Observatory, gave careful study through many years to the electrical phenomena attending Vesuvian eruptions,

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[1] A friend who was in Pompeii during the great outburst of the 7th has emphasized the grandeur of the electrical phenomena.

including the important one of 1872.[1] By putting up a conductor in the ascending current of steam he was able experimentally to show

Fig. 6.—View of Vesuvius during the eruption of 1906 (earlier stages). Stage of April 5.

Fig. 7.—View of Vesuvius during the eruption of 1906 (earlier stages). Later than Fig. 6, probably on April 7.

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[1] Luigi Palmieri, *Elettricità negl' incendi vesuviani, studiata dal 1885 fin' ora con appositi instrumenti. Lo spettatore del Vesuvio e dei Campi Flegrei.* (Naples, 1887; pp. 77–79.)

that the steam as it is condensed by expansion to water vapor becomes positively electrified. Many samples of the Vesuvian *sabbia* from different localities when washed and heated were found to become negatively electrified. He thus found an experimental explanation for the origin of the atmospheric electricity developed during eruptions.

Disturbances of the sea.—On the 5th of April, when the violent stage of the eruption may be said to have commenced, the Bay of Naples is said to have been in unusual agitation, without apparent explanation of the weather conditions of that or earlier days. On the 6th a tidal wave struck the "Barbarossa" one day out from New York en route to Naples. It seems unlikely that either of these phenomena was directly the result of disturbances within the crater of Vesuvius, and it is far more probable that they were attributable to a more or less distant seaquake, which we may be able to locate when the next report of the seismological stations co-ordinated under the British Association has been issued. The time of the Vesuvian eruption falls so nearly in coincidence with the earthquakes of California, Hawaii, and Formosa that relationships of tidal disturbances are otherwise difficult to trace.

Fig. 8.—View of the "Pine Cloud" over Vesuvius on April 11. View taken from Ponte della Gatta looking over the ancient *bocca* of Camaldali della Torre.

Increased activity of the fumaroles in the Solfatara.—It was reported that the fumaroles of the Solfatara showed increased activity during the eruptive phase of Vesuvius. Having last visited them in October, 1905, the writer was able to confirm this by a visit made on April 16 during the closing stages of the main eruption. The vapors which issued from the main fumarole on the later date rushed up with a hissing sound, and in a volume which resembled that from the escape-valve of a locomotive. The services of the attendant, who had been accustomed to stimulate the fumarole with torches, had become unnecessary, and he had deserted his post.

FIG. 9.—View of the main lava stream of 1906. Above Boscotrecase.

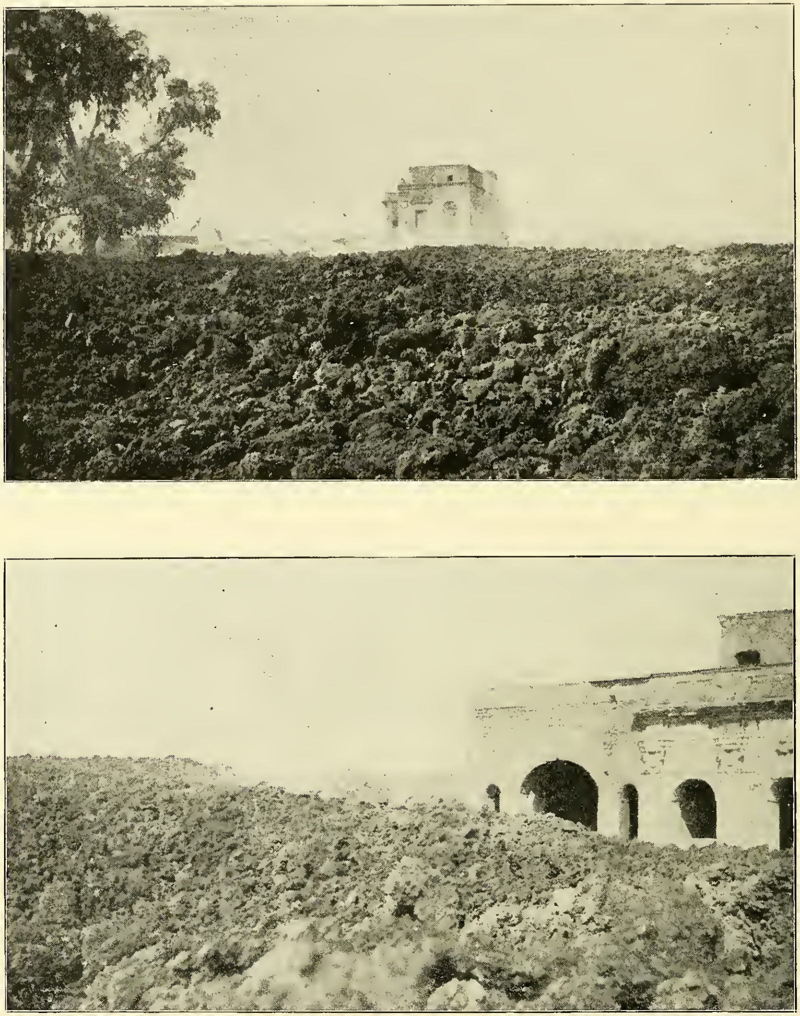
The lava streams.—Three large and several smaller lava streams issued from Vesuvius during the recent eruption. The one which caused the greatest damage appears to have been the largest, and flowed from a *bocca* near the *piano* above Torre Annunziata to the cemetery on the outskirts of that city, completely enveloping the city of Boscotrecase and burying it to a roughly estimated average depth of 12 feet (see Figs. 9–12). Above an altitude of about 2,200 feet and almost immediately above the corner monument of Torre del Greco (see Fig. 1), this stream sent off a branch to the westward, which branch, following the course of a diverging *vallone*, was again reunited to the main stream near the altitude of 1,500 feet. The *bocca* of this principal stream is above the monument referred to and probably near the *piano*.

A second large stream, which probably issued from a *bocca* somewhat farther to the west, passed over vineyards and isolated houses, and descended to a point near Trecase and only 670 feet (vertically) above Torre Annunziata in a direction a little west of north (see Fig. 1). Fig. 14 shows where this stream had passed through a grove of small stone pines, some of which it broke off and carried along. The several smaller streams were all higher up upon the slopes and in the vicinity of this one. They could be distinctly followed by the eye from the high point reached on the 15th.

FIG. 10.—View of the main lava stream of 1906. In the *vallone* below Boscotrecase. (The lava filled the valley with arching upper crust which collapsed after outflow of lava·beneath.)

The third large stream the writer has not personally followed, but it was reported to him by Professor Sabatini to extend in a direction parallel to and north of the narrow stream of Caposecchi (1834) and to end near Terzigno.

The streams personally examined presented a black scoriaceous surface made up of blocks irregular in shape and generally quite separate from each other, varying in size from a man's fist to great angular pieces too heavy for a man to lift. The destruction wrought by lava to structures began by the damming back of the stream until the structures were fractured and toppled over from the pressure exerted against them. Trees situated near but within the edge of



FIGS. 11 and 12.—Views of the lava over Boscotrecase with partly buried villas projecting. (Taken April 11, 1906.)

the stream were surrounded and remained standing. Farther within the margin, however, where the developed stresses were

FIG. 13.—View of the cone of Vesuvius on April 13, from the roof of a deserted villa above Resina. The flat dome is in contrast with the earlier pointed form.

FIG. 14.—View of the surface of the western lava stream above Trecase, where it has overrun a group of pines. (Taken on April 15.)

greater, they were snapped off and carried along upon the surface as passengers. Little if any burning resulted, though the snapped stems were sometimes found charred near the fractured surface. This immunity of inflammable objects from combustion when in contact with lava is apt to cause surprise, though simply enough explained by the insulating nature of the non-conducting lava crust.

The ejectamenta.—The events of the eruption have been so enlarged upon by the fertile imagination of an excited press that the figures given below will doubtless seem to be underestimates. Yet, while it has seldom been practicable to carry out actual measurements, owing to the irregularities of distribution, and in the deeper layers because of the necessity of extensive excavation, it is confidently believed that the figures given are generally within 15 per cent. of the true averages.

The ejectamenta may be roughly classified into lava fragments, lapilli, and ash. The lava fragments and lapilli, if we except the area above the atrium and hence near to the crater, have been restricted in their distribution to the area northeast of the mountain (see Fig. 1), whither they were carried by the wind on the 7th and 8th, during the climax of the outburst. In the belt of cities encircling the mountain lapilli begin to be observed near Somma, and farther east are found almost throughout the thick deposit. Their southern limit, probably near Terzigno, has not been sought by the writer.

Section of the deposits.—The total maximum thickness of the deposits at Ottaiano and San Giuseppe may slightly exceed three feet. The deposits consist of a lower layer, a few inches in thickness, made up of black scoriaceous lava fragments, the largest of which are an inch or more in diameter (in the press reports red-hot blocks weighing 200 kilos descended upon the town). This layer is succeeded by gray lapilli mixed with ash, the former decreasing in size more or less uniformly toward the top. The uppermost inch of the deposit shows in great perfection the succession of colors characteristic of the closing stages of an eruption. The dull gray which succeeds the black lower layer, and which constitutes the major portion of the deposits, here changes into the penultimate thin red layer, the *sabbia rossa*, which was falling upon the 11th and 12th.

Upon this is the surface layer of nearly white impalpable ash. Von Buch, who observed the quite important Vesuvian eruption of 1794, has given the order of colors, which, he states, was then recognized as characteristic, to be black, bright gray, and white.[1] The falling of the *sabbia rossa* during the late eruption was joyously hailed by the Neapolitans as the beginning of the end.

This red ash is probably of the same general characters as the gray underlying material, save for its finer state of subdivision and the greater oxidation of the contained iron. Its fall appears to indicate that, having been long suspended in the higher layers of the vaporous atmosphere above the crater, the diminution in violence of the uprushing steam has left it without support and allowed it to settle. The ultimate layer of nearly white material appears to be still more finely divided.

Effect of the projectiles upon windows.—The windows of Ottaiano and San Giuseppe afford material for an interesting study. On the sides of houses opposite the mountain they were broken in apparently much more generally than on the side facing it, and even when protected from falling blocks by deeply set casings. In several of the windows specially examined possibility of reflexion from neighboring walls was excluded, and in all cases rather improbable. Sometimes almost entirely broken out, in other instances they presented only a few cleanly cut holes almost perfectly circular in form, and generally between two and three inches in diameter. These holes were wholly devoid of radial fractures. Sometimes two or more holes overlapped, but always with the same cleanly cut outlines. In a number of cases the circular crack appeared, but with the inclosed disk still in its place to indicate that the missile had rebounded. The holes are clearly much larger than the flying missiles which produced them. The large amount of ash in the air at the time of the writer's visit to these cities made photographing difficult, and the exposures from these windows were unfortunately failures.

The explanation of these fractured windows on the sides of buildings away from the volcano is probably to be found in the inrush of air from all sides toward the crater to replace that removed by

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[1] L. v. Buch, *Gesammelte Schriften*, Vol. I, pp. 397–404.

the great uprush of the steam. In times of grand eruption Vesuvius becomes a gigantic steam injector (see Fig. 3). As already stated, the light wind blew at the time of the grand paroxysm from the southwest, or over the crater toward Ottaiano. On the side toward the bay the force of this current would simply be increased, whereas on the Ottaiano side the southwest wind would be replaced near the surface by a contrary current blowing in the direction of the crater. From the fact that lapilli even are not found west of the crater at points below the *piano*, it is clear that projectiles which fell at Ottaiano must have followed a course determined largely by air currents, and presumably similar to that indicated in the diagram. That they reached the ground in directions inclined at fairly flat angles in the direction of the volcano would appear to follow from the damage done to the upper portion of windows protected by casings nearly or quite a foot in depth.

The ash layer to the north and west.—To the west of Somma, and along the shores of the bay only ash is found. Its depth may reach six inches between Portici and Torre del Greco, though elsewhere it is generally considerably less. Higher up on the slopes its thickness increases until at the observatory it attains a thickness of perhaps ten inches, and with it are associated extremely fine lapilli.

In Naples the depth of the ash deposit hardly exceeded an inch, certainly not an inch and a half. The collapse of the roof of the market of Monte Oliveto, and of a few other buildings in Naples, is adequately explained by the high specific gravity of the ash and the weak construction of the buildings. The agriculture of all this northwestern, western, and southern belt will quickly recover from the loss which it has sustained. As regards Somma, Ottaiano, San Giuseppe, and to a less extent the more distant cities to the northeast of the mountain, a considerable time must probably elapse before the soil will again become productive.

The truncation of the cone.—It is impossible at this writing to give accurate figures concerning the reduction in height of Vesuvius; but that the cone has been reduced to near the level of the Punta del Nasone, the highest point of Somma, appears from views of the mountain.[1] It was reported in the newspapers, upon the

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[1] Such data are illusory and later measurements show the truncation to have been much less.

authority of the director of the Vesuvian Observatory, that this truncation amounts to 250 meters, or about 800 feet; but when the writer visited the observatory on the 12th, Professor Matteucci stated that he had never given out this estimate. The height of the cone before the eruption was not far from, though probably in excess of, 4,265 feet (1,303 meters on the military map of 1900), while the Punta del Nasone reaches 3,779 feet.

Truncations of the same order of magnitude have occurred in 1631 and 1794.[1]

In place of the beautiful outlines which the cone of Vesuvius presented before the recent eruption (see Figs. 4 and 5), it now shows a flat dome corresponding to the larger crater and the wider radius of distribution of the ejectamenta (see Fig. 13). Its somber hue is replaced by the dim gray color of sand which seems to extend almost to its base, where before was the rich green of a sub-tropical vegetation.

Apparent relationships of events.—The recent eruption of Vesuvius belongs to the paroxysmal rather than to the explosive type, though no sharp line divides the two. The order of events has been that generally recognized to be characteristic of this type. Starting in this instance from almost absolute repose in October, 1904, activity in the crater increased gradually, and lava began to dribble from a *bocca* high up upon the inner cone late in May of the following year. Both these manifestations of returning life increased more or less steadily until early in April, 1906, when the grand stage was ushered in. It may be presumed that during these initial stages lava found its way to the *bocca* from which it issued through a comparatively narrow channel, since otherwise the weak inner cone, especially in its upper portion, could hardly have withstood its hydrostatic pressure. This channel must have been slowly but constantly widened through the gradual fusion of its walls, thus augmenting both the quantity of lava which could reach the *bocca* and the hydrostatic pressure of the column upon the now weakened walls. When the cone was no longer able to withstand the pressure, it was cleft radially to the accompaniment of light earthquakes,[2] with partial

[1] J. Roth, *loc. cit.*

[2] These earthquakes were felt in Naples, one in the late evening of the 7th, and

destruction of the crater and great reduction in its height. The exposure within the fractured crater of larger surfaces of the hitherto imprisoned lava allowed of the more rapid escape of steam, which produced much more violent explosions. The fragments and lapilli, lifted by the uprushes of steam, were distributed by a southwesterly wind over the cities at the northeastern base of the mountain and beyond. The clefts opened being on the south side of the cone, *bocche* were there formed and the lava streams following the slopes descended respectively toward Trecase, Boscotrecase, and Terzigno. The rapid descent of these great lava bodies is explained both by the steep slopes and by the head under which they flowed—the difference in elevation of the new *bocche* (near the *piano*) and the old one high up upon the central cone. The pressures now relieved, the closing phases of the eruption followed in the slow escape of the remaining steam within the lava of the crater, now doubtless covered with ash shaken down from the walls. Much of this ash was probably again and again sent up to fall in considerable part within and about the crater, the finer portions only making contribution to the comminuted material derived from the rapid expansion of the steam within the lava itself.

Mutual relationships of tectonic movements and volcanic eruptions.—Few facts have been more securely established by experience than the lack of correspondence in time of great earthquakes and volcanic eruptions, in those regions where both are common. It has even been shown by Milne that central Japan, where there are many active volcanoes, is singularly free from earthquakes. Yet, while there is apparent lack of quick sympathetic response of the one phenomenon to the other, evidence is not wanting that the influence of the one *slowly* makes itself felt upon the other. Milne has shown that the West Indian earthquakes have been broadly related in time to the greater outbursts of its volcanoes.[1] Suess[2] long ago

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two in the early morning of the 8th. It may be significant that there were three main lava streams, all of which appear to have started at about this time and apparently from separate, though near-lying, *bocche*.

[1] John Milne, "Seismological Observations and Earth Physics," *Geographical Journal*, London, Vol. XXI (1903), pp. 15 ff.

[2] Ed. Suess, "Die Erbeben des südlichen Italien," *Denkschriften der Wiener Akademie, Mathematisch-Naturwissenschaftliche Klasse*, Vol. XXXIV (1872), pp.1–32.

pointed out that the greatest of Calabrian earthquakes, that of 1783, followed upon grand eruptions of both Vulcano and Etna. The new eruption of Vesuvius, the greatest since 1631, follows close upon the greatest earthquake in near-lying territory for more than a century, not long after which had occurred the really important eruption of 1794.

ROME,
April 23, 1906.

EDITORIAL

THE ISRAEL C. RUSSELL LIBRARY

Through the generous gift of Mrs. Russell, the library of the late Professor Israel C. Russell has become the property of the University of Michigan; and by her request it will be kept separate to form the nucleus of a Departmental Library of Geology. The Regents of the University in accepting the gift authorized changes in the Museum Building—at present the home of the Geological Department—and in a few weeks the books will be arranged upon shelves in a new geological seminary room to be known as the "Israel C. Russell Room" and prepared as a memorial to this distinguished geologist. The collection which thus comes into the possession of the University of Michigan is especially rich in the separate publications of geologists; and these, like the reports and bound volumes of the collection, are to be entered in the main library catalogue of the university. An appeal will be made to working geologists here and abroad, in the hope that they will place upon their exchange lists in place of Professor Russell's name the name "Russell Library," continuing the old address (University of Michigan, Ann Arbor, Mich., U. S. A.). Contributions to the collection will be acknowledged by the University Librarian, promptly entered in the catalogue, and sent to the Russell Room, where they will at once become accessible to all students of geology. A similar request will be made of the Directors of Geological Surveys and of other geological institutions, in order that the very valuable series of their publications may be kept complete. It is thought that means will be found to continue the subscription on behalf of the Library to the important geological and geographic journals which were regularly taken by Professor Russell.

Printed address slips for mailing or expressing publications will be supplied upon application either to the University Librarian or to Professor William H. Hobbs, in care of the University. If notified in advance, the Library will generally be willing to pay the charges upon express packages.

REVIEWS

Geology of the Northern Adirondack Region. By H. P. CUSHING. (New York State Museum *Bulletin No. 95*, 1905.) Pp. 271–454, 18 plates and 9 figures.

About a year earlier Professor Cushing published *Bulletin No. 77* of this same series, in which the "Geology of the Vicinity of Little Falls, Herkimer Co. [N. Y.]," was admirably described. The present bulletin is devoted mainly to the geology of Clinton and Franklin Counties, but one interested in the geology of the Mohawk Valley will find in the descriptions and comparisons much of genuine interest. Professor Cushing's reputation as a petrographer guarantees an accurate and valuable study of the pre-Cambrian rocks which cover so large a part of the area under consideration; but the reader interested in the structural geology and Paleozoic formations of northern New York will also find it a most interesting report. The figures, colored geological maps, and excellent plates giving views of typical outcrops of the various formations, add greatly to the attractive appearance of the bulletin.

Under pre-Cambrian history it is stated that the oldest rocks certainly recognized in the Adirondack region consist of well-banded gneisses and schists with bands of coarsely crystalline limestone, believed to be water-deposited rocks which are referred to the Grenville formation of Canada. In parts of the region is a mass of gneisses of doubtful age and formation, thought, however, to be of igneous origin, which are given the name "Saranac formation" from the exposures along the river of that name in Clinton County. Professor Cushing states that "after the present surface rocks had become deeply buried, they were invaded from beneath by a series of great igneous intrusions, broken up into patches." These igneous rocks are grouped into the following four classes: anorthosites, syenites, granites, and gabbros.

Pre-Cambrian time was very long, and the amount of erosion very great, so that Professor Cushing estimates that in this region "in all likelihood at least from three to five miles of rock thickness were worn away from the surface and perhaps considerably more, especially locally."

In early Paleozoic time a subsidence began in the northeastern part of the area and slowly moved to the southwestward. On account of overlap, the oldest Paleozoic formations, those of Lower and Middle Cambrian age do not appear about the Adirondacks. The oldest Cambrian formation of this region is the Potsdam, a coarse, often pebbly, massive sandstone which was deposited in shallow water on the old land surface of the present Adirondack region. This was succeeded by the Beekmantown formation, composed generally of beds of sandy dolomite. In the Champlain valley the Beekmantown is overlain by a considerable thickness of quite pure marine limestones, which are very fossiliferous and known as the Chazy formation. During Chazy time there was an elevation to the southwest of the Adirondacks, followed by a depression; so that the Chazy formation does not appear on that side of the Adirondacks, and the Beekmantown is succeeded unconformably by the thin band of pure limestone known as the Lowville, which does not appear to the east and north of the Adirondacks. The Chazy limestone on the northeast and the Lowville on the southwest are both overlain by marine fossiliferous limestones, known as the Black River and Trenton formations. Through the invasion of mud the Trenton limestones pass gradually into the Utica shale, which is the youngest formation carefully described. Professor Cushing concludes that "this submergence apparently completely overswept the old Adirondack island," and "the whole of New York State would seem to have been submerged, and that for the last time in its geologic history."

C. S. Prosser

Corundum and the Peridotites of Western North Carolina. By Joseph Hyde Pratt and Joseph Volney Lewis. (Vol. I, N. C. Geological Survey, Raleigh, 1905.) Pp. 464, 45 plates and maps, 35 figures.

The North Carolina Geological Survey has heretofore published only "Bulletins" and "Economic Papers" of rather a preliminary nature. This volume is the first of a series of more elaborate reports on special subjects. It treats of the peridotites and associated basic magnesian rocks of North Carolina, and describes incidentally similar occurrences elsewhere in the world. The geology of the state, the petrography of the rocks, their alteration and their origin are discussed in the first part of the work. Then follow chapters on corundum, its physical and chemical properties, varieties, and uses; its occurrence and distribution; its alteration, its origin, and the method of mining and milling. The last chapter treats of chromite and other minerals of economic value which occur in the corundum-peridotite belt.

E. W. S.

The Nature of Ore Deposits. By DR. RICHARD BECK. Translated and Revised by WALTER HARVEY WEED, E.M. (*Engineering and Mining Journal*, 1905.) Pp. 685, 272 figures and map; 2 vols.

The arrangement of this work is based upon the method of deposit, instead of grouping the descriptions under the name of the predominant metal. Primary ore deposits are treated first, and are classified as "syngenetic" (formed simultaneously with the country rock) and "epigenetic" (formed later than the country rock). Syngenetic deposits are divided into "magmatic segregations" and "sedimentary ores." Epigenetic deposits are classified as either veins or deposits other than veins, of which there are four kinds. These are (*a*) impregnation of non-calcareous rocks (deposits usually in beds); (*b*) epigenetic stocks, formed by metasomatic replacement of calcareous rock; (*c*) contact metamorphic ore deposits; (*d*) ore-bearing cavity fillings.

Secondary deposits are classified as (1) residual deposits formed by alteration of primary deposits, and (2) placer deposits.

The subject of ore deposits is treated in an exhaustive way and examples are taken from all parts of the world. The translator has slightly abridged the historical matter and has revised and added a little to the descriptions of American ore deposits.

E. W. S.

Physiography of the Archean Areas of Canada. By PROFESSOR A. W. G. WILSON, McGill University, Montreal, Canada. (Eighth International Geographic Congress Report, pp. 116–35; 2 maps, 6 plates.)

The basis of this paper is the reports of explorers, together with some of the author's own work. It is an excellent discussion of the physiography of this little-known region. The geology is not taken up, but the purpose of the paper is rather to draw attention to the physiographic unity of the whole region. This broad Archean area is held to be an old peneplain which has been subjected to differential elevation, denudation, and slight incision by the sea around the margin. It is bordered by an ancient belted coastal plain. A younger coastal plain borders Hudson Bay. Glacial drift covers most of the territory, and the glaciation of this peneplain of crystalline rocks has resulted in the present lakes, muskegs, and other features of topography.

E. W. S.

Economic Geology of the United States. By HEINRICH RIES, A.M., PH.D. New York: Macmillan Co., 1905. Pp. 435, 25 plates, 97 figures.

To say that this work is designed as a textbook will give a general idea of its nature. The arrangement is somewhat different from that of other works on this subject, in that the non-metallic minerals are discussed first. The reason assigned is that the non-metallic are more important and their deposits simpler. The order of treatment is: Part I, "Coal; Petroleum, Natural Gas, and Other Hydrocarbons; Building Stones; Clay; Lime and Calcareous Cements; Salines; Gypsum; Fertilizers; Abrasives; Minor Minerals; Water; Soils and Road Materials;" Part II, "Ore Deposits; Iron; Copper; Lead and Zinc; Gold and Silver; Silver-Lead; Aluminum, Manganese, and Mercury; Minor Metals."

E. W. S.

Structural Features of the Joplin District. By C. E. SIEBENTHAL. (*Economic Geology*, Vol. I, No. 2, November-December, 1905, pp. 119–28.) *Discussion* by H. FOSTER BAIN. (*Ibid.*, pp. 172–73.)

This paper is of especial interest in that it shows a way in which incorrect conclusions may be drawn as to the throw of faults. Throws of 150 feet or more have been described for the Joplin district. Shale is found in horizontal juxtaposition with limestone strata whose normal position is 150 feet below. These conditions vary much in short distances, and the author accounts for them by showing (1) that the shale is unconformable on the limestone and was laid down on an uneven erosion surface; (2) that solution and the giving way of roofs of caverns have let blocks of strata down; and (3) that there has been faulting of much less throw.

E. W. S.

Geological Survey of North Dakota. Third Biennial Report. By A. G. LEONARD and Assistant Geologists. Bismarck, 1904. Pp. 217, 33 plates, 8 figures, 2 maps.

This work contains articles on "Lignite on the Missouri, Heart, and Cannon Ball Rivers, and its Relation to Irrigation;" "Report on the Region between the Nothern Pacific Railroad and the Missouri River;" "Topography of North Dakota;" "Geological Formations of North Dakota;" "Methods of Stream Measurements;" "The Run-off of the Streams in North Dakota."

E. W. S.

Methods and Costs of Gravel and Placer Mining in Alaska. By CHESTER WELLS PURINGTON. (U. S. Geological Survey, Bulletin No. 263, 1905.) Pp. 273, 42 plates, 49 figures, 30 tables-

The American placer miner finds himself confronted with new conditions when he goes to work in Alaska. The object of this report is to give the most expeditious way of getting out and working the auriferous material. One of the chief difficulties in working the material arises from its frozen character. There are many methods in use now in Alaska, and these are described in detail. The estimates of cost include not only labor, machinery, and arrangements of water supply, but also freight transportation and road-building. E. W. S.

Tertiary Lignite of Brandon, Vermont, and its Fossils. By G. H. PERKINS. (Bulletin of the Geological Society of America, Vol. XVI, pp. 499–516; plates 86–87; December, 1905.)

No trace of animal life appears in this lignite, but there are abundant plant remains. Exogenous trees are unusually well represented. Leaves, fruits, and bark show many of them to belong to existing genera. The age of the formation has not yet been determined. The author believes it is Miocene. E. W. S.

Sixth Annual Report of the Chief of the Mining Bureau (Philippine Islands). By H. D. McCASKEY, Chief of the Mining Bureau, Manila, 1905. Pp. 66, 14 plates and map.

This report treats of the work of the year and of the mineral resources and mining conditions of the Philippines. American machinery and methods have done much in the development of the mining industry. The deposits are those of gold, copper, iron, and coal. E. W. S.

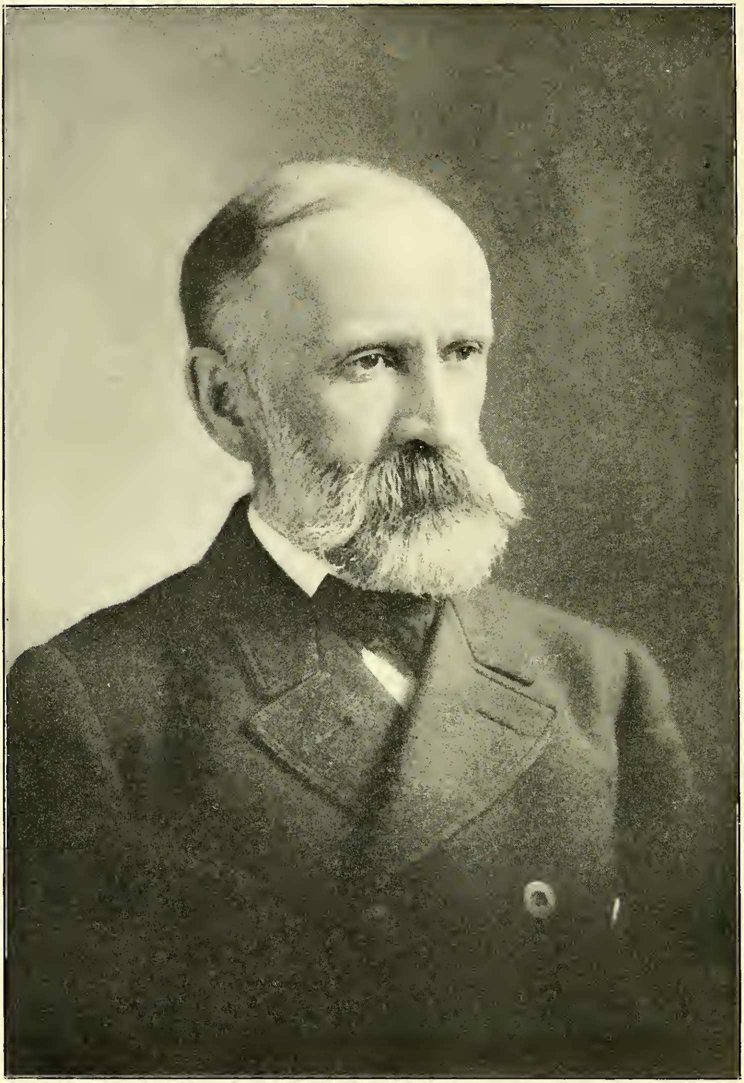
On the Glaciation of Oxford and Sutton Mountains, Quebec. By ALFRED W. G. WILSON. (Extract from *American Journal of Science*, Vol. XXI [March, 1906], pp. 196–205; 5 figures.

The upward limit of glaciation in Eastern Quebec has been put as low as 1,800 feet above sea-level by some writers. Mr Wilson finds that the highest elevations of the region are glaciated. This puts the upward limit at least as high as 2,820 feet. E. W. S.

Mineral Solution and Fusion Under High Temperatures and Pressures. By Arthur L. Day. (Carnegie Institution of Washington, extracted from Fourth Year Book, pp. 224–30.)

After a statement of the new equipment of the laboratory, the results of experiments with feldspars and pyroxenes is given, and the paper closes with a brief description of the author's visit to European laboratories.

E. W. S.



ISRAEL COOK RUSSELL

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ISRAEL COOK RUSSELL
1852–1906

G. K. GILBERT

The subject of this sketch was known to the world as an investigator, explorer, writer, and teacher, in the fields of geology and geography. He was descended from New England stock; his beginnings were simple; his development followed the usual lines of the American professional man; and, apart from his scientific work, the course of his life was not eventful. The end came abruptly, and seemingly at the zenith of his activity.

He was the son of Barnabas and Louisa Sherman (Cook) Russell, and was born near Garratsville, N. Y., on December 10, 1852. His home was at Garrattsville till he was twelve years old and was afterward at Plainfield, N. J. His education included preparatory studies at the Rural High School, Clinton, N. Y., and Hasbrook Institute, Jersey City, a college course at the University of the City of New York (B.S. and C.E., 1872), and a postgraduate course at the Columbia School of Mines.

In 1874 he was a member of the United States Transit of Venus Expedition, visiting New Zealand and Kerguelen Island, and making observations which were the basis of his first publications on natural history. As the arrangements for the expedition made no provision for work in natural history, he sought and obtained an appointment as photographer, qualifying himself therefor by a hurried course of study under Rutherfurd, and incidentally acquiring photographic skill that was afterward of service in physiographic and exploratory work. On his return he became assistant professor of geology in the School of Mines, where he remained two years. In 1878 he accompanied Professor J. J. Stevenson in geologic exploration in New Mexico under the auspices of the Wheeler Survey; and the following year was spent in European travel.

My own association with him began in 1880, when he became a member of the United States Geological Survey and was assigned to my corps—the Division of the Great Basin—then engaged in the study of the Quaternary lake Bonneville. After a year of subsidiary duty he was given independent work, investigating the Quaternary histories of a series of desert basins in northern Nevada and adjacent parts of California and Oregon. To these and cognate studies he gave four years, his results being embodied in an important series of reports, which gave him assured status both in this country and abroad. The duties next assigned him were much less congenial, and I think he always regarded the three years given to them as nearly wasted. They comprised the detailed study and mapping of Paleozoic formations in the southern part of the Appalachian area, and, later, a general investigation of the Jura-Trias formations of the United States. The scope of the latter work was afterward reduced, and he finally reported only on the Newark formation.

The field of research most attractive to him, and the one to which his whole life would doubtless have been devoted, had circumstances favored, was geographic exploration. It was also a field for which he was peculiarly fitted. In 1889 he sought and obtained permission to accompany, as representative of the Geological Survey, an expedition sent by the Coast and Geodetic Survey to establish a portion of the eastern boundary of northern Alaska. He ascended the Yukon River to the neighborhood of the boundary, and then in early winter crossed the mountains southward to the head of Lynn Canal, whence he returned by sea. With continued assistance of the Coast Survey, and under the joint auspices of the Geological Survey and the National Geographic Society, he spent the two succeeding summers in exploring the slopes of Mount St. Elias and the region about Yakutat Bay.

In 1892 he was elected to the chair of Geology in the University of Michigan, filling the vacancy created by the death of Alexander Winchell; and he retained this position for the remainder of his life. As a teacher he concerned himself chiefly with the instruction of undergraduates, reserving a considerable share of his time and energy for other activities. Most of the summers were occupied by geologic field-work, chiefly under the auspices of the United States Geological Survey; and winter leisure was devoted to literary work. A few of the out-of-door studies were in Michigan and near his home, but the greater number were in the mountains and valleys of Washington and Oregon, and one was in the West Indies during the eruption of Pelée. The literary output, in addition to reports on summer work, comprised five semi-popular volumes and a large number of scientific essays.

A few lines will complete the statistical record of his life. He was married in 1886 to Miss J. Augusta Olmsted; and is survived by his wife and family—three daughters and a son. The honorary degree of Doctor of Laws was conferred on him by his alma mater and by the University of Wisconsin. Geographers have signalized his eminence in Alaskan exploration by naming a glacier and a fiord in his honor. He was a member of many professional and learned societies, served as vice-president of the American Association for the Advancement of Science and as president of the Michigan Academy of Science, and at the time of his death was president of the Geological Society of America. He was an associate editor of the *Journal of Geology*. A list of his published writings compiled by the librarian of the University of Michigan comprises 124 entries, to which are added the titles of five unpublished manuscripts. One of the latter—"Concentration as a Geological Principle"—was to have been used, after revision, as his presidential address to the Geological Society. Another, a report on the surface geology of three counties of Michigan, had been transmitted to the state Geologist for publication. Of the published writings seven are books, thirty are treatises of importance or reports of considerable extent, fifty contain minor contributions to scientific knowledge or discussion, and eighteen are to be classed as contributions to the popularization of science.

His more important additions to knowledge are in the fields of descriptive geology, dynamic geology, and physical geography. He described the Newark formation in New Jersey and Virginia, the Quaternary lakes of the northwestern part of the Great Basin, the recent faults and block mountains of part of the same region, and the surface geology or general geology of various areas in Washington, Oregon, Idaho, Utah, Michigan, and Alaska. He wrote on the origin of the red color of certain sedimentary formations. He discussed the nature of massive solid eruptions, and proposed a genetic classification of igneous intrusions. He studied and described glaciers in the Cascade region and Sierra Nevada, and about Mount St. Elias, Yakutat Bay, and Glacier Bay; discussed cirques, and the influence of incorporated débris on glacial flow; and added to the nomenclature of glaciers the now familiar term "piedmont." He treated of the genesis of tundras and the natural history of playas, playa lakes, and playa deposits.

His wide range of first-hand knowledge abundantly qualified him for five works involving extensive compilation, and his simple and attractive literary style made them acceptable to a wide range of readers. Four of these pertain severally to the rivers, lakes, glaciers, and volcanoes of North America, and are called "reading lessons for students of geography and geology;" the fifth is a general treatise on the geography of the continent; and all are recognized as standard works.

Russell was pre-eminently a scientific observer. His best work was in seeing, recording, and discussing the phenomena of a new field. His observation was sharpened by knowledge of existing theories, but not biased by them. He was not a theorist seeking confirmatory facts, but an observer seeking explanations of the thing seen. His contributions to the body of scientific philosophy were many, but were not of the broadest scope, because they were largely restricted to the field of his own observation. His contribution to the body of scientific fact was exceptionally large, primarily because he was keen, energetic, and industrious, but also because he was content with immediate explanations and did not delay publication to search for the broadest generalizations. By promptness in publication he doubtless incorporated some errors of interpretation which might have been avoided by a more conservative practice, but he also enlarged his output of permanently valuable material and avoided the reproach of resultless effort.

In personal character he was of sterling quality, simple and unassuming. His manner was quiet, and he often seemed diffident, although he did not actually lack self-confidence. In lecturing he held his audience rather by the interest of his subject than by vigor of presentation. His conversation was not aggressive, but was distinguished by occasional bits of humor, spontaneous, sudden and peculiarly apt, so that his *bon mot* was not rarely the remembered gem of a social evening. Of medium height and rather slightly framed, his physique gave to the eye little suggestion of that capacity for sustained effort and endurance without which his more strenuous exploration would have been impossible.

ON THE SO-CALLED "POSTGLACIAL FORMATIONS" OF SCOTLAND

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The purpose of this paper is to pass in review the several geographical and climatic changes which followed on the disappearance of the last very considerable snow-fields and glaciers from the Scottish mountains. Three well-marked stages in the glaciation of our country are readily recognized. The earliest of these is represented by the widespread ground-moraine long known here as our "Lower Bowlder Clay." This deposit was laid down during the epoch of maximum glaciation, when the whole country—mainland and islands alike—lay buried underneath one vast ice-sheet, which extended south as far as the valley of the Thames. The succeeding stage is evidenced by our "Upper Bowlder Clay"—a deposit of the same general character and origin as the lower ground-moraine. The ice-sheet underneath which it accumulated, however, did not flow so far southward as its predecessor. It seems, indeed, to have barely reached the midlands of England. Nevertheless, Scotland was as broadly covered by this ice-sheet as by that of the earlier epoch. The next stage of glaciation was marked by the presence of district ice-sheets and large valley-glaciers in our Highlands and Southern Uplands, and by less imposing snow-fields and glaciers in the mountainous parts of England, Wales, and Ireland. This stage is represented by local accumulations of bowlder-clay, terminal moraines, and sheets of torrential gravels.

There has always been considerable doubt among geologists as to where we should draw the line between glacial and postglacial deposits. Nor is this strange when we reflect that glacial conditions must have lingered longer in some regions than in others. The valley moraines of the Scottish Highlands, for example, belong to a much later stage than the "chalky bowlder-clay" of the Thames

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[1] The substance of a lecture given to the Scottish Natural History Society, June 7, 1906.

valley. The deposits overlying that bowlder-clay have nevertheless been classified as *postglacial*, although it is obvious that they must be of much greater antiquity than the alluvia and peat resting upon the valley moraines and fluvio-glacial accumulations of our district ice-sheets in Scotland. The fact is, the term "postglacial" is quite misleading, and ought never to appear in any general classification of formations.

Continued research in Europe, America, and Asia has demonstrated that the so-called Ice Age was not one long uninterrupted period of glacial conditions, but an extensive cycle of alternating cold and genial conditions, which commenced before the close of Pliocene times and endured down to the very dawn of the present. I believe, therefore, that the upper members of the Pliocene system will before long be included in the Pleistocene, and that the latter will embrace all the glacial and interglacial stages. In a word, the term "Pleistocene" will eventually cover every accumulation formed during the great cycle of alternating climatic conditions. This being so, it will certainly include most of the deposits which in our and other glaciated regions are commonly termed *postglacial.*

For the present, however, let us consider the epoch of the "District Ice-Sheets and Mountain-Valley Glaciers," to be the closing phase of the Ice Age in Scotland, and proceed to inquire into the history revealed by the co-called "postglacial deposits" of our country. The most representative of these accumulations are our *raised beaches*, *estuarine* and *fluviatile terraces*, *lacustrine alluvia*, and *peat-mosses.*

RAISED BEACHES, ETC.

At least three well-marked raised beaches are visible at many places upon our coastlands. Of these the oldest occurs at a height of 100 to 135 feet above the present sea-level. There can be no doubt that this beach belongs to the true glacial series, and I only refer to it in this place because the phenomena connected with it are similar in many respects to those associated with some of the younger "postglacial" raised beaches. In the great valleys of the Forth and Tay, for example, it forms extensive terraces, which, as they are followed inland, gradually rise to higher and higher levels and merge into fluvio-glacial gravels, while these last eventually become associated with large terminal moraines. In short, the beach in question belongs to that stage of the Ice Age which I have termed the epoch of "District Ice-Sheets and Mountain-Valley Glaciers." During that stage our Highland fiords or sea lochs were invaded by great glaciers, and in their upper reaches we look in vain therefore for any trace of the 100 foot beach. At their lower ends, however, and on the open coast between adjacent sea lochs, the beach is frequently conspicuous. We can thus readily picture to ourselves the general aspect of Scotland at that time. The sea, with its arctic fauna, covered such of our present low grounds as do not exceed 130 feet in height or thereabout. Our estuaries were in winter largely frozen over, while in spring and early summer the ice, broken up into flows, often ran aground in shallow water—contorting and confusing the marine sediments in course of formation. Many erratics were by the same agency distributed over the floor of the sea. A continuous snow-cap covered the Highlands, from which large glaciers descended in many places to the coast, where they calved their icebergs—another fruitful source of erratics. In the Southern Uplands very considerable ice-streams likewise existed —some of which were of such extent that they escaped from their mountain valleys and deployed upon the low ground beyond, but none reached the seacoast. The central lowlands were at this time clothed with a truly arctic flora—among the characteristic plants being various northern willows (*Salix polaris*, *S. herbacea*, *S. reticulata*), dwarf birch (*Betula nana*), mountain avens (*Dryas octopetala*), etc. Associated with these arctic plants in the lacustrine deposits of the time *Apus glacialis* occurs in great abundance. As this phyllopod is now met with only in fresh-water lakes in Greenland and Spitzbergen, its presence in the ancient alluvia of central Scotland tells a plain tale.

All the deposits belonging to this stage, therefore—glacial, fluvio-glacial, lacustrine, and marine alike—we are justified in assigning to the Ice Age, and we may provisionally consider them as representing its closing phase.

The next succeeding raised beach is met with at a height of 45–50 feet above the present sea-level. Like its predecessor (the 100 foot beach), it is best developed in our great estuarine valleys—as those of the Tay, the Forth, and the Clyde. Usually it assumes the form of well-marked terraces of gravel, sand, clay, and silt; but on the more open seacoasts it is not infrequently represented by ledges or benches cut in the solid rock. Most of the shells, etc., which it contains belong to still indigenous species.

Obviously a considerable interval of time separated the formation of these two raised beaches. Before the 45–50 foot beach began to be formed, the characteristic arctic species of the older beach had disappeared from our coasts. Further, there is evidence to show that after the 100 foot beach had been lifted out of the water, it was for a lengthy period subjected to severe erosion—more especially in our estuarine valleys. Moreover, it is quite clear that this erosion was effected by rain and rivers when the land stood at a relatively higher level than it does today, and at a date long prior to the formation of the 45–50 foot beach. In the valleys of the Tay and Earn, for example, the accumulations of the 100 foot beach have been extensively trenched and swept away from broad tracts, so that they now form terraces, the bluffs of which overlook the later carse deposits of the 45–50 foot beach. That the erosion referred to was not the work of the sea in which these younger estuarine beds were formed is proved by the simple fact that the latter do not rest directly upon the denuded deposits of the 100 foot beach. On the contrary, they are separated from these by a widespread sheet of peat, and this is directly underlain by river silt, clay, sand, and gravel.

It is clear, then, that the latest stage of the Glacial Period was accompanied or followed by a change in the relative level of land and sea. The sea retreated to a lower level than the present, while rivers plowed their way down through the deposits of the 100 foot beach, and in time formed broad alluvial flats which were overlooked on either side by the bluffs and terraces of the denuded shelly clays. By and by these younger "haugh-lands" were overspread with dense vegetation—the general character of which betokens a climate not less temperate than the present—the dominant species of trees being oak, alder, hazel, birch, etc. This old land-surface is now represented, as I have already mentioned, by a thick bed of peat—the rootlets of trees and other plants penetrating the underlying fluviatile deposits.

The deposits of the 45–50 foot beach immediately covering the peat are crowded, especially toward the base, with leaves, branches, and twigs of the trees just mentioned. When these estuarine accumulations are followed up the Tay valley, they gradually become more and more arenaceous, until eventually they merge into ordinary river alluvia—the materials of which become increasingly coarser as they approach the mountains.

It is worthy of note that the 45–50 foot beach often fails to appear at the heads of particular fiords in the west Highlands, although it may be well developed in their lower reaches. This is explained by supposing that glaciers may have occupied the upper ends of such fiords during the depression of the land—an inference much strengthened by the fact that at the head of Loch Torridon, where the beach in question is well seen, it is capped by conspicuous terminal moraines. This evidence, so far as it goes, leads to the conclusion that the more important phenomena characteristic of the 100 foot beach, were repeated—but on a smaller scale, and in a less pronounced degree—in the case of the 45–50 foot beach. In a word, we are forced to believe that during the formation of the latter snow-fields and glaciers existed in the Highlands.

The latest conspicuous raised beach is that occurring at an average level of 25 to 30 feet above the sea. The only shells it has yielded belong to still indigenous species. Nowhere, so far as known, do the deposits of this beach merge inland into fluvio-glacial gravels, nor does the beach appear to be anywhere associated with moraines. It frequently contains drifted stools and trunks of pine and other trees of large size. Now and again also we find it resting directly upon peat with trunks and stools of trees rooted in an underlying soil. It is often hard to say, however, whether these ancient land-surfaces may not sometimes be on the same geological horizon as the peat that underlies the deposits of the 45–50 foot beach.

PEAT-MOSSES

Postponing for the present any further remarks on the evidence supplied by our so-called postglacial raised beaches, I would shortly direct attention to certain other accumulations, which indubitably belong to later times than the closing stage of the Glacial Period, as heretofore defined. I refer to our peat-mosses. Everyone is familiar with the fact that in and underneath these the relics of forest vegetation frequently occur. In many places throughout Scotland—as well in high grounds as in low grounds—the peat-mosses cover at least two ancient forest-beds. Typically the older forest-bed occurs at the base of the peat, while the younger tier of trees rests upon, and is covered by, a variable thickness of peat. In some bogs only a foot or two may separate the forest-beds, while elsewhere the intervening peat may attain a thickness of many yards. So far back as 1866 I endeavored to show that the very general occurrence of these phenomena was indicative of climatic changes.[1] The forest-beds, I maintained, were the products of relatively dry or continental conditions, while the intervening and overlying sheets of peat indicated colder and wetter conditions. I further pointed out that at the present time all our peat-mosses are more or less rapidly decaying, and being denuded by rain and wind—that, although peat is now forming here and there under favorable conditions, still that this is exceptional—the rate of growth being generally much exceeded by the rate of decay and removal. From this striking fact I inferred that the climate of Scotland has become drier since the formation of the peat overlying our upper forest-bed.

The earlier writers on the origin of the Scottish peat with its buried trees did not recognize the influence of climatic changes in the destruction of the old forests and their subsequent entombment in peat. According to them, the formation of the peat-bogs was due to the overthrow of the forests, chiefly by man's hand, but also perhaps by natural causes, such as tempestuous wind. The wholesale downfall of the forests, it was believed, had obstructed the natural drainage of the land, and thus induced marshy conditions favorable to the growth of sphagnum and its allies. More recently it has been suggested by some writers that in certain cases the drainage may have been interrupted by the heaping-up of banks of sand, clay, or other superficial accumulations, across broad valleys, whereby the forests over wide areas may have been destroyed by stagnant water, and thus have given rise to the formation of bogs. This is a somewhat far-fetched explanation. If it had any evidence

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[1] *Transactions of the Royal Society of Edinburgh*, Vol. XXIV (1866), p. 363.

in its favor, this should not be hard to recognize. Where, one might ask, are those convenient bars or banks behind which the stagnant water is supposed to have accumulated?

That none of these explanations can be accepted as sufficient to account for the phenomena of our peat-bogs in general is shown by the mere fact that the buried forests are not confined to the peat of lowlying and gently undulating ground—to situations, namely, where the drainage might possibly have been disturbed by one or other of the causes suggested. On the contrary, they occur just as constantly in the peat covering mountain slopes and hilltops, where owing to the form of the ground, interruptions of the drainage could not possibly take place. Moreover, the nearly constant occurrence, throughout the peat of low grounds and high grounds alike, of at least two buried forests, obviously points to the operation of some widely acting recurrent cause.

Conclusions similar to mine were subsequently advocated by the late Professor Blytt, who, after a careful study of the peat-mosses of Norway, was convinced that these gave evidence of a well-marked alternation of wet and relatively dry climatic conditions having obtained after the low grounds of that country had been vacated by the great inland ice of the Glacial Period.[1] I need only add that the phenomena of successive "buried forests" have long been recognized almost everywhere in the peat-bogs of northern and northwest Europe. The occurrence of these trees, however, has been variously interpreted—some authors upholding views that are practically the same as those I ventured to set forth so many years ago, while others would attribute the origin of the peat-mosses to the overthrow of the trees by the various causes already referred to.

When we come to inquire into the relation of our Scottish peat-mosses to the glacial deposits, we have no difficulty in discovering that they are of later date than the epoch of "District Ice-Sheets and Mountain-Valley Glaciers." This is proved by the fact that the peat with its buried trees overspreads the fluvio-glacial gravels and moraines of that epoch. It would appear, then, that the oldest of our inland peat-mosses occupy the same geological horizon as

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[1] *Essay on the Immigration of the Norwegian Flora during Alternating Rainy and Dry Periods*, 1876.

the peat and alluvia which have been referred to as underlying the deposits of the 45–50 foot beach, and which, as we have seen, rest upon the denuded deposits of the 100 foot beach. It is thus hardly possible to escape the conclusion that the ancient land-surface buried under the carse clays of the 45–50 foot beach is contemporaneous with the lower forest-bed of our inland peat-mosses. This, as I believe, gives us the key to the history of all the later climatic and geographical changes experienced by our country.

Summing up the evidence, we may recognize the following succession of events in the history of postglacial Scotland:

1. After the District Ice-Sheets and Mountain-Valley Glaciers had disappeared, the land gained in extent—the sea eventually retreating considerably beyond the present coast-line. The climate at the same time gradually improved, until genial conditions supervened and a strong forest growth covered the low grounds, and extended upward to elevations which trees in our country no longer attain. The relics of that great forest epoch we find in the Lower Forest Zone of our peat-mosses.

2. Next followed partial subsidence of the land, accompanied before long by a relapse to cold conditions. Snow-fields now reappeared, and considerable glaciers descended our mountain valleys and in some places reached the sea. The climate was wet and ungenial—the forests decayed, and bog-mosses gradually usurped their place. To this stage we assign the Lower Peat of our inland "mosses," and the 45–50 foot beach, as well as certain moraines and fluvio-glacial gravels.

3. The succeeding stage was characterized by re-elevation of the land, and the retreat of the sea beyond the present coast line. But the land was probably not so extensive as during the preceding forest epoch. This geographical change was marked by the disappearance of perennial snow and ice, and by a return to dry, genial conditions, apparently similar to those that formerly obtained. Forests again clothed the land—flourishing in many places over the surface of the now desiccated peat-mosses. This stage is represented by the Upper Forest Zone of our inland peat, and by the trees which occur under the deposits of the 25–30 foot beach.

4. Once more partial subsidence ensued, and the climate again

became somewhat cold and wet. Over wide areas the forests, as before, began to decay, and were eventually buried under the rapidly extending peat-mosses. We cannot actually demonstrate that snow-fields and glaciers reappeared at this stage. The latest beach we are able to correlate with the upper peat, but that beach is nowhere associated with moraines or glacial gravels. Nevertheless, we are not without evidence suggestive of the appearance at this time of inconsiderable glaciers among our highest mountains. The small glaciers referred to undoubtedly belong to a later date than the glaciers that dropped their moraines on the 45–50 foot beach. It is therefore not unreasonable to infer that our high-level corrie glaciers may have been contemporaneous with the formation of the 25–30 foot beach, and the Upper Peat of our inland "mosses." But the chief evidence of cold, wet conditions is unquestionably that furnished by the Upper Peat itself. It covers the Upper Forest Zone in precisely the same way as the Lower Peat overlies the Lower Forest Zone.

5. The final stage witnessed the retreat of the sea to its present level. The climate now became drier, and peat-mosses ceased to flourish as they had done in the immediately preceding epoch. Thus the final phase of postglacial history may be said to be characterized especially by the general decay and denudation of our peat-mosses—the vegetation growing upon which is almost invariably of a drier type than that found in the immediately underlying peat itself.

Did space permit, I might follow other lines of evidence, all leading to the conclusion that oscillations of climate marked the closing stages of Pleistocene times. For example, the phenomena presented by the alluvial terraces of our larger river valleys might be referred to. It would not be hard to show that, during the so-called "postglacial" period, our rivers have at some stages been most active as eroding agents, while at other stages their chief work has been the transportation and deposition of sediment. During genial epochs, when the land stood at a higher level than now, our rivers busied themselves especially in deepening and widening their courses—in trying to sweep away the glacial and fluvio-glacial detritus with which their valleys had been so largely choked. During cold, wet epochs the land was depressed below its present level, and the larger rivers were then chiefly engaged in filling up the lower reaches of their valleys with the abundant sediment brought to them by their active tributaries. In a word, epochs of dominant erosion alternated with epochs of prevalent deposition.

I might also cite, in support of my general conclusions, certain facts relating to the present and past geographical distribution of animals and plants. The appearance, for example, in the North Atlantic, of isolated colonies of southern types of molluscs, surrounded on all sides by boreal and cold-temperate forms; and the occurrence now and again of similar no longer indigenous molluscs in the raised beaches of Nova Scotia, Greenland, Spitzbergen, and Scandinavia, are all alike strongly suggestive of warmer conditions having at a very recent period characterized the North Atlantic. Quite in keeping with these phenomena is the fact that the beaches in question are often crowded with southern types which, although still lingering on in these northern seas, do not now attain so large a size as their postglacial predecessors, while they are obviously much less abundant.

But these, and other lines of evidence, suggested especially by the geographical distribution of plants in temperate Europe, cannot be considered at present.

Although the proofs of alternating genial and ungenial climates supplied by our peat-mosses seem to me too strong to be resisted—fortified as they are by the evidence yielded by our raised beaches and recent morainic accumulations—I have yet long felt that they would probably be still further confirmed if our peat-mosses were subjected to a thorough examination by competent botanists. I could not doubt that a careful study of the constituents of our peat-mosses would throw light on the changing character of the climate during the period of their accumulation. It was obvious, even to me who am no expert in botany, that peat was composed of other plants than the bog-moss—in many sections I could see what appeared to be a succession of layers made up of the remains of different kinds of plants. And often have I regretted the botanical ignorance which forbade any attempt on my part to interpret what that succession meant—that it had some interesting tale to tell I did not doubt. Fortunately the work of interpretation has at last been taken up by an accomplished botanist. Mr. Francis J. Lewis, of the University of Liverpool, has during the last few years subjected our peat-mosses to a careful examination, with results that are sufficiently striking. His work is not yet completed, but he has already studied the peat of our Southern Uplands, and carried on similar researches throughout wide areas in the Highlands. The data now collected have convinced him that a definite succession of plants everywhere characterizes the Scottish peat: and he confirms the view of alternating climatic conditions which I formulated forty years ago.

The Southern Uplands is the general term applied to that belt of hilly and mountainous country which extends from the coasts of South Ayrshire and Wigtonshire to the high grounds that terminate on the east coast between the valleys of the Tweed and the Tyne. Throughout this broad tract peat-mosses abound—large areas of the higher grounds being of a dominantly moorland character. Nowhere are the peat-mosses better developed than in the mountainous district of Merrick, in Galloway, and in the lofty region in which the river Tweed takes its rise. To these two typical areas Mr. Lewis has devoted special attention, and the results of his observations have already been published.[1] In both districts the peat-mosses bear the same relation to the glacial and fluvio-glacial deposits —they everywhere overlie the moraines and morainic detritus of our "District Ice-Sheets and Mountain-Valley Glaciers."

The first well-marked zone at the base of the peat in the Southern Uplands is a solid layer of the remains of white birch (*Betula alba*), mixed with such plants as heather (*Calluna vulgaris*), and willow (*Salix repens*). Mr. Lewis thinks it is hardly possible that this zone represents the primitive vegetation which covered the Uplands immediately after the disappearance of glacial conditions. The first-comers would naturally be arctic types, the preservation of which, however, would entirely depend upon climatic and local conditions. In the Merrick District Mr. Lewis observed that in many places a thin layer of peat occurred immediately underneath the birch zone, but unfortunately the material was in too decomposed a condition to allow of the identification of any particular

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[1] "The Plant Remains in the Scottish Peat-Mosses; Part I: The Scottish Southern Uplands," *Transactions of the Royal Society of Edinburgh*, Vol. XLI (1905), p. 699.

plants. It is quite possible, he thinks, that the structureless peat referred to may represent the primitive vegetation of the district.[1] I may remark that similar structureless peat not infrequently underlies the lower forest-zone in the peat-bogs of Scandinavia.

The birch zone is directly overlain by a thick stratum of peat, composed entirely of bog-moss (sphagnum). This succession is constantly repeated throughout the Southern Uplands—alike in the peat at the bottoms of valleys, and in that upon steep hillsides and flat hilltops. The sphagnum bed thus bears witness to a general increase of precipitation—it represents, in short, a change from birch-forest conditions to wet moorland.

As successive layers of the peat are followed upward, Mr. Lewis finds that the bog-moss gradually gives place to cotton-grass (*Eriophorum vaginatum*) and rushes (*Scirpus*). After these plants had flourished for some considerable time, a decided change of climate supervened. In the Merrick district the cotton-grass peat is covered by a dense layer of the stems of crowberry (*Empetrum nigrum*), and two characteristic Arctic willows (*Salix herbacea* and *S. reticulata*). The same zone is represented in the peat of Tweedsmuir by the crowberry, and the creeping azalea (*Loiseleuria procumbens*)—the latter being a typical Arctic form. The constant appearance of this remarkable zone throughout the Southern Uplands can have only one meaning—it points unmistakably to a decided decrease of temperature. It indicates a stage during which the valleys of Southern Scotland were characterized by a climate as rigorous as that now experienced on the summits of our loftiest mountains.

The gradual dying-away of this cold epoch, and the reappearance of forest vegetation, are, according to Mr. Lewis, faithfully chronicled by the peat. The crowberry, the arctic willows, and the creeping azalea give place above to cotton-grass, and this in its turn to bog-moss or sphagnum—a succession common to the peat throughout the Southern Uplands. Eventually the wet moorland conditions indicated by the sphagnum peat passed away; the bogs dried up, and were invaded by trees—by forests of pine in the Merrick district and forests of white birch in Tweedsmuir.

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[1] The evidence wanting at the base of the peat is supplied by the lacustrine alluvia of the central Lowlands already referred to. See p. 5.

Finally, the conditions again became adverse to forest growth, and the trees of this Upper Zone were gradually buried under a stratum of peat, consisting chiefly of rushes, bog-moss, and cotton-grass.

In comparing the peat-mosses of the Southern Uplands with those of the Northern Highlands, Mr. Lewis finds that the latter begin their history at a later stage than the former. At high levels in the highlands none of the beds underlying the zone of arctic plants in the Southern Uplands puts in an appearance. The reason for this is obvious. The recurrence of cold conditions, indicated by the arctic plants of the Southern Uplands, was more strongly marked in the Northern Highlands. In those elevated regions considerable snow-fields and glaciers reappeared, and all peat-beds representing the lower forest zone of southern Scotland were swept away. As these glaciers in the north began to retreat, a tundra vegetation invaded the formerly glaciated tracts. Arctic willows (*Salix reticulata and S. herbacea*) at first were dominant forms, but these gradually gave place to subarctic types (*Salix Arbuscula*, *Betula nana*, *Empetrum nigrum*, etc.). By and by this subarctic brush-wood disappeared, and was succeeded by a close growth of cotton-grass and bog-moss, interspersed with some scraggy birch. That the climate eventually became more humid is suggested by the fact that the birch in its turn vanished, and sphagnum alone continued for a long time to occupy the ground. These wet moorland conditions next passed away—the thick sphagnum peat drying up, and eventually supporting a forest of large pines, with an undergrowth of common heather. The great pine forests of this Upper Zone, it may be mentioned, flourished at elevations between 2,000 and 3,000 feet above the present sea-level. Finally they decayed, and were gradually buried under peat consisting chiefly of bog-moss and rushes.

My limits will not allow me to enter into other interesting evidence adduced by Mr. Lewis. I may just mention, however, that he finds everywhere evidence that existing conditions no longer favor the general growth of peat. On hilltop, hillside, and in upland valleys alike, the peat, he says, is almost without exception being rapidly wasted away. The vegetation at present covering the peat is nearly always of a drier type than that occurring at slightly greater depths—a fact, he remarks, not without its bearing upon the present denuded state of the "mosses."

From this brief and imperfect summary of the results obtained by Mr. Lewis, it will be admitted that the geological evidence of climatic changes in so-called postglacial times has been decidedly strengthened. It is most satisfactory to learn that a definite zone of arctic plants is intercalated in the peat separating the lower from the upper forest-bed. The occurrence of these plants midway between the two forest zones, and the succession of plant remains in the peat-beds immediately overlying and underlying the zone of arctic plants, all point to a gradual change from dry forest to wet moorland, and from wet moorland to cold tundra, and again from cold tundra to wet moorland, and from the latter to dry forest.

In the peat overlying the Upper Forest zone no trace of arctic plants has been met with. Mr. Lewis thinks it is possible, however, that these may yet be detected in those high-level peat-mosses which were formed contemporaneously with the moraines of the youngest corrie glaciers. It may be so; but I doubt whether the wet and relatively cold conditions indicated by the high-level corrie moraines, and the peat which covers the Upper Forest zone, were sufficiently pronounced to induce any conspicuous modification of the flora. All we can infer is that the climate was inclement enough to check forest growth, and to favor the increase of the bog-moss and its allies. The temperature, however, need not have differed greatly from the present. Only a slight lowering of the present temperature, with a corresponding small increase of precipitation, would cover our highest mountains with perennial snow-caps and reproduce their corrie glaciers.

The various superficial accumulations which have formed the subject of this address are usually classified as *postglacial*. But as they obviously carry on the story revealed by the older glacial and interglacial deposits, they ought not, in my opinion, to be separated from these. They form the concluding chapters of the history of Pleistocene times. That great cycle of climatic oscillations which commenced before the close of the Pliocene period and reached down to the dawn of the present, forms one of the most remarkable episodes of the past, and ought to be recognized in our classification as constituting a distinct division of time. By refusing to do so, and including the Weybourn Crag, the Cromer Forest bed, etc., in the Pliocene, we cut off from the Pleistocene the earliest recognizable glacial and interglacial epochs; and we similarly separate from the great cycle its closing phases when we classify these as postglacial. So far as temperate Europe is concerned, it is only the *present* which is postglacial.

How many climatic oscillations may eventually be included in the so-called glacial period we cannot tell. If we confine attention to such glacial and interglacial stages as are actually known, it would seem that the climax of each phase was attained in early Pleistocene times. After that climax was passed, each successive glacial and interglacial epoch declined in importance—the contrast between the two phases gradually became less pronounced. Interglacial conditions reached their maximum with the advent in our latitude of the great southern pachyderms—hippopotamus, elephant, and others—and died out with the Upper Forest Zone of our peat-mosses. Glacial conditions culminated with the appearance of the enormous ice-sheet of the Saxonian stage, and finally disappeared, so far as Scotland was concerned, with the small isolated snow-fields and diminutive glaciers of our loftiest Highland mountains.

THE THREE PALEOZOIC ICE-AGES OF SOUTH AFRICA

ERNEST H. L. SCHWARZ

When Mr. Rogers and myself commenced the systematic geological survey of Cape Colony in 1896, we had no evidence before us which would allow us definitely to refer to one period of glaciation in the stratigraphical series. Sir Andrew Ramsay's discovery of ice-action on pebbles in the Permian Conglomerates of Great Britain[1] had been discredited, and the failure of the Paleozoic glacial theory in Europe had been taken to mean that it must be a failure in other parts of the world as well; no matter how good the specimens of glaciated bowlders and the photographs of ice-scored floors, or that came home from India, Australia, or South Africa, no one would believe in the Permian Ice Age. I was myself skeptical when I first came to South Africa, and at a meeting in Cape Town, when some of the glaciated Dwyka Conglomerate pebbles were exhibited, assisted in recording the belief that there was in these scratches no satisfactory evidence of ice-action. I have before me at the Albany Museum some earlier bowlders collected by Mr. E. I. Dunn, together with a slab from beneath the till which is scored by ice, and I do not see how any definite opinion can be derived from them alone.

In the field it is different; there the evidence is overwhelming, as I was soon to see when I joined the Geological Survey later on, but the difficulty is to obtain specimens which in themselves show unmistakable signs of ice-action. When, therefore, I was in due time convinced of the glacial origin of the Dwyka Conglomerate, I could not merely record my opinion that the field evidence was satisfactory; I had to produce specimens which would convince headquarters in Cape Town. I sought for specimens of bowlders which were not only characteristically scratched, but were also faceted. I obtained several in the first year showing three or four definite friction-cut planes on each, all bearing several series of parallel grooves, while the remainders

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[1] *Quarterly Journal of the Geological Society,* London, 1855, pp. 185–202; *ibid.,* 1894, p. 463.

of the bowlders were rough and water-worn.[1] The inability of the mind to imagine natural causes for the production of thse facets, other than that which assumes that the foot of a glacier held the bowlders firmly against the floor as the ice moved onward, and ever and again allowed the bowlder to slip and turn slightly, has been sufficient to convert most skeptics to belief in the glacial origin of the Dwyka Conglomerate, and for ten years Mr. Rogers and myself have been slowly converting to this view the travelers who enter the country at Cape Town, culminating in the visit of the British Association last year.

The Dwyka Conglomerate, and its equivalent in Australia and India, is too well known now to require description here, but I have introduced the account of the part which Mr. Rogers and myself played in the elucidation of the problem in order to show the credentials with which we offer evidence of two more glacial periods in South Africa. The evidence of each was discovered by Mr. Rogers; the evidence of one, probably Devonian in age, I have examined in the field;[2] the other is probably Archean, and although I have not seen the glacial beds in place, the specimens which Mr. Rogers has sent me afford ample material for confirming his interpretation.[3]

The rocks of South Africa may be divided into a Pal-Afric and Neo-Afric series, the latter beginning about the close of the Silurian or commencement of the Devonian period, and lasting up to the time of the Kimberley and Stormberg volcanoes, say, to the Jurassic period. The Pal-Afric rocks are pre-Devonian. The resemblance of some of them to the Lake Superior Archean rocks has suggested a like age for them.[4] The enormous displacements they have been

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[1] *Annual Report of the Geological Commission*, 1896 (Cape Town, 1897), p. 28; *ibid.*, 1897 (Cape Town, 1898), p. 41; *ibid.*, 1899 (Cape Town, 1900), p. 13.

[2] A. W. Rogers and E. H. L. Schwarz, "Report on the Cederbergen and Adjoining Country," *Annual Report of the Geological Commission* for 1900 (Cape Town, 1901), p. 79; A. W. Rogers, "On a Glacial Conglomerate in the Table Mountain Sandstone," *Transactions of the South African Philosophical Society*, Vol. XI, pp. 236–42 (Cape Town, 1902); *ibid.*, Vol. XVI, pp. 1–8 (1905).

[3] A. W. Rogers, "The Campbell Rand and Griquatown Series in Hay," *Transactions of the Geological Society of South Africa*, Vol. IX, pp. 1–9 (Johannesburg, 1906).

[4] E. H. L. Schwarz, "The Transvaal Formation in Prieska," *Translations of the Geological Society of South Africa*, Vol. VIII, p. 95 and p. lxiii. (Johannesburg, 1905)

subjected to, the vast extent of the volcanic rocks injected through them, the number of successive periods of vulcanism and the greatness of the unconformities between the several members of the Pal-Afric series, and between it and the Neo-Afric series, all tend to establish a great age for the Pal-Afric rocks. Leaving out the Barberton and Witwatersrand beds, which do not concern us here, the later beds may be classified as follows:

Matsap or Waterberg Series
Ongeluk Volcanic Series
Griquatown or Pretoria Series (with glacial beds).
Campbell Rand Series
Black Reef Series
  Pneil Volcanic Series

Possibly there is a second quartzite series, the Keis series, below these.

The Pal-Afric rocks end on a line running roughly northeast-southwest, south of which they are covered by the Neo-Afric beds. On the northeast and southwest, however, the older rocks bend round to embrace the younger ones round the rim of a basin-shaped depression, and they were probably at one time continued right round the southern limit of the Neo-Afric beds as well. We can, indeed, find some evidence for two lines of older elevation, both of them running northeast-southwest, the more northern of the two following the northern rim of the Karroo, and the more southern one continuing the Madagascar ridge southward along the margin of our coasts. At first there was a sinking where the southern shores of South Africa now lie, and in the comparatively narrow strait thus formed the coarse-grained, intensely false-bedded table mountain sandstone was deposited. A deepening of the basin allowed the settlement of the Bokkeveld beds with their Lower Devonian fossils. Then came the Witteberg quartzites, with Lower Carboniferous plants, the Dwyka, Ecca, Beaufort, and Stormberg beds. We may tabulate the Neo-Afric beds thus:

DRAKENSBERG LAVAS

Stormberg Series	Rhaetic
Beaufort Series	Triassic
Ecca Series	Permo-Triassic
Dwyka Series (with glacial beds)	Carbo-Permian
Witteberg Series	Lower Carboniferous
Bokkeveld Series	Lower Devonian
Table Mountain Series (with glacial beds)	?

The full conformable series is found only on the south; on the north, the series begins with the Dwyka Conglomerate, here a subaërial deposit, which can be followed southward along the rim of the structural basin to where it is essentially a subaqueous deposit, and the Witteberg, Bokkeveld, and Table Mountain beds may be seen coming in successively beneath it. The Stormberg beds, again, are only found in the east.

The Griquatown beds are a highly ferruginous series of shales and slates, sometimes moderately soft and unaltered, when the characteristic color of the whole is blue-black, and the fissures are filled in with blue asbestos or crocidolite. But more often an intense alteration has taken place, and the rocks have become jaspers and quartzites, heavily charged with hematite and magnetite, and the crocidolite has been changed to the quartz pseudomorph, the beautiful honey-yellow tiger eye. Near the top of the series, in the district of Hay, west of Kimberley, there is the well-developed glacial till, the matrix now converted into a red jasper; yet the bowlders of chert, when weathered out, show the unmistakable faceting and scratching which can have been caused only by glacial action. The freshness of the appearance of the ice-scratched bowlders is the more remarkable when one realizes that not only the matrix, but the inclusions as well, have been indurated by metamorphism. The size of the bowlders varies up to two feet, and they are scattered at random through the matrix, to which they bear a very small proportion in regard to bulk; but occasionally there is a small bed of pebbles or coarse grit. Mr. Rogers records at one locality a number of "Dreikanters," but I do not know whether anything additional can be learned from them. I have found them in large numbers in some of the Witwatersrand conglomerates. The whole thickness of the glacial till is probably under 100 feet, but the extent of country covered by it in the area already mapped is over 1,000 square miles.

The Table Mountain sandstone glacial bed is very similar in position and character, though not of course in metamorphism, to the Griquatown one. When the Geological Survey commenced operations, there were two series of quartzites, the Table Mountain and the Witteberg, which had been mixed up, so that, in order to find some way of either distinguishing or definitely joining up the two, I took the two series bed by bed. I found that both series were characterized by a shale band near the top. In the Table Mountain bed, when it became clear that this series underlay the fossiliferous Devonian Bokkeveld beds, I hoped to find some organic remains, and searched some good exposures in Ceres District fairly thoroughly, but I never came across any bowlders in it. It was not till several years afterward that we found the ice-scratched bowlders in the same bed and along the same range of mountains.

The Karroo in the southwest is bordered by ranges of mountains which run east and west along the south, and north and south along the west, meeting in a great knot, perhaps as good an example of Suess's *Schaarung* as exists anywhere. The folds of the southern ranges have been huddled against granite bosses by pressure from the interior, and the rocks have been so compressed that it is hard to distinguish separate beds; on the east, where the granite ends, and the folds have had room to expand seaward, the shale band at the top of the Table Mountain series is again apparent. Owing, however, to the nature of the rock in this band, which allows its more easy disintegration, as compared with the quartzites above and below it, it is, wherever I have seen it, covered with débris, so that I cannot say positively that the glacial beds do not extend eastward, but I do not think they do.

Following the shale band northward of the junction knot of mountains, the rocks composing it consist of soft slates very finely laminated in places. The quartzites above it are about 500 feet thick, while the band of shale perhaps might be put down at 300 feet, the whole Table Mountain series being estimated at 5,000 feet. The mountains soon become exceedingly rough and difficult of access, and the slopes become cumbered with débris. Broadly, the mountains are formed by an S-shaped bend, the anticline on the Karroo side, constituting the Cederberg Range, and the syncline holding in its embrace the valley of the Olifants River. At a certain point in the Cederbergen, the Cape Ceder, *Callitris* (*Widdringtonia*) *juniperoides* is found growing, but not south of this, nor, indeed, anywhere else in the world. Up to this point, from the south, the shale band is not conglomeratic, and in the first road-cutting north of this point the shale band does contain ice-scratched bowlders. As there is no other difference in the nature of the rock north and south of the point, nor is there any difference in the elevation or structure of the mountains, or of the rainfall upon them to account for the cedars stopping at this point, one is left, by the process of elimination, to somehow connect the distribution of the trees with that of the glacial conglomerate.

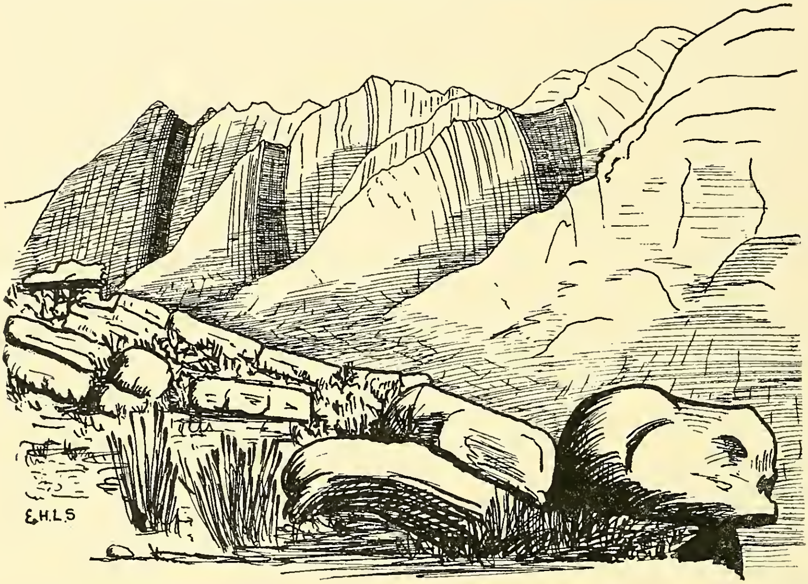

Fig. 1.—The Witzenbergen, from the top of the Schurftebergen, showing the steeply inclined Table Mountain sandstone near the head of the Witzenberg Valley, and the shale band at the top of that rock series. Ceres Division, Cape Colony.

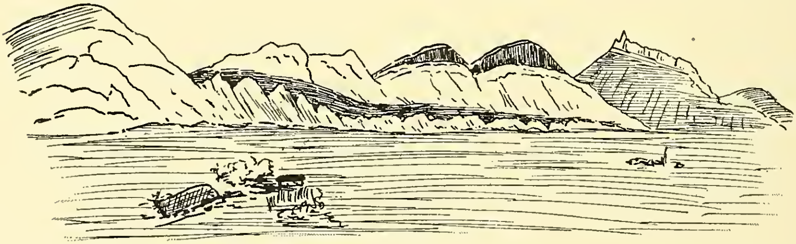

Fig. 2.—The shale band in the Table Mountain sandstone, a little south of where it becomes conglomeratic. The foreground is made of Devonian slates. The reduplication of the shale band is due to a sharp fold, and on the right a sudden change in the strike is seen. The Cold Bottweld, Ceres Division, Cape Colony.

A typical section of the shale band on the Clanwilleain side of the Cederbergen gives:

Shale	200 feet
Shaly conglomerate	20 feet
Conglomerate	100 feet

The conglomerate is a mudstone containing pebbles and bowlders up to fifteen inches in diameter. The latter consist of quartz, three distinct varieties of quartzite, sandstones, felspathic grits, diabase, amygdaloidal melaphyre and granite, and are well faceted, and the closer-grained ones strongly and characteristically scratched. North of Clanwilleain, the Table Mountain sandstone rapidly thins out, and the upper beds one by one drop out till, in Van Rhyn's Dorp, the Dwyka Conglomerate is separated from the Pal-Afric beds by only a few feet of quartzite, and in Bushmanland rests directly upon them. There may be a locality where the Permian glacial beds rest directly on the Devonian ones, but we have not found such a one. Apart from stratigraphical evidence, it would be extremely difficult to separate the two; the only difference we could find—and it amounts to very little—is the presence of quartz pebbles in the Table Mountain conglomerate.

The area of the Devonian glacial beds is uncertain. The actual outcrop from which bowlders have been obtained is 23 miles long, but the ends plunge under débris and are certainly continued north and south. Eastward the limb of the great Cederberg anticline dips under the Karroo beds, so that it is uncertain how far the glacial beds extend in this direction. We find bowlders of Table Mountain sandstone brought up from great depths in the agglomerates in the Sutherland volcanoes, right in the deepest part of the Karroo sinking, but we can naturally see nothing in them which would help us in tracing the glacial beds. On the east, where the Table Mountain sandstone comes again to the surface in Pondoland, we have not been able to trace the shale band, nor have geologists recorded it in Natal.

At some future date it will perhaps be established that there is a rhythmic recurrence of glacial conditions in subtropical and even tropical countries, and we shall be able to date the rock strata according to the positions of these tills. In Australia they have two—the

Permian or Carbo-Permian, and the so-called Cambrian one, which is, at any rate, older than the Ordovician, and possibly Algonkian.[1] We have three in South Africa, the oldest of which may be equivalent to the older of the two Australian ones. The great importance of our two older bowlder clays is that they are not mere chance moraines that have somehow become preserved, and which might have formed on lofty mountain ranges, as moraines now form under the Equator in South America, and therefore are no indication whatever of changes of climate or of the sun's heat. Both our Table Mountain and Griquatown glacial beds occur interstratified with undoubted subaqueous deposits, and themselves show evidence of subaqueous origin. The prevalence of glaciers down to the water's edge in South Africa is undoubted, and both the older, as well as the Permian, conglomerates clearly point to rigorous climatic conditions.

Sir Andrew Ramsay's evidence as to the European Paleozoic Ice Age,[2] and the character of the striations on the stones, is admitted, even by those who do not accept his explanation, to be strongly suggestive, and had Sir Andrew Ramsay stopped at this, his theory, perhaps, by now would have been accepted; but he attempted more. He believed that he could trace the origin of the pebbles and bowlders to the Silurian hills of north Wales, and he concluded that they had been transported by floating ice connected with glaciers which existed among those mountains in the Permian period. It was, however, easily demonstrated that the blocks need not have been transported from afar; the ridge of old Paleozoic and pre-Cambrian rocks which has been exposed in the Charnwood forest area may very well have been the parent source of the inclusions. The breccias, again, instead of becoming coarser nearer the source attributed to them by Sir Andrew Ramsay, as was required by his theory, were found to become so as they were followed to the east and southeast. As far as I can gather, the Paleozoic Ice Age theory in Europe

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[1] W. Howchin and J. W. E. David, *Report of the Australian Association for the Advancement of Science*, Vol. IX (1902), pp. 194–200.

[2] "On the Occurrence of Angular, Sub-angular, Polished and Striated Fragments and Bowlders in the Permian Breccia of Shropshire, Worcestershire, etc., and on the Probable Existence of Glaciers and Icebergs in the Permian Epoch," *Quarterly Journal of the Geological Society*, 1885, p. 185.

has been discredited on the failure of a non-essential feature in the original exposition, and the whole question calls for re-examination. And not only the Permian breccias, but conglomerates and breccias of all ages, even in the zone of intense metamorphism, require to be minutely and critically studied; for, as our South African bowlder clays show, the striae and faceting characteristic of ice-action may be preserved in the most unexpected way.

THE TEXTURE OF IGNEOUS ROCKS

WHITMAN CROSS, J. P. IDDINGS, L. V. PIRSSON, H. S. WASHINGTON

The vagueness that characterizes descriptions and conceptions of textures of igneous rocks is due in part to a lack of systematic treatment of the subject by petrographers, and a consequent inexactness in the terminology by which definite conceptions may be expressed. It is also due to the intricacies of the textures to be described and to their diversity.

The first may be remedied by more systematic consideration of the fundamental factors that make up rock textures, and by the introduction of more definite descriptive terms. The second difficulty can be met by more accurate and detailed descriptions of the complex fabrics, and by the recognition of the more frequently recurring ones as types for reference.

In considering the fundamental factors constituting rock texture it is necessary to begin with the simpler, elemental factors, and also the simpler fabrics; afterwards taking up the more complex and intricate fabrics. This is not the order of the more common first, and subsequently the less frequent fabrics. On the contrary, many of the commonest fabrics are the most intricate and the most difficult to describe. This is probably a reason why the subject has never been satisfactorily developed. A systematic treatment must commence with more or less abstract, general, principles, which eventually may be applied to concrete cases. It is hoped that the following discussion may advance this part of petrography.

Fundamental factors constituting texture in igneous rocks.—Defining *texture* as the material features of rocks exhibited by the mineral components and by the groundmass of dense or glassy rocks, whether they are viewed megascopically or microscopically, it has already been said[1] that these features fall into three categories:

1. *Crystallinity*—the degree of crystallization.
2. *Granularity*—the magnitude of the crystals.

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[1] This *Journal*, Vol. X (1902), p. 611.

3. *Fabric*—the shape and arrangement of the crystalline and non-crystalline parts.

It is proposed to consider further each of these factors in the general constitution of texture separately, in order to determine what characters in each need special recognition and specific descriptive terms.

I. Crystallinity

The degree of crystallization attained by an igneous rock is measured by the relative amounts of crystallized and glassy portions. All degrees of crystallinity are known to exist, from perfectly glassy rocks, through those consisting of glass with more or less crystals, to completely crystalline rocks. The size of the crystals is not involved in the crystallinity, but is a factor in the granularity.

The idea of *complete crystallinity*, as the condition most commonly observed, has a definite term in *holocrystalline*, while the general idea of *partly crystalline* is expressed by *hypocrystalline*. The general idea of *glassiness* is expressed by the terms *vitreous* and *hyaline;* and *partly glassy* is expressed by *hypohyaline*. The term *subvitreous* is commonly employed in describing the luster of some minerals, but has not been applied to rock texture. Completely glassy is expressed by *holohyaline*. There is a term signifying that a rock is evidently crystalline to the unaided eye—*phanerocrystalline*—and one that signifies that its crystalline character can not be recognized by the unaided eye—*aphanitic*.

It would be proper to use the term *phanerohyaline* for rocks whose glassiness is evident to the unaided eye; and the term *phaneric* should be applied to those rock textures that are apparent megascopically, whether crystalline or glassy; just as the term *aphanitic* is used for textures that cannot be discerned by the naked eye, whether crystalline or glassy. But there are no terms to indicate any intermediate degrees of crystallinity. Such terms would permit more definite descriptions which become more and more necessary with the introduction of quantitative standards.

Definitely determined proportions between glassy and crystalline parts should be expressed in exact mathematical terms, but it may frequently happen that approximate proportions only are known or are considered sufficient for the purpose of the description. In this case it is suggested that five degrees of comparison be adopted, corresponding to the five divisions used in magmatic classification. These would be, in addition to the absolute terms already in use:

Holocrystalline,	wholly crystalline.		
Hypocrystalline or *hypohyaline*	*percrystalline,*	$\frac{\text{crystals}}{\text{glass}} > \frac{7}{1}$,	extremely crystalline with some glass.
	docrystalline,	$\frac{\text{crystals}}{\text{glass}} < \frac{7}{1} > \frac{5}{3}$,	dominantly crystalline.
	hyalocrystalline,	$\frac{\text{crystals}}{\text{glass}} < \frac{5}{3} > \frac{3}{5}$,	crystals and glass equal or nearly so.
	dohyaline,	$\frac{\text{crystals}}{\text{glass}} < \frac{3}{5} > \frac{1}{7}$,	dominantly glassy.
	perhyaline,	$\frac{\text{crystals}}{\text{glass}} < \frac{1}{7}$,	extremely glassy.
Holohyaline,	wholly glassy.		

II. Granularity

The magnitude of crystals composing rocks is considered in two ways: first, as regards the absolute size; second, with respect to relative sizes of associated crystals. The second is a factor entering into the fabric of a rock. *Granularity* may properly be limited to the first character, that is, *the absolute size of the crystals of a rock.*

When a rock is evenly or uniformly granular, or nearly so, the granularity—the grain—of it may be considered to be the size of the average-sized crystals. But when a rock is porphyritic—that is, consists of a matrix, or groundmass, with phenocrysts—it is clear that there may be two or more expressions for the size of crystals; one relating to the components of the groundmass, another to the phenocrysts. For reasons which will be explained in the discussion of porphyritic textures, it is advisable in these cases to apply terms of granularity primarily to the groundmass.

The size of crystals in rocks ranges through extremely wide limits—from dimensions that are submicroscopic, and are only recognized by the exhibition of aggregate polarization, to those that may be expressed in meters; a range of more than 1:1,000,000. In the great majority of rocks, however, the range is more nearly 1:1,000. Up to the present time no effort has been made to describe the grain of rocks with anything like mathematical definiteness, even to stating an approximate average size of the crystals. The terms in use express certain general ideas of magnitude based on the limits of vision, as follows:

Phanerocrystalline—All sizes large enough to be seen with the unaided eye, that is, megascopically.

Cryptocrystalline (aphanitic)—all sizes too small to be seen with the unaided eye. *Aphanitic* is a purely negative term which does not state whether the rock is crystalline or glassy, and is very convenient when it is desirable to express simply the fact that the matter is not determinable megascopically. Cryptocrystalline states that the rock is crystalline, and that the crystals are too small to be seen megascopically.

Microcrystalline—all sizes recognizable only with a microscope, and therefore embracing most of those that are megascopically cryptocrystalline.

Microcryptocrystalline—sizes too small to be seen with a microscope, but recognized as crystal particles by the exhibition of aggregate polarization.

Microaphanitic—This term may very well be employed to cover those doubtful cases of microscopic and submicroscopic aggregation which have been sometimes described as microfelsitic.

Phanerocrystalline rocks have been described as *coarse*, *medium*, or *fine* grained, with little effort to fix absolute values for these terms. Zirkel's suggestion that they be compared with the size of peas and millet seed has led to the more definite suggestion, already made by us, that the average diameter of crystals in—

Fine-grained rocks be taken as *less than* 1 *millimeter;* in
Medium-grained rocks, *between* 1 *and* 5 *millimeters;* and in
Coarse-grained rocks, *greater than* 5 *millimeters.*

Coarse-grained rocks are vaguely described as very coarse, or extremely coarse, without any indication of the actual degree of granularity. It would be more definite to express the approximate size of the grain of rocks in terms of the various units of the metric system. There are some extremely coarse rocks, such as pegmatites, whose crystals may be measured in meters; more whose crystals are several decimeters in diameter; many that may be measured in centimeters. Using a decimal series of units, it would be reasonable to employ the following terms for approximate descriptions of the grain of rocks, remembering that in finer-grained rocks the millimeter is oftener the unit of measurement, especially in microscopic work:

Meter-grained rocks, when the average size of the crystals is over 1 meter.

Decimeter-grained rocks, when the size of the crystals is from 1 to 10 decimeters.

Centimeter-grained rocks, when the size is from 1 to 10 centimeters.

Millimeter-grained rocks, when the size is from 1 to 10 millimeters.

Millimeter-grained rocks would include medium-grained and slightly coarse-grained rocks.

Decimillimeter-grained rocks; those in which the average size of the crystals is from 0.1 to 1.0 millimeter.

Micron- (millimillimeter-) grained rocks; those in which it is from 1 to 10 microns, from 0.001 to 0.010 millimeter.

Decimicron- (decimillimillimeter-) grained rocks; those in which it is from 0.1 to 1.0 microns, 0.0001 to 0.0010 millimeter.

The terms just described may be found useful in describing rocks in a general manner, but each includes a wide range of variations in the size of grain, which in the extreme reaches a ratio of 10:1 for the diameters of the crystals, which is a ratio of 100:1 for areas of crystal sections; differences which might be found in the crystals of porphyritic rocks. It follows that the grain of the rocks that may be described by any one of the terms mentioned—as, for example, *millimeter*-grained—is not always of the same *order of magnitude*, since in one case it may be eight or nine times larger in diameter than in another.

III. Fabric

The arrangement of the crystalline parts of a rock, or of the crystalline and glassy parts when glass is present, which we have called the *fabric*, depends on the relative sizes of the parts, on the shape of the crystals, and on the positions with respect to one another and to the glass base when present. The significance of these factors will appear upon further consideration.

Relative size of crystals.—While it never happens that all crystals in a rock are of one size, it often happens that they are approximately of the same size, at least as far as the great majority of component crystals are concerned. Crystals that are approximately of the same size may be of the *same order of magnitude.* It becomes necessary, then, to give this term a quantitative expression. Since identity of size is not assumed, the question rises: What latitude of variation in size is permissible in the petrographical use of the term—"The same order of magnitude" or "like magnitude," when applied to the crystals of a rock, or to sections of crystals in a rock section? If the crystals are nearly equidimensional, as in the accompanying diagram, it would appear reasonable to consider those as having *like magnitude* whose diameters varied within the ratio of 3:2 (Fig. 1).

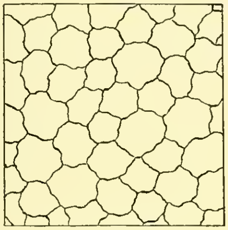

FIG. 1

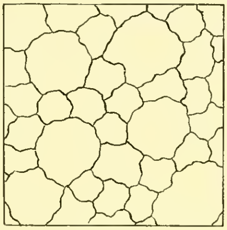

FIG. 2

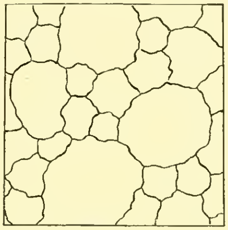

FIG. 3

Those whose diameters vary as 2:1 or 3:1 are clearly of different magnitudes (Figs. 2 and 3). The areas of the sections of the limiting sized crystals in the three cases are as 9:4, 4:1, 9:1, respectively, and the actual volumes as 27:8, 8:1, 27:1. That is, the possible limits are as follows:

	Ratio of Diameters	Ratio of Areas	Ratio of Volumes
First case..................	1.5:1	2.25:1	3.37:1
Second case..................	2.0:1	4.00:1	8.00:1
Third case..................	3.0:1	9.00:1	27.00:1

When the cross-sections of the crystals are not equidimensional, but have different shapes, it is evident that the basis of comparison is naturally the area of the cross-section: consequently such crystals may be said to have *like magnitude* when the areas of their cross-sections in a rock section or on the surface of the rock vary within the limits of $3^2:2^2$; that is, 9:4, or 2.25:1. It is interesting to note in this connection that the range in orders of magnitude used by astronomers in the comparison of stars is $\sqrt[5]{100}$ or 2.51.

Basing the comparison of the sizes of crystals on those of the great number of crystals that give character to the fabric of the rock, the following general distinctions may be recognized:

I. *Equigranular* rocks—composed chiefly of crystals of like orders of magnitude.
II. *Inequigranular* rocks—composed of crystals of different orders of magnitude.

I. EQUIGRANULAR ROCKS.—The fabric of equigranular rocks depends further on the—

(A) *Shapes* of the crystals.
(B) *Arrangement* or distribution of them.

(A) *Shapes* of crystals may be described in general terms with reference to the presence or absence of crystallographic faces as:

Euhedral—completely bounded by crystal faces; automorphic, idiomorphic.
Subhedral—partly bounded by crystal faces, hypautomorphic, hypidiomorphic.
Anhedral—without crystal faces, xenomorphic, allotrimorphic.

The crystals of equigranular rocks may be:

Equiform—all the same shape, or nearly so; or
Multiform—having various shapes.

With reference to their dimensions the shapes may be described as:

Equant—equidimensional or nearly so.
Tabular—in plates or tables.
Prismoid—in prismatic forms.
Irregular—not one of the three preceding divisions.

More specifically crystals may be described further under each of the general shapes just named, as follows:

Equant.—Cuboidal, polyhedral, spheroidal, equant anhedral, equant subhedral.—The simplest examples of *equant*, *equiform*, *equigranular*, *fabric* are found in an evenly granular quartz vein, in some quartzites and crystalline limestones, and in certain anorthosites, dunites, and pyroxenites.

Tabular.—Tabular, platy, foliated. The crystals may be in plates, tables, disks, folia, scales.—The best examples of *tabular*, *equiform*, *equigranular fabric* are found in certain feldspar rocks: syenite with so-called trachytic fabric, hedrumite, and certain anorthosites. It will be found in some micaceous metamorphic rocks with highly developed foliated texture.

Prismoid.—Parallelopipedons, lath-shaped blades, prisms, spindles, fibers.—Examples of *prismoid, equiform, equigranular, fabric* are rare among igneous rocks. The most familiar examples are certain metamorphic, actinolite rocks: strahlstein.

The great majority of equigranular rocks are *multiform*, since they consist of several kinds of minerals whose characteristic shapes are not alike. Quartz is almost always equant, micas are nearly always tabular, amphiboles frequently prismoid; whereas feldspars may be equant, tabular, or prismoid, and pyroxenes may be equant or prismoid. The various combinations of these shapes produce fabrics which have no simple character and require specific description. They frequently recur and should be distinguished by simple terms for convenience.

(B) *Arrangement* or distribution of crystals in equigranular rocks produces differences of fabric.

1. *Equant.*—Where crystals are equant there can be no variability in the arrangement which would affect the fabric, so far as form alone is concerned. But in case there are more than one kind of mineral present, especially if they are of different colors, the distribution of equant crystals of different kinds produces variations in fabric as regards color—varieties of color pattern.

2. *Tabular.*—The tabular crystals may be arranged in the following ways:

Parallel.
Subparallel.
Diverse, in all directions (omniversal).
Radial, divergent, fan-like, spherulitic, concentric, imbricated.

3. *Prismoid.*—The prismoid crystals may lie in the following positions:

Parallel.
Subparallel.
Diverse, in all directions (omniversal).
Radial, divergent, spherulitic, axiolitic.
Tangential, around a nuclear crystal.

4. *Irregular.*—Crystals of irregular shapes forming equiform,

equigranular rocks may be related to one another in two ways. They may be in *juxtaposition*, or they may *interpenetrate* one another.

(*a*) *Consertal.*—Irregularly shaped crystals in juxtaposition yield cross-sections that are closely fitted together or conserted. The fabric may be called consertal. This fabric is well developed in some metamorphic rocks where adjacent crystals interdigitate with serrated outline.

(*b*) *Graphic.*—Mutually interpenetrating crystals produce irregularly shaped forms, which in some cases yield straight-edged patterns as in graphic granite, where quartz and feldspar are intergrown.

II. INEQUIGRANULAR ROCKS, composed of crystals of more than one size, possess different fabrics according to the manner in which the sizes of the crystals vary from one another. The sizes may vary gradually from one extreme to the other; or there may be marked contrasts in size among the crystals. For these two ideas we may use the terms:

(A) *Seriate*—where the sizes of the crystals vary gradually or in a continuous series.

(B) *Hiatal*—where the sizes are not in a continuous series, but in a broken series with hiatuses, or where two or more sizes are markedly different from one another.

The most familiar variety of hiatal fabric is that porphyritic fabric in which there is a marked contrast between the sizes of the crystals forming the groundmass, and those of the phenocrysts. Another hiatal fabric which is the antithesis of the porphyritic is the *poikilitic*. In this there is also a marked contrast between the sizes of the crystals forming the matrix and of those scattered through it, but the crystals of the matrix are the larger. The small crystals scattered through the matrix may be called *xenocrysts* (ξένος = stranger). The large ones may be called *oikocrysts* (οἶκος = house).

Omitting for the present a discussion of *seriate* fabrics, which are intermediate, as it were, between equigranular fabrics and hiatal fabrics, let us consider the various expressions of *hiatal* fabric, commencing with the commoner kinds, the porphyritic.

(B) *Hiatal fabric.*—(1) *Porphyritic fabric* may be defined as one in which a *groundmass* of glass or crystals carries scattered through it crystals noticeably larger than those composing the groundmass.

In porphyries the phenocrysts may be of any size, microscopic or megascopic. Groundmass and phenocrysts are the essential parts of porphyritic fabric, variations in which produce different porphyritic fabrics. The kinds of variation are as follows:

(*a*) *Relative amounts of groundmass and phenocrysts.*
(*b*) *Character of the phenocrysts.*
  Sizes.
  Shapes.
  Arrangement.
(*c*) *Character of the groundmass.*
  Texture: Crystallinity.
    Granularity.
    Fabric.

(A) *The relative amounts of phenocrysts and groundmass.*—Differences in the amounts of phenocrysts give a noticeable character to porphyritic rocks, which up to this time has found very little expression in petrographic literature. At one extreme are porphyries with very few phenocrysts; at the other, those crowded with phenocrysts and having very little groundmass. Employing the French word for groundmass, *pâte*="paste," and *semé*="sown" or "sprinkled," comparisons are easily described by the terms:

Perpatic,	$\frac{\text{g.m.}}{\text{ph.}} > \frac{7}{1}$,	extremely rich in groundmass.
Dopatic,	$\frac{\text{g.m.}}{\text{ph.}} < \frac{7}{1} > \frac{5}{3}$,	groundmass dominant.
Sempatic,	$\frac{\text{g.m.}}{\text{ph.}} < \frac{5}{3} > \frac{3}{5}$,	groundmass and phenocrysts equal or nearly equal.
Dosemic,	$\frac{\text{g.m.}}{\text{ph.}} < \frac{3}{5} > \frac{1}{7}$,	phenocrysts dominant.
Persemic,	$\frac{\text{g.m.}}{\text{ph.}} < \frac{1}{7}$,	extremely rich in phenocrysts.

Having noted the relative amounts of groundmass and phenocrysts, the relative sizes, shapes, and arrangement of the phenocrysts may be taken into account.

(*b*) *Character of phenocrysts.—Size.* Phenocrysts may be large enough to be seen megascopically, or they may be so small as to be only visible microscopically; for these distinctions we have the terms:

Megascopic phenocrysts, or megaphenocrysts.

Microscopic phenocrysts, or microphenocrysts.

In the first case the rock may be said to be—

Megaphyric, having megascopic phenocrysts;

and in the second case it may be called—

Microphyric, having microscopic phenocrysts.

Considering the *megaphyric* rocks, the phenocrysts may be large or small, of any size. Following the custom in describing the grain of equigranular rocks, we might establish three common distinctions:

Magnophyric—coarsely porphyritic, the phenocrysts greater than 5^{mm} in longest diameter.

Mediophyric—moderately porphyritic, the phenocrysts between 5^{mm} and 1^{mm} in longest diameter.

Minophyric—minutely porphyritic, the phenocrysts from 1^{mm} to 0.2^{mm} in longest diameter.

In case corresponding distinctions in the size of microscopic phenocrysts are desirable—that is, in *microphyric* rocks—the same terms may be used with the change of the letter *o* to *i*, and a corresponding decrease in the value for the diameters.

Magniphyric—coarsely microphyric, the phenocrysts having longest diameters from 0.2 to 0.04^{mm}.

Mediiphyric—moderately microphyric, phenocrysts having longest diameters from 0.04 to 0.008^{mm}.

Miniphyric—minutely microphyric, phenocrysts having longest diameters less than 0.008^{mm}.

Such minute phenocrysts are microlites in a glass base.

There is further the distinction as to whether all the phenocrysts are:

Of *like magnitude*, or

Of *different magnitudes.*

Shape.—The shape or form of phenocrysts is an important factor in determining fabric. While the specific shape of a phenocryst may be a crystallographically complex form requiring somewhat elaborate description, there are certain terms which serve to describe the crystals without reference to crystallographic detail. Some of these are as follows:

Equant—with surfaces about equidistant from the center, sometimes cuboidal or spheroidal.

Tabular—flattened in one plane.

Prismoid—elongated in one direction.

All of the phenocrysts may have the same kind of form—that is, they may be *equiform;* or they may possess several forms, they may be *multiform.*

Specific shapes of phenocrysts, when sufficiently distinctive, may give rise to special terms, such as *rhombenporphyry,* in which the large feldspar phenocrysts have rhombic cross-sections. Another instance is *spherophyre,* in which phenocrysts are composite or simple aggregations of crystals in the form of spherulites.

Arrangement.—The arrangement or distribution of phenocrysts through the groundmass is another factor in the composition of fabric. Phenocrysts may be—

1. *Scattered* more or less uniformly through the groundmass. Such a porphyry may be called a *skedophyre,* and the texture is *skedophyric.* This is the commonest case.
2. *Grouped* together in various ways, as in—
    (*a*) *Clusters*—or irregular groups of phenocrysts; such a porphyry may be called a *cumulophyre,* and the texture *cumulophyric.* When the phenocrysts are equant, the texture is *glomerophyric* (glomeroporphyritic, Judd, 1886).
    (*b*) *Layers* or *laminae*—constituting a *planophyre,* or *planophyric* texture.
    (*c*) *Lines* or *streaks*—producing a *linophyre,* or *linophyric* texture.

(*c*) *Character of the groundmass.*—The groundmass of a porphyry may have any texture. It may exhibit any degree of crystallinity. It may possess any degree of granularity, from microscopic to megascopically coarse-grained, and may have any fabric.

Crystallinity.—All the terms denoting degrees of crystallinity or glassiness may be applied to the groundmass of porphyries. Certain general terms have been in use, one of which (granophyre) has been variously defined.

Vitrophyric—with groundmass megascopically glassy, or vitropatic.

Vitriphyric—with groundmass microscopically glassy, or vitripatic.

Felsophyric or *aphanophyric*—with groundmass megascopically aphanitic, or felsopatic.

Felsiphyric or *aphaniphyric*—with groundmass microscopically aphanitic, or felsipatic.

Granophyric (Vogelsang)—with groundmass holocrystalline granular.

It has been suggested that this term be used when the rock is granopatic phanerocrystalline, and—

Graniphyric, when the groundmass is microcrystalline, or granipatic.

The texture called granophyre by Rosenbusch is called by us *graphophyre* or *graphiphyre*, according as the groundmass is megagraphic or micrographic.

Granularity.—The terms that may be applied to the grain of equigranular rocks are applicable to the groundmass of porphyritic rocks, and do not need to be repeated in this place. A distinction between megascopic and microscopic sizes may be effected by using the letters *o* and *i*, respectively, when the textural term is used as a prefix, as in *grano-* and *grani-*.

Fabric.—The fabric of the groundmass of a porphyry may be the same as that of a rock taken as a whole, so that any term applied to one may be used in describing the other.

2. *Poikilitic fabric* is that kind of hiatal fabric in which the matrix consists of relatively large crystals, through which are scattered relatively small crystals. The rock may be called a poikilite, in contrast to a porphyry. The two factors in this fabric, inclosing crystals or *oikocrysts* and inclosed crystals, *xenocrysts*, may vary (*a*) in relative proportions, and (*b*) in relative size; (*c*) the xenocrysts may vary in shape, and (*d*) in arrangement or distribution.

(*a*) *Relative proportions* between oikocrysts and xenocrysts. All possible proportions exist, from that in which the host constitutes the slightest interstitial cement between the xenocrysts, which in such a case may form the greater part of the rock, to that in which the xenocrysts occupy a very small space in the oikocrysts. To express the relative amount of outer and inner crystals in poikilitic fabric, the following terms may be used:

Peroikic,	$\frac{\text{oikocryst}}{\text{xenocryst}} > \frac{7}{1}$,	oikocryst extremely abundant.
Domoikic,	$\frac{\text{oikocryst}}{\text{xenocryst}} < \frac{7}{1} > \frac{5}{3}$,	oikocryst dominant.
Xenoikic,	$\frac{\text{oikocryst}}{\text{xenocryst}} < \frac{5}{3} > \frac{3}{5}$,	oikocryst and xenocrysts equal or nearly equal.
Doxenic,	$\frac{\text{oikocryst}}{\text{xenocryst}} < \frac{3}{5} > \frac{1}{7}$,	xenocrysts dominant.
Perxenic,	$\frac{\text{oikocryst}}{\text{xenocryst}} < \frac{1}{7}$,	xenocrysts extremely abundant.

(*b*) *The sizes* of the xenocrysts as compared with the matrix crystal in which they occur may be described as relatively *large*, *medium*, and *small or fine*. The relative sizes are best expressed in terms of the average diameters of the inner crystals and host.

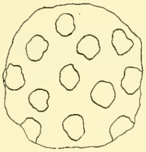

FIG. 4

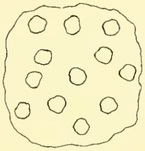

FIG. 5

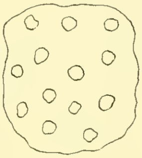

FIG. 6

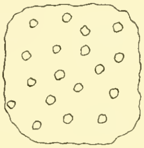

FIG. 7

Relatively large xenocrysts—those whose average diameter is greater than one-eighth the average diameter of the host (Fig. 4.)

Relatively medium-sized xenocrysts—having average diameters between one-eighth and one-twelfth that of the host. (Figs. 5, 6.)

Relatively small xenocrysts—having average diameters less than one-twelfth that of the host. (Fig. 7.)

Poikilitic fabric may be megascopic or microscopic, when its granularity may be described with reference to the *size* of the oikocrysts in the terms applied to equigranular rocks as *coarse*, *medium*, or *fine* grained.

(*c*) *The shapes* of the xenocrysts lead to modifications of poikilitic fabric, as in porphyritic fabric. The general shapes may be—

Equant.
Tabular.
Prismatic. .

All the xenocrysts may have similar shapes; they may be *equiform*. Or they may have different shapes; they may be *multiform*.

(*d*) The arrangement of the xenocrysts further modifies the fabric. They may be—

(1) Scattered more or less uniformly through the oikocryst; or
(2) Grouped together in various ways.

Those xenocrysts that are tabular or prismatic may stand in all possible positions, or they may be *parallel* or nearly parallel to one another, *sub-parallel*, or their positions may be *diverse*.

Ophitic fabric is a particular case of poikilitic in which the xenocrysts are tabular or prismatic, are relatively large to medium as compared with the oikocryst. It is usually doxenic to xenoikic, but it may be domoikic, or also perxenic. It may be magascopic or microscopic. The term has been employed only when the xenocrysts are feldspar and the oikocrysts are pyroxene.

Seriate fabrics.—These fabrics form the connecting links between equigranular and hiatal, between even-grained and distinctly porphyritic or poikilitic. According to the relative amounts or abundance of the larger or smaller crystals, they approach one or other of these extremes of the series. Abundant large crystals with relatively few of the smaller ones produce a fabric approaching equigranular, whereas relatively few large crystals with abundant smaller ones produce a form of porphyritic fabrics, not necessarily hiatal, but resembling hiatal porphyries.

The first fabric would consist of relatively large crystals nearly, or in fact, touching one another, with smaller and smaller crystals between, or to some extent included in, the larger ones, giving rise to the following fabrics:

(1) *Seriate-intersertal*—the rock might be called a seriate-intersertal aphyrite; an aphyrite being a nonporphyritic rock.
(2) *Seriate-poikilitic*—a seriate poikilite.

The second kind of seriate fabric would be—

Seriate-porphyritic—the rock may be called a seriate porphyry.

The multitude of variations in the relative sizes, shapes, and proportions of crystals constituting rocks with seriate fabrics makes it necessary to describe the fabric in detail in order to convey a correct impression of it. The study of a hundred granites from different localities will quickly convince one of the diversity of fabrics in rocks with so-called "granitic" texture. They might all be described as having multiform, seriate, aphyric fabric. But this would not convey a definite picture of any one rock. In order to accomplish this it is necessary to state the shapes of different kinds of crystals, their relative sizes, and proportionate amounts.

With such a definite picture before one, if possible in the form of a diagram or photograph as well as in words, it is possible to compare with it the fabric of another rock, which may be described as like the first or as differing from it in certain particulars. If a certain fabric is found to recur frequently, it may be given a specific name, which may possess more or less elasticity, according to the definiteness of the description to which it has been applied.

It will be observed that the foregoing discussion is confined almost wholly to general features of textures, and that the terms suggested have a general application. They contribute to the general descriptive equipment of petrography. The specific description of a definite rock texture must of necessity be a complex expression, which, if needed frequently for other rocks, may be represented by a denotive term, derived from a geographical name, with the termination *al*, as suggested in our essay on a Quantitative Classification of Igneous Rocks.[1]

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[1] This *Journal*, Vol. X (1902), p. 635.

NATURAL MOUNDS

MARIUS R. CAMPBELL[1]

Recently the subject of natural mounds has attracted unusual attention, and a number of persons have described their occurrence and attempted an explanation of their origin.

What are here designated as natural mounds are low, broad mounds, varying from 10 to 140 feet in diameter, and from a few inches to 5 or 6 feet in height. They are wonderfully symmetrical, both in plan and in elevation, and generally they closely approach a circle in outline, but in places they are slightly elliptical, and where such is the case the major axes of all mounds in the vicinity have a common direction.

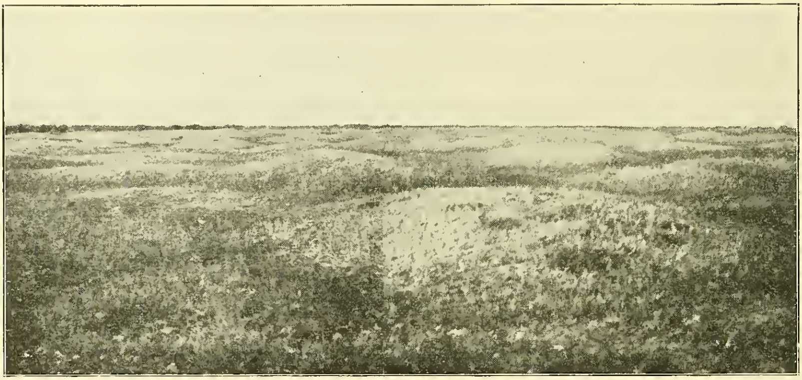

FIG. 1.—Group of natural mounds on old sea terrace back of San Diego, Cal.

Figure 1 is reproduced from a photograph of a group of slightly elliptical mounds occurring on the old sea terrace back of San Diego, Cal., at an altitude of about 380 feet. Frequently the mounds are closely bunched, as shown in the figure, but they occur also singly and in small groups.

According to the descriptions of various writers, the composition of the mounds vary considerably, probably being affected by the

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[1] Published by permission of the Director of the U. S. Geological Survey.

character of the local material. As the writer has observed them in California and in Arkansas, they are made up of clay, or clay with a slight admixture of gravel, depending upon the character of the underlying subsoil; but in Texas and Louisiana, according to report, they are made up largely of sand, and in Missouri of chert fragments from the Carboniferous limestones.

So far as the writer has observed or has been able to obtain references to them, mounds of a similar character occur in abundance in Louisiana, Texas, Arkansas, Missouri, Kansas, Indian Territory, Arizona, California, Oregon, Washington, Mexico, and Argentine Republic.[1] Generally they are reported as occurring on low, flat lands; but Turner[2] has described and figured similar topographic features covering low hills on the east side of the San Joaquin valley in California, and recently Hill[3] has noted their occurrence on the high plateau of Mexico, nearly 7,000 feet above sea-level.

To account for the origin of these mounds various hypotheses have been advanced, but in most cases they are speculative only and have little or no foundation in fact, or they are based upon limited observations and fit only the conditions prevailing in one locality.

It is altogether probable that the mounds which have been noted in various parts of the country are not exactly similar and have not had a common origin, but this cannot be proven until they have been more carefully studied, and studied by one person who can compare the mounds in different localities and judge whether or not they are all due to the same cause.

The principal hypotheses may be summed up as follows:

1. Human agency.
2. Animal burrows, such as ground squirrels, gophers, and prairie dogs.
3. Ant hills.
4. Water erosion.

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[1] Since the above was written the writer has observed similar mounds on the broad flat valley bottom near Logan, Utah.

[2] H. W. Turner, "Further Contributions to the Geology of the Sierra Nevada," U. S. Geological Survey, *Annual Report*, Part 1, pp. 681–83, Plate 33.

[3] R. T. Hill, "On the Origin of the Small Mounds of the Lower Mississippi Valley and Texas," *Science*, N. S., Vol. XXIII, No. 592 (May 4, 1906), pp. 704–6.

5. Chemical solution.
6. Wind action.
7. Physical or chemical segregation.
8. Glacial action.
9. Uprooted trees.
10. Spring and gas vents.
11. Fish nests.

From the widespread distribution of the mounds it is evident that, if they have a common mode of origin, this mode of origin must be such that it will fit a variety of climatic, geologic, and topographic conditions. On this basis it is easy to rule out as general causes a number of the above hypotheses without discussing them in detail. For instance, on the sea terrace back of San Diego, Cal., where the mounds are beautifully developed, or on the prairies south of Tacoma, Wash., the hypothesis which attributes their origin to fish nests might be applicable, for those localities have in recent geologic time been under water; but certainly it would not be applicable to the mounds which occur in other parts of the country. The spring and gas-vent hypothesis might fit the conditions prevailing in Louisiana or Texas, but mounds are just as abundant in areas in which neither of these agencies has acted. It is evident, therefore, that this hypothesis cannot have a broad application, and consequently may be eliminated. The mounds resulting from uprooted trees have been cited as analogous to the mound in question, but such a hypothesis would never have been advocated by a person thoroughly familiar with the mounds in their best development. We should be obliged to presuppose the existence of giant sequoias over the low arid region of southern California and Arizona, and over the moist humid prairie of Texas and Louisiana. Manifestly this is absurd and may be disregarded. Glacial action might be appealed to in explanation of the mounds of Washington, but evidently is not applicable to the great number of mounds found in southern California and the Mississippi valley.

By this method of elimination the number of hypotheses has been reduced to seven, but these seven have a far greater degree of probability, and hence will have to be considered in detail before they are discarded.

The hypothesis of physical or chemical segregation was proposed by Branner,[1] but absolutely no evidence was advanced in support of it. He says:

> One other theory has been in my own mind for several years, but it is almost entirely without observations to support it, and it is perhaps too vague to be clearly expressed. The idea is that in solutions of certain kinds, long exposed to weathering agencies, chemical reactions possibly take place around centers that result in the transfer of minerals in solution, and the precipitation in nuclei that are now represented by the position of the mounds, while the withdrawal of these minerals from the intervening areas causes the depression around the mounds.

Purdue[2] found himself at a loss to account for similar mounds in the Arkansas valley, and took refuge behind Branner's vague hypothesis, but he likewise failed to produce any direct evidence to substantiate it. Manifestly in the present stage of our knowledge this hypothesis has no support, and, until such evidence is presented, it need not be considered.

The question of wind action is not so easily disposed of; doubtless many mounds have been produced by such action, and probably many others of an entirely different origin have been modified by the action of the wind. Nevertheless the great number of natural mounds are far too symmetrical in profile and in plan to have been formed by wind-blown material. Usually it is supposed that dunes may be recognized by their unsymmetrical shape, while the mounds are noted for their symmetry; consequently the only resort was to suppose that they are the result of wind acting in various directions. It is possible to conceive that fine, dry material may be heaped up by winds blowing first from one direction and then from another, producing a measure of symmetry; but when one considers the vast territory over which these mounds occur both in dry and in humid climates, it is evident that such special conditions could not have prevailed, and thus we are forced to drop this hypothesis.

We are thus reduced to five hypotheses, but, since No. 2 and No. 3 are essentially the same as far as the mode of origin is concerned,

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[1] J. C. Branner, "Natural Mounds or 'Hogwallows,'" *Science*, N. S. Vol. XXI, No. 535 (March 31, 1905), pp. 514–16.

[2] A. N. Purdue, "Concerning the Natural Mounds," *Science*, N. S., Vol. XXI, No. 543 (May 26, 1906), pp. 823, 824.

we may say that the choice lies among four hypotheses: animal burrows, erosion, solution, and human construction. These hypotheses involve two fundamentally different processes, construction and destruction, and it seems possible to determine definitely which of these processes has taken place.

Many writers have argued that the mounds are the result of erosion, but in most cases they have realized that under normal conditions such forms could not have been produced, and hence they have been compelled to assume unusual conditions, but rarely have they stated clearly what were the unusual conditions.

Practically all of the mounds observed by the writer are located on smooth surfaces, and generally on level plains. Where the mounds are close together they may touch and the slope of one merge into the slope of its neighbor, forming a concave surface; but where mounds are scattering, the space between is always *flat*, being in reality a part of the surface of the plain. In arguing for erosion this fact has generally been neglected, or it has been assumed that the inter-mound surface is not a plain. Thus Barnes,[1] in describing the mounds at San Diego, illustrated in Fig. 1, gives a profile showing the mounds separated by a concave surface. The mounds in this locality were examined very carefully by the writer, and in every case where they were not in actual contact the space between them is flat and not concave, as represented in Barnes's profile. It therefore seems that much of the misapprehension regarding the origin of the mounds is due to imperfect observations and assumptions that are not warranted.

When one considers the way in which surfaces are eroded, it is manifestly impossible to produce a flat surface unless that surface is at base-level, or the process of erosion is controlled by a barrier or by underlying hard rocks. If the surface was at base-level, and the plain a base-level plain, it would mean that the cycle of erosion was practically complete, and in that event the mounds would be reduced as well as other portions of the surface, unless in some abnormal way the mounds were protected from the action of erosion. In order to protect mounds with such symmetrical, spherical surfaces,

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[1] G. W. Barnes, "The Hillocks or Mound-Formations of San Diego, California," *American Naturalist*, Vol. XIII (September, 1879), pp. 565–71.

one would have to suppose a circular segregation of hard material, which certainly would call for unusual conditions. It is true that analogous topographic forms have been produced by such conditions as shown by Gilbert and Gulliver[1] as existing in the Tepee buttes of eastern Colorado. In that case the symmetrical form is due to the protective influence of a calcareous core, which is supposed to have been of fossil origin. In the case of the mounds, however, no one has reported any protective material, except in a few cases where gravel has been noted in more abundance in the mounds than elsewhere. Gravel might answer as a protective cap, but such accumulations are not universal, for in hundreds of cases observed by the writer in Arkansas no gravel is to be found, either in the mounds or in the soil in the vicinity.

FIG. 2.–Section of a mound 3 miles northwest of Dardanelle, Ark., showing that the material composing the mound is of different color and texture from the underlying subsoil.

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[1] G. K. Gilbert and F. P. Gulliver, "Tepee Buttes," Geological Society of America, *Bulletin*, Vol. VI pp. 333–42, Plate 17.

Although the evidence given above seems to show conclusively that mounds are not the result of erosion nor of solution, the writer is able to produce more positive evidence that will appeal to everyone, whether he is familiar with the processes of erosion or not.

During the month of April, 1906, the writer had an opportunity to observe thousands of mounds in the valley of the Arkansas between Little Rock and Fort Smith. They are abundant everywhere on the lowland above the flood-plain of the river, and while many of these have been cut through in grading for railways and highways, it is difficult to find a fresh section in which the structure and composition of the mounds are well shown. At last a mound was found on the Paris road about 3 miles northwest of Dardanelle, Ark., which recently had been dissected by a small stream flowing by the roadside, and a fresh section was exposed. Figure 2 is a photograph of the mound as it appeared in the section.

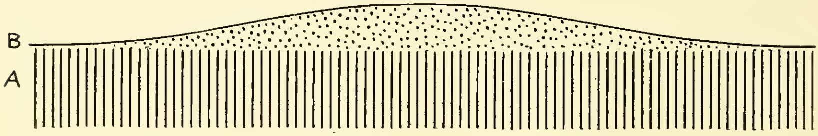

FIG. 3.—Diagrammatic section of mound shown in FIG. 2. *A* is yellowish-white clay. *B* is soil composed of the clay subsoil reworked with the addition of carbonaceous material. Mound same as soil.

The plain upon which the mound appears is flat and composed of a deep subsoil of yellowish-white clay, formed by the decomposition of Carboniferous shale. The clay is homogeneous and structureless, except that it shows a tendency to vertical cleavage in much the same way that such cleavage is shown in loess. At the surface and for a depth of from 6 to 12 inches the clay has been opened up and reworked by grass and tree roots, and a small amount of carbonaceous matter has been incorporated in the clay, giving it a slightly darker color than it had originally.

The mound which had been dissected was approximately circular before it had been cut away, with a diameter of about 60 feet and a height of 4 feet. The diagram in Fig. 3, which is drawn to scale, gives a good idea of the size and shape of the mound as it was seen in profile. The underlying clay subsoil is shown at *A*, the ordinary soil at *B*, and the line separating them was visible as an approximately straight line entirely across the mound. The material composing the mound is essentially like the soil on either side; that is, it is reworked clay, probably derived from the underlying subsoil.

The above section shows clearly that the body of the mound is composed of material exactly like the surrounding soil, which is derived from the underlying clay; and consequently it is a fair inference to suppose that the mound material came from the same source; but, whether this be true or not, the arrangement of the materials proves conclusively that the mound was *built*, and is not a residual left by erosion or solution. Since in this case the evidence is positive that this mound is not the result of erosion, and also since, in the opinion of the writer, the general evidence against such a mode of origin, at least for the mounds of Arkansas and California, is conclusive, the two hypotheses of erosion and solution, as applied to the great multitude of mounds in the southern part of the United States, may be dropped.

The case is now narrowed down to two modes of origin—namely, human construction and the action of burrowing animals.

Although much has been written regarding the human origin of these mounds, the arguments against it are so strong that it may be classed with the other hypotheses which have been disregarded. It is doubtless true that similar mounds have been erected by prehistoric man, but it is absurd to suppose that the countless millions of mounds which exist in the regions noted above have been the result of human activity.

This disposes of all the hypotheses, except that which ascribes their origin to the action of burrowing animals; but whether the mounds are due to ants or to small rodents, the writer is unable to say. Personally he inclines to the ant-hill hypothesis, but there is little or no evidence to determine which is correct. No burrows or chambers of any kind have been discovered in the mounds, and in the case observed by the writer no differences were observed in the character of the underlying clay, which would indicate the former presence of chambers, even though they are now filled. No excavations were noted in the neighborhood which could have supplied outside material for the mound, and consequently it is assumed that this material must have come from a long distance under ground, and the minute channels through which it was transported have been closed by material falling in from above or carried in by water in suspension.

The constructional feature of the mound is considered to have been proved in this particular case, but it still remains to account for the agent that performed the work. It is believed, however, that careful work in trenching some of the best preserved examples of these mounds would furnish some evidence to determine this part of the question, but such investigations have never been undertaken, at least not on an extensive scale.

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ROCK FOLDS DUE TO WEATHERING

MARIUS R. CAMPBELL

The recent article by Professor Sardeson on "The Folding of Subjacent Strata by Glacial Action"[1] is of considerable interest, and doubtless he has a case in which he can demonstrate the origin of the movement; but in studies of this kind it should be borne in mind that folds of a similar character occur far beyond the limit of glaciation, and that before attributing surface folds in general to glacial action other possible causes should be considered.

During a recent visit to the Carboniferous coal-field of Arkansas the writer had a good opportunity to examine a number of minor surface folds, which are very common in the great synclinal valleys adjacent to the Arkansas River. In most cases the folds were simply apparent in the disturbed sandy shales or thin-bedded sandstones in the roadway, and it was impossible to determine, without considerable excavation, the depth and extent of the disturbance.

In one case, however, an excellent example was obtained, which is illustrated in the accompanying cut. The occurrence is in the north part of Section 2, T. 7, N., R. 25 W., in the central northern portion of Logan County and about 50 miles east of Fort Smith.

The locality in which the fold is exposed is a shallow quarry in which sandstone for the construction of the large Catholic college near Spielersville was obtained. The surface material, as shown by the figure, consists of sandstone, the beds of which range in thickness from 1 to 5 or 6 inches. Near the bottom of the section shown in the cut is a rather heavy bed with a thickness of a foot or 18 inches. This is the main rock which is quarried, the surface material simply being stripped off for this purpose.

As shown in the photograph, the lower beds, especially the thick layer just mentioned and all below it, pass under the fold without being disturbed, the rocks having a dip of about 3° to the southwest. Not only does the heavy bed shown at the bottom of the

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[1] *Journal of Geology*, Vol. XIV, No. 3, pp. 226–32.

photograph pass below the fold, but the overlying bed, having a thickness of about 4 inches, appears to be undisturbed also. Above this the strata, for a depth of from 3 to 4 feet, have been thrown into a distinct anticline with a height on its axis of at least 2 feet.

FIG. 1.—Surface fold in thin-bedded sandstone near Spielersville, Ark.

The linear extent of this small fold is unknown, as the country immediately adjacent is covered by a heavy mantle of turf which makes it difficult to trace such features.

It is evident that glacial action has had no part in the formation of this fold, since it lies entirely beyond the southern limit of any known ice-sheet. The movement, however, is just as pronounced as in the cases shown by Professor Sardeson, and it is evident that some competent force other than moving ice has acted in a direction parallel with the bedding in producing the disturbance.

Since the underlying beds are not affected, it seems evident to the writer that the movement is not due to stresses which affect the crust of the earth to any great depth, for if such stresses are present, the heavy layer shown at the bottom of the photograph and the underlying beds would take the force of the strain, and the upper surface beds would be relieved. Moreover, the folds, so far as they have been observed, are surface features, and in this particular case occur near the outcrop of the beds affected. This entirely precludes the possibility of the movement being deep-seated, for in that event the rocks lying on the hillside above the fold, and between it and the point of outcrop, would probably have been moved bodily and no fold would have been produced.

Professor Sardeson has shown that similar features have been produced in Minnesota by the heaving action of frost, but in Arkansas the climate is so mild that freezing could not have played an important part in the formation of a fold. Moreover, the fold is not the result of vertical movement such as described by Professor Sardeson, but movement along the bedding planes of the rock.

The only way in which freezing could have produced such a result as the fold in question is by the cumulative effect of water freezing in the joints of the rock. This would tend to produce stresses in the surface rocks alone, and these stresses would continue or accumulate until they were relieved by some break or fold in the surface beds. Thus freezing might account for the phenomenon. If freezing alone were the active force, we should, however, find the results of its action much more common in northern regions than in southern; but, so far as the writer is aware, this is not the case. Therefore we must conclude that freezing, while possibly a factor in the case, has not been the dominant one.

The creep of surface rocks down the slope may be appealed to as a possible cause. It is true that in this region there is a close correspondence between the attitude of the beds and surface topography. Lightly dipping sandstones are usually marked by sloping surfaces, and, in this particular case, the ridge has an altitude of 60 or 80 feet above the surrounding plain. It hardly seems possible that in surface beds having a thickness of about 3 feet the superincumbent load of material which lies on the hill-slope above the point where the fold was formed has been sufficient to overcome friction and cause the rock to creep down the slope.

The only other explanation that seems at all plausible is that of expansion due to weathering. The process ordinarily called weathering is doubtless complex, consisting of chemical and mechanical changes in the body of the rock itself, most of which result in increased volume, but probably the most important element is the opening of joints and cleavage fissures. In this field jointing is highly developed. In unweathered sections the joints are scarcely visible, showing simply as incipient cracks in the rocks, but when exposed at the surface the joints are very abundant and almost always open.

The opening of joints is probably largely due to changes in temperature which result in the expansion and contraction of the rock itself, as well as of any rock particles which may have fallen into the cracks; to the freezing of water in the joints, and to the expansive force of roots. Although the amount of opening on each joint is small, the aggregate of hundreds or thousands of joints would tend to set up stresses parallel to the bedding, and in course of time these stresses would reach the point of rupture of the beds involved, and a fault or fold would be produced.

The phenomenon is most interesting to the students of structural geology, and it affords a measure of the amount of expansion these beds have undergone since the present surface was formed.

GEOLOGY OF THE LOWER AMAZON REGION[1]

CHARLES SCHUCHERT

Dr. Katzer has shown remarkable ability in writing local geological treatises of a comprehensive nature. His largest and best work is *The Geology of Bohemia;* and the smallest, *The Geology of Bosnia.* The present admirable memoir under review is the third one of his local summaries. All are written in the German language.

Much of Dr. Katzer's knowledge of the geology of Brazil (more especially of Pará) was obtained during the seven years he was state geologist and stationed in the Museu Paraense; yet it is quite evident that he is also familiar with the literature, in many languages, treating of the geology of South America.

The present article chiefly calls attention to the general geological sequence in the lower Amazon region. Those desiring further information must consult the *Grundzüge* itself.

The succeeding pages give, in the language of the reviewer, a condensation of the chapter entitled, "The Geological Development of the Lower Amazon Region" (pp. 237–62). Following this statement, the present writer will take up the Paleozoic formations in more detail, especially those of the Devonic.

PART I. KATZER'S SUMMARY OF AMAZONIAN PALEOGEOGRAPHY

Katzer states that the general observation, that the present relation of the Atlantic Ocean to Brazil was the same in the older geological epochs—i. e., that the old oceans spread upon the land from the east—is not supported by the facts.

The distribution of the Archean shows that in the north and east occur the oldest rocks of the lower Amazon region. Upon these rest fresh-water deposits of Tertiary and Quaternary age. The

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[1] This paper is largely based on Friederich Katzer's *Grundzüge der Geologie des unteren Amazonasgebietes* (*des Staates Pará in Brasilien*) (Leipzig, 1903; pp. 298, a geological map, numerous text-figures, and 16 plates of fossils; 8vo). The writings of Hartt, Rathbun, Derby, and Clarke have also been liberally drawn on.

northern and eastern portions of the state of Pará represent a very ancient continent, and probably formed the margin of the Paleozoic seas. This land extending across the broad and deeply eroded valley at the mouth of the Amazon, and uniting with the Archean mountains of the state of Ceará and east Brazil, apparently continued to exist in younger Tertiary time. The above hypothesis, therefore, cannot be true for pre-Neogenic time, because across the mouth of the present Amazon there then stood a highland uniting Guiana with the present highland of Ceará.

This old land is folded. West of Pará the folds strike southwest-northeast; farther east, in the region of the Serra Tumuc-Humac, nearly east and west; and along the Atlantic, northwest-southeast. This bowlike trend of the basal mountains continues northward into the Orinoco lowland; in fact, into the Caribbean Sea, while to the southeast of the mouth of the Amazon they extend along the Atlantic coast into the state of Ceará.

This folding took place before the metamorphic sedimentaries underlying the Siluric originated, the exact age of which is unknown. In their petrographic habit they closely resemble the Archean, but are separated from it by a discordance, while above they seem to grade without disturbance into Siluric strata.

According to the present distribution of the Paleozoic deposits, the sea was open to the west, as the younger formations occur with great regularity farther and farther away from the Archean. The Carbonic apparently attains the Parú, the Devonic probably continues to Maraca, and the Siluric possibly reaches the Araguari.

The Siluric and Devonic fossiliferous deposits of the lower Amazon region are tolerably coarse-clastic in character, and undoubtedly were laid down in a shallow sea. The Devonic faunas are very similar to those of North America, and this is all the more remarkable when one considers the great distances by which they are separated. This leads to the conclusion that this old Paleozoic sea had free communication between North and South America.

As no young Middle and Upper Devonic deposits are known in the Amazon region, it appears that beginning with that time great changes took place in the distribution of land and water. This seemingly connects, on the one hand, with the outbreaks of eruptive rocks beginning in the lower Devonic, and, on the other, with the breaking-down of the old Atlantic-Ethiopean continent. This hypothetic event, which separated the probable great continents of younger Paleozoic time—Atlantis and Gondwana of Suess[1]—gave rise to a sea transverse to the present Atlantic, and this apparently occurred at the beginning of the Upper Devonic. [This is the mediterranean named by Suess "Tethys."] The shallow sea then retreated from northern and middle South America.

It must therefore be concluded that toward the end of Devonic and the beginning of Carbonic time the greater part of South America was land.

In the southeast there was apparently a continuous elevation of land; in the west (Chile), partial elevation; and in the northern region—i. e., Bolivia, Peru, and Brazil—there was a widespread sinking which led to another transgression of the sea.

In these countries of South America the marine Carbonic is that of the Upper Carbonic. It is worthy of note that this sea occupied about the same area as that of the Devonic. The transgression begins with sandy deposits with traces of plants, as *Lepidodendron* and *Calamites*, but there are no beds of coal.

All undoubted marine deposits of the Carbonic of South America appear to be closely interrelated, but the fossil evidence outside of the Amazon region is scanty and in the main depends upon brachiopods. Upper Carbonic fossils are known from the east base of the Cordillera Oriental, Peru; Lake Titicaca at Yarbichambi and Yampopata; Arque in the province La Pag, vicinity of Cochabamba, and Santa Cruz, Bolivia; Choapa valley, at La Ligua, Chile; in Brazil, other than the Amazon region, in southern Matto-Grosso and the adjoining regions of Paraná and São Paulo. Katzer regards this distribution as indicating that toward the end of Carbonic time there were flat and swampy islands and peninsulas separated by comparatively deep marine bays and straits. This peculiar distribution made it possible for the South American sea to have communication in all directions, but the author wisely adds that the great similarity of these faunas with those of Europe and Asia may be due to a loose identification of the species.

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[1] *Antlitz der Erde*, Vol. I, p. 516; Vol. II, p. 317.

The Amazon faunas are regarded by Katzer as Upper Carbonic, with partial extension into the Permic. For the other regions (Chile, Peru, Bolivia) nothing more can be said than that they are Upper Carbonic. It should be mentioned that the latter are far more closely related to those of North America, as Arkansas, Missouri, Kansas, Nebraska, and Nevada, than are these North American regions to those of the Amazon.

Reviewing the Carbonic and Permic of Asia, Katzer thinks it certain that the Amazon Carbonic is to be correlated with the Schwagerina or Ufa stage of the Ural, especially the limestone of the Sim region, in part with the uppermost Carbonic of central Russia, and in part, also, with the Artinsk stage.

While the Amazon region and adjoining lands and nearly all of western South America were covered by the Carbonic sea, the eastern margin and the entire southeastern portion of South America remained land. The Carbonic deposits of the latter regions are of terrestrial origin, and in Santa Catharina, Rio Grande do Sul, Uruguay, and Argentina the coal-bearing deposits are well known; but in Paraná, Bahia, Piauhŷ, and apparently also in Maranhão there are plant-bearing Neo-Carbonic beds without known coal-beds. All these deposits, according to Zeiller, belong to about one epoch, namely, Lower Permic or transitional to Permic. The flora is a mixed one and embraces an older Permic flora of the Northern Hemisphere, with elements of the Glossopteris flora of the Southern Hemisphere. This flora lends support to the acceptance of a great Brazil-India-South African and Australian continent, known as Gondwana Land, on the north-western coast of which lay the Amazon sea. At the same time, the eastern Amazon continent was possibly a portion of that bridge over which the southern Brazil floras connected with the European boreal Carbonic.

At the close of Neo-Carbonic time, the sea of the Lower Amazon retreated, and thereafter the interior of this extended land, as far as observations will permit of judging, was not again subjected to marine deposits.

Of marine Triassic and Jurassic there is not a trace in the Amazon region, and the same is true of marine Cretacic in the interior of the land. Along the Atlantic coast one only meets with a narrow fringe of young Cretacic marine sediments, and the same condition prevails in the southern states of Brazil, as Parahyba, Pernambuco, Alagóas, and Sergipe. A great marine Cenomanian Cretacic transgression, as given in several geological works, is not true of the interior of Brazil nor of the Amazon valley. This development is as follows:

With the beginning of the Mesozoic, to the old Guiana-east-Amazonian land, there was added the young Paleozoic deposits, and the resulting Guiana-Brazilian continent formed the eastern shore of the Triassic sea whose deposits are found in the Andes. The southern Pacific continent of this time remained as it was during older Paleozoic time. At the close of the Jurassic the sea extended and spread toward the east.

The first indications of the Atlantic and its transgression upon the land of northern South America took place in Upper Jurassic time.

The Guiana-Brazilian continent, which extends southward across the Amazon region, was maintained, although decreased in size along the east, and dissolved into islands toward the southeast. Similarly, there still existed the old land connections between South Africa and southern South America on the one side, and on the other with Australia and New Zealand.

Between these two continents the inclosed sea of about Middle Cretacic time began to enlarge and covered portions of the state of Sergipe, where Cretacic deposits rich in ammonites discordantly rest upon the Paleozoic. Dr. Charles A. White referred these beds to the Upper Cretacic; F. Kossmat, to the Cenomanian; Douville, to the Upper Albian (Gault). In all probability they belong to the transition zone between the Lower and Upper Chalk, and indicate a restricted Cenomanian marine extension over this part of Brazil.

Incomparably larger, however, was the transgression of the youngest Chalk (Senonian, in part Danian), which also touched the lower Amazon region. This transgression was from the south, attaining first Sergipe, later Pernambuco, and finally also Pará. The main part of the Sergipe Chalk belongs at the base of the Upper Cretacic, but some faunal elements indicate the presence of higher zones (Turonian, even Senonian). In Pernambuco the Senonian prevails, and in Pará, only Senonian, with some transition to the Eocenic.

During the continuance of the east-Brazilian Cretacic transgression there existed on the north side of the Guiana-Amazonian land an old ocean strait extending over the Antilles, Venezuela, and Columbia, to Peru. These are the Hippurite and Actäonella deposits of Jamaica, the Gault and Lower Senonian of Venezuela, the Chalk of Columbia, and the Upper Albian and Senonian of Peru.

During the Tertiary the lower Amazon region remained land—i. e., in the sense that it was not covered by the sea. The land waters continued to flow into the Pacific until Miocenic time, before the elevation of the Cordilleras. In Middle Miocenic, the drainage was reversed, lakes were formed, and finally a great lake covered the entire low land between the Guiana-east-Amazon land on the east and the continually rising Cordilleras in the west, extended from Naute to Madeira and from middle Parú to the Rio Negro.

As a result of the continued elevation of the Cordilleras, the connection between the Atlantic and the Pacific ceased in young Miocenic time, and South America was then united with North America. At this time *Mastodon* came from the north, as *M. humboldti* and *M. andium* are found in the young Miocenic deposits of the middle Amazon (Parú) region.

"A retrospect over the present short presentation brings out most clearly that the entire younger geological history of the lower Amazon region, beginning with about the Permian, took place upon the land. From this it follows that the local floras and faunas must have been continuous and that they were spared great disturbances. This, in fact, is shown by certain details, as the very ancient forms of fishes, as Lepidosiren, have been enabled to continue to the present. This hypothesis, however, will become clearer when the organic remains of the Tertiary deposits are better known. Their gathering and study are now the most important task of geological investigation on the sunny shores of the majestic great river: Amazon."

PART II. SILURIC SYSTEM

The Siluric strata, Derby (**6**:167) states,

> appear on the Guiana side in a belt of a few miles in width, which extends in the direction east-west for a considerable distance, if not along the whole southern margin of the metamorphic region to Guiana. They have been recognized on the Trombetas, Curuá, and Maecurú, and . . . . I judge that they extend eastward nearly to the Atlantic. I estimate the total thickness of the series at about 1,000 feet.

In the valley of the Trombetas this series rests unconformably upon felsite or eurite (**6**:145). It

> consists almost exclusively of hard argillaceous and micaceous [variously colored, white, yellow, red, and purple] sandstones, generally thin bedded, but with some massive beds of pure sandstone. . . . . One set of beds of cherty schist, about 20 feet thick, is found at the base of the series, in contact with syenite. . . . . Just above the cherty rocks there is a bed of fine-grained, yellowish sandstone containing a few fossils (**6**:168).

These fossils, according to Clarke (**5**), are of the following species, restricted to Brazil: *Lingulops derbyi*, *Orbiculoidea hartti*, *Pholidops trombetana*, *Orthis callactis amazonica*, *Dalmanella freitana*, *D. smithi*, *Chonetes* cf. *novascoticus*, *Anabia paraia*, *Anodontopsis putilla*, *A. austrina*, *Tellinomya pulchella*, *T. subrecta*, *Clidophorus brazilianus*, *Bucaniella trilobata viromundo*, *Tentaculites trombetensis*, *Conularia amazonica*, *Primitia minuta*, *Bollia lata brasiliensis.*

In higher beds occurs *Arthrophycus alleghaniensis.*

Clarke (**5**) regards this fauna as transitional between Ordovicic and Siluric or Middle Siluric, but quite different from that of the island of Anticosti. Derby (**6**:168) states that it indicates "a close correspondence with the Medina sandstone." Katzer refers it to the lower portion of the Siluric.

The correlations of these authors are harmonious, but the question is raised: What is meant by transitional between Ordovicic and Siluric? In other words, is the Brazilian Siluric fauna comparable with the Medina of the Appalachian region or with the Middle Siluric of Anticosti? Nothing definite can be said in regard to Anticosti Divisions 1 and 2, as these faunas need to be restudied in the light of modern knowledge. In regard to the Medina no new reading could be given, were it not for considerable evidence gathered by Ulrich in the Mississippi valley from Iowa south into Arkansas, and as yet unpublished. Underlying unmistakable Clinton faunas of the Interior type (Dayton, Ohio) he has found a zone usually quite thin and intimately connected with the highest Ordovicic or the uppermost Richmond member of the Cincinnatian division. In this zone, near Edgewood, Mo., Ulrich has collected a Stromatoporoid of Siluric character, *Zaphrentis* n. sp., *Favosites* near *asper*, *Calapoecia canadensis*, *Tentaculites incurvus*, *Dalmanella* of the *meeki* or *jugosa* type, *Leptaena rhomboidalis*, *Schuchertella missouriensis* (earliest appearance of this genus), *Rhynchotrema* n. sp. (near *inaequivalvis.* No *R. capax* occurs in this fauna, the diagnostic species of the Richmond formation), *R.* near *dentata*, *Triplecia* n. sp. (a form externally with the characters of *Atrypa rugosa* or *A. marginalis*), *Clorinda* (all other forms of this genus are Siluric), *Atrypa* near *marginalis* (a decided Siluric reminder), *Zygospira putilla*, *Cypricardinia* near *arrata* (earliest occurrence of this genus), *Conradella* near *dyeri*, *Encrinurus* of Siluric character, *Calymene* near *niagarensis*, and *Homalonotus*. In other places at about this same horizon have been found *Halysites*, *Lingulops*, *Pholidops*, *Orthis* near *callactis* and *Rhynchotreta* near *cuneata.* This fauna therefore immediately suggests the Brazilian Siluric and links it unmistakably also with the Richmond below, but less so with the Clinton above. More recently Ulrich has re-examined the Medina deposits of the Appalachian region, more especially in Pennsylvania, Virginia, and Tennessee, and has concluded that they are the eastern shore deposits equivalent to the Richmond series of the Ohio and Mississippi valleys. This result therefore forces stratigraphers to place the line separating the Siluric from the Ordovicic, not at the base of the Medina formation of the New York standard section, but at its uppermost limit and beneath the Clinton. *Arthrophycus harlani*, which should be written *A. alleghaniensis* (Harlan), and *Daedalus archimedes*[1] are therefore not the guide fossils to indicate the base of the American Siluric, but mark the marginal littoral facies of the sea toward the close of the Ordovicic. This reference of *Arthrophycus* to the Ordovicic is in harmony with its similar occurrence in Portugal. It will eventually be shown by Ulrich that the Medina is Ordovicic in age, and when his work appears it will be seen that the Brazilian fauna fits in well with the Mississippi valley highest Richmond, and that the lost time interval between the Ordovicic and Siluric is not long. This reference of these formations to the Ordovicic is also in harmony with the sequence in Russia along the shore of the Baltic Sea. Here the Lyckholm and Borkholm beds have many Siluric corals and brachiopods, but the European stratigraphers always regard these formations as belonging to the Ordo-

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[1] Sarle, "Arthrophycus and Daedalus of Burrow Origin," *Proceedings of the Rochester Academy of Sciences*, Vol. IV (1906), pp. 204–10.

vicic. Then follow faunas comparable with those of the American Clinton and the higher Niagaran formations.

DEVONIC SYSTEM

The Devonic of the state of Pará consists of marine littoral deposits. All the fossil localities are to the north of the Amazon.

The most complete development of the Devonic is that of the valley of the Rio Maecurú. Here, according to Katzer (p. 191), the sequence is the following (zones 2 and 3 are referred by the present writer to the Ereré formation of Derby, and 4, 5, and 6 to the Maecurú of Derby):

Upper Carbonic.

Unconformity.

1. Black, in part thin-layered shales, with lenticular beds of sandstone and very large concretions of highly bituminous blue-black limestone. Toward the top the beds are rich in pyrite. Thickness not determined, but considerable. The only known fossils are *Spirophyton* and *Nuculites ererensis.* Curuá formation of Derby.

2. A series of reddish, micaceous, sandy shales or shaly sandstones. Thickness not given. The only fossils are *Spirifer pedroanus*, *Camarotoechia dotis*, and *Tentaculites eldredgianus.*

3. Dark-gray or blackish, rough-layered sandstone, without fossils. Thickness, 10^m.

4. Hornstone. Thickness, 10^m.

5. Sandstone full of fossils. It is from this horizon that most of the fossils of the Rio Maecurú are derived. (See faunal list.) Thickness not given, but on the Rio Curuá, about 10^m thick.

6. Thin-layered sandstones interspersed with shales. Thickness not given, but probably about 10^m to 15^m.

Siluric sandstones.

West of the Rio Maecurú (about 25 miles), on the Rio Curuá, the entire thickness of the Devonic is about 50^m, and the system seems to rest comformably upon the Siluric. The development in both places is analogous.

To the east of the Rio Maecurú (about 75 miles) there is another good exposure of the Devonic in the bays of the Campo of Ereré. The exposures indicate a thickness of about 75^m. In many places this Devonic is traversed by dikes of diabase. Here the sequence is the following (zones (1 ?) 2 and 3 are referred by the present writer to the Ereré formation, and 4 is the top of the Maecurú):

Upper Carbonic.

1. Black shales, in part sandy and micaceous. Locally fossiliferous. Thickness estimated at from 15^{m} to 20^{m}, but increases to the north. Toward the top these beds are interbedded with, and finally covered by, masses of "schalstein," attaining a thickness up to 40^{m}.

2. Thin-bedded to shaly sandstone, with hematite particles colored rose to brown-red. Single thin zones are very rich in fossils. (See faunal list.) Some interspersed beds are gray; others, white. Thickness, probably not less than 25^{m}.

3. Alternating dark-gray to black sandstones and black bituminous and coaly shales. Toward the top occur rarely *Orbiculoidea lodensis*, var., and small *Lingula*. Thickness, about 20^{m}.

4. Black, tough, thin-bedded hornstones, with interbedded seams of sandy or clayey beds. These weather to light gray, also red and banded. Traces of fossils. Thickness, about 10^{m}. This zone is correlated by Katzer with zone 4 of the Rio Maecurú section.

Balance concealed.

The above sections indicate that the Devonic of north Brazil is not less than 100^{m} thick (about 325 feet), 75^{m} of which occur above the base of the hornstone zone and 25^{m} beneath the same formation. This hornstone bed is provisionally suggested as the one distinguishing between the Lower Devonic and the Middle Devonic. This is done, because, on the one hand, it is the only place where a sharp lithic difference exists in the section; and, on the other, on account of the two distinct faunas occurring one beneath and the other above the hornstone zone. Whether a time break exists here cannot be determined from the published record, but the faunas indicate that the one from the Rio Maecurú and Rio Curuá, found beneath the hornstone, is to be correlated with the Oriskany, while that above the same zone, or the fauna of Ereré, is indicative of lower Middle Devonic.

Before proceeding to a general discussion regarding the interrelation of the Devonic faunas of South and North America, it will be best first to note the peculiarities of the Amazon faunas. A complete list of these faunas is given at the end of this paper.

Notes on the fauna of the Maecurú formation (=Oriskany).—Clarke (**5**:80) states that the trilobites

> indicate very strong early Devonian (Hercynian) traits. In fact, no other element of the fauna bears so strongly the impress of the earliest Devonian. . . . . It must therefore be conceded that the very early Devonian expression of the trilobitic element of the Maecurú fauna affects the time value of the entire faunal association.

Of the gastropods, the laterally compressed species of *Platyceras*, as *P. whitii*, *P. hussaki*, and *P. steinmanni*, are related to *P. compressum* Nettelroth, of the Louisville Onondaga. *P. hartti* is the type found in the Helderbergian and Oriskanian. The bellerophontids are of the type found in the German "Spiriferen-Sandstein" (=Lower Devonic). *Bucania freitasi* is of the *Bellerophon leda* type of the Hamilton, and *Ptomatis forbesi* has its nearest ally in *P. patulus* of the Onondaga and Hamilton.

Of the pelecypods, *Actinopteria eschwegii* is closely related to *A. boydi* of the Hamilton of New York and the Onondaga of Louisville. *Modiomorpha helmreicheni* and *M. sellowi* are representative of forms in the Schoharie grit and the Onondaga. *Taechomya rathbuni* and *T. freitasi* have affinities with Onondaga and "Spiriferen-Sandstein" species. *Cimitaria karsteni* is another form of the latter type.

Of brachiopods, *Productella maecuruensis* is related to *P. shumardiana* of the Louisville Onondaga. *Chonetes freitasi* is closely related to *C. macrostriata* Walcott, of the Lower Devonic of the Eureka District. *C. jerseyensis* Weller is another species of this type. *Anoplia nucleata* is a North American Upper and Lower Oriskanian and basal Onondaga species. Clarke (**5**:87) states that its existence in the Maecurú and Curuá faunas is of much significance. *Rhipidomella musculosa* is another characteristic North American Oriskanian form. Of alate *Spirifer* of the Oriskanian *S. cumberlandiae-intermedia* type there are three species (*S. buarquianus*, the guide fossil of the Maecurú formation, *S. coelhoanus*, and *S. derbyi*, *S. lauro-sodreanus* is of the *S. macropleura* type, and a similar undescribed form occurs in the Frog Mountain, Alabama, Oriskanian. *Anoplotheca flabellites* is one of the most characteristic Oriskanian brachiopods. In North America *Amphigenia elongata* is an Onondaga species, but in the Oriskanian of Illinois and Tennessee occurs the small variety *A.*

curta. *Tropidoleptus carinatus* is known in a single example from the Oriskanian of Maryland; it is also abundant in the Lower Devonic of Germany, and, as Williams has shown that this shell is also known in the Chemung, it therefore has lost its diagnostic value as a marker of the Hamilton formation. *Vitulina pustulosa* is thus far in eastern North America a good Hamilton marker, but in South America it is always found in faunas that have an older aspect.

This Maecurú fauna has ninety-two species, and of these the following six Oriskanian forms are known in it: (1) *Rhipidomella musculosa*, (2) *Leptostrophia perplana*, (3) *Anoplia nucleata*, (4) *Amphigenia elongata curta*, (5) *Anoplotheca flabellites*, and (6) *Tropidoleptus carinatus.* Certainly numbers 1, 3, and 5 are diagnostic of the Oriskanian, and are usually regarded as guide fossils. Combining these occurrences with the other facts mentioned above, it seems to the writer that there cannot be any doubt that the Maecurú fauna holds the horizon of the North American Oriskanian. If further proof of this is required, the reader is referred to Katzer's Plates X, XI, XII, and XV. On the other hand, the view of Clarke (who has studied nearly the entire fauna by the specimens), while not exactly that of the writer, is still not widely different (hardly one formation apart). He states (**5**:91, 92) the following:

> The opinion expressed by Derby [**6**:169] and Rathbun that the Maecurú and Ereré groups bear about the same stratigraphical and paleontological relation to each other as the Upper Helderberg group to the Hamilton, is supported by all evidence now accessible.
>
> It is indeed probable that the Maecurú group embraces elements of faunas that elsewhere precede those of the Upper Helderberg (Schoharie grit, Corniferous limestone), a fact indicated by the earlier expression of the trilobitic element and by the presence of certain molluscan species (*Platyceras hartti*, *Anoplia nucleata*) of the same import.

Notes on the fauna of the Ereré formation.—Hartt (**2**:213) in describing the Ereré locality states:

> This fauna has an unmistakable Devonian facies, but it is difficult to determine its exact equivalency. In some features, as for instance in *Spirifer pedroana*, which closely resembles *S. varicosa*, the fauna recalls that of the Corniferous, while in the occurrence of *Tropidoleptus* and *Vitulina* it approaches the Hamilton.

Rathbun (**3**:260) in his first studies of the Ereré brachiopods concludes:

> The Brachiopod fauna, such as it is, resembles so closely that of the Hamilton group of New York state as to leave no doubt that the beds in which it was found, the sandstones and shales of Ereré, represent about the same horizon as the Hamilton group of North America.

This view is repeated four years later (**4**:38).

Clarke (**5**:90), regarding this fauna, states:

> The middle Devonian composition of this fauna as determined originally from a study of the brachiopods is decided. It may well be regarded, in this respect alone, a miniature of the Hamilton fauna. The two trilobites *Homalonotus Oiara* and *Cryphaeus Paituna*, Hartt and Rathbun, all that are here known, fortify this resemblance presented by the Pelecypoda and there is no lack of harmony on the part of the Gasteropoda and Pteropoda. . . . . It is, with all its resemblance to the Hamilton, a more typical and better defined middle Devonian fauna than that.

The present writer does not *now* see wherein the Ereré fauna is "a miniature of the Hamilton fauna,"[1] and while he would refer it to a horizon about that of the Onondaga (Corniferous), he holds that it has no close faunistic relationship with it. It will therefore be well to examine more carefully into this conclusion of most students, that the Ereré horizon is that or about that of the Hamilton, to learn on what it is based.

The Ereré fauna consists of 45 species, 35 of which are restricted to the formation. Of the 45 species, 41 are found in the sandstones and 4 are restricted to the black shales beneath the sandstone. The 10 species also found in the Maecurú formation are *Dalmanella*

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[1] In a former paper (*American Geologist*, September, 1903, p. 152) the writer stated that "the southern portion of the Indiana basin also was open during Onondaga, Hamilton and Genesee time, establishing communication between the Mississippian sea and Brazil. Evidence of this is seen . . . . in the very similar faunas of the Hamilton of the Mississippian sea and that of the Ereré formation of the State of Pará." When this was written, too much reliance for correlation was given the Ereré species *Tropidoleptus carinatus*, *Vitulina pustulosa*, *Orbiculoidea lodensis*, and *Lingula spatulata*. On the other hand, at that time *Rhipidomella musculosa* and *Anoplotheca flabellites* were not known in the Maecurú, nor *Tropidoleptus carinatus* in the Maryland Oriskanian.

The writer still holds to the above statement that "the southern portion of the Indiana basin also was open during Onondaga, Hamilton and Genesee time," but with this correction, that the Mississippian sea did not have open faunal communication with Brazil; nor did either area have connection with Tethys at this time, because the Mississippian and Brazilian seas did not receive the *Calceola* nor the *Stringocephalus* fauna so characteristic of this mediterranean.

nettoana (Clarke thinks that the small Ereré specimens should be separated from the larger Maecurú form), *Vitulina pustulosa*, *Schuchertella agassizi*, *Chonetes comstocki*, *C. herbert-smithi*, *Camarotoechia dotis*??, *Spirifer pedroanus*, *Trigeria* (?) *wardiana*, *T.* (?) *jamesiana*, and *Tentaculites eldredgianus*. None of these perduring species appear to have significant stratigraphic value, either for Middle or Lower Devonic correlation.

Concerning the species restricted to the sandstone horizon, the following notes will help to a clearer understanding: *Lingula spatulata* is certainly not this New York Upper Devonic species. *Orbiculoidea lodensis* may be the New York Genesee form. However, any student of brachiopods knows how variable the species of those genera are, and that no safe identification can be made in similar forms so widely separated as those of the state of Pará, Brazil, and Kentucky. This is because in *Lingula* and *Orbiculoidea* there are so few characters present for comparison; further, when the shells are preserved in shales, they are invariably flattened. On the other hand, *Orbiculoidea lodensis* occurs beneath the Ereré fauna and not above it. *Tropidoleptus carinatus* in North America is now known in the Oriskanian, Hamilton, and Chemung, and is no longer diagnostic for the Middle Devonic of this continent. *Vitulina pustulosa*, it is true, is known only in the Hamilton of North America, but in South America it certainly occurs in older formations. *Chonetes onettianus* is related to *C. scitula* of the Hamilton and Chemung. Clarke suggests that *Spirifer pedroanus* may include two species similar to *S. mucronatus* and *S. audaculus*, two characteristic Middle Devonic forms. This species, however, as figured by Katzer, recalls the Lower Devonic *S. cumberlandiae*. *Modiomorpha pimentana* seems to be related to *M. concentrica* of the Hamilton. *Nuculites ererensis* suggests *N. oblongata* of the Hamilton. *Leda diversa* Hall and *Pholadella parallela* Hall are Hamilton species. The other forms not noted here do not teach anything specifically from the standpoint of the Hamilton or of the Middle Devonic.

In the Ereré fauna there are therefore four Hamilton species—*Tropidoleptus carinatus*, *Vitulina pustulosa*, *Leda diversa*, and *Pholadella parallela*. The first is no longer regarded as diagnostic for limited correlation within the Mississippian sea, and the second, outside of this area. The last two species, it is true, are Hamilton forms, but it would be claiming too much for them to state that their presence in the Ereré formation correlates it with the Hamilton. Knowledge of pelecypods is as yet too fragmentary for safe stratigraphic correlation. The genera present in the Ereré are almost without exception those of the Maecurú. The exceptions are: (1) *Goniophora*, (2) *Leda*, (3) *Pholadella*, (4) *Edmondia*, (5) *Tropidocyclus*, (6) *Pleurotomaria*, and (7) *Cryphaeus*. Numbers 1, 6, and 7 are known in the Lower Devonic or in still older formations. Numbers 2 and 4 have no restricted stratigraphic range. One is therefore limited to *Leda diversa*, *Pholadella parallela*, and the genus *Tropidocyclus*.

Viewing this proposition from another standpoint, it is seen that all the characteristic Hamilton corals, brachiopods, gastropods, and cephalopods are absent in the Ereré. This is also true for the Onondaga.

As the Amazon Devonic deposits are of a littoral nature and the combined known sections about 400 feet in thickness, one should not expect them to represent a long duration of time. At least 100 feet are of Lower Devonic age, comparable with the North American Oriskanian. The remainder appears to be about that of the Onondaga in age, but from the preceding remarks it seems clear that the two widely separated areas had at this time little, if any, free interchange of faunas. On the other hand, it is clear that there was considerable faunal intercommunication between the seas of Maecurú and the Oriskanian of the southern states of North America.

The presence of two Genesee brachiopods in the Ereré formation—*Orbiculoidea lodensis* variety and *Lingula spatula*?—led Clarke (**5**:91) to state that "we may regard these beds in the Ereré group [black shales] as embodying the equivalent of this Genesee shale fauna." The zone in which the former and three species of *Lingula* are found is, according to Katzer, the next one below the Ereré sandstone, and it cannot therefore be referred to the horizon of the Genesee without placing there also the entire Ererè fauna. The experience of the writer is that *Lingula*, *Orbiculoidea*, and other related inarticulate brachiopods have little stratigraphic value for correlation in widely separated areas.

Conclusion.—The present knowledge of the Amazon Devonic stratigraphy and faunas indicates that the Maecurú formation is near the top of the Lower Devonic, and is comparable with the North American Oriskanian, not only in its facies, but also in its having six of the guide fossils of the class Brachiopoda of the latter formation. These facts indicate, further, that the two areas (Brazil and the Oriskanian of the southern United States) were at this time in communication. The northward extension of the Amazon Maecurú fauna is known sparingly about Frog Mountain, Alabama, for here occurs *Spirifer arenosus*, **S. murchisoni*, and *Amphigenia*. This fauna is better represented in the region of Armuchee, near Rome, Georgia, as here are found **Rhipidomella musculosa*, *Stropheodonta magnifica*, *Anoplotheca dichotoma*, **Spirifer tribulis*, *Ambocoelia umbonata*, and *Meristella rostellata* n. sp. The best of the southern localities are in the Camden formation of Tennessee and southwestern Illinois. The more important forms found at the last-named localities are *Lingulopholis terminalis*, *Chonostrophia reversa*, **Anoplia nucleata*, *Metaplasia pyxidata*, **Spirifer tribulis*, **Anoplotheca flabellites*, *Eatonia peculiaris*, **Amphigenia curta*, and *Megalanteris condoni*.

The southern Oriskanian sea appears not to have connected openly, but rather sparingly northward, either across western or eastern Tennessee, with another basin of the same age whose deposits are found in the Appalachian (Cumberland sea)—Gaspé region. The northern basin is characterized by *Edriocrinus*, *Hipparionyx proximus*, *Spirifer arenosus*, and *Rensselaeria*, none of which are in the southern facies of the Oriskanian—the Camden-Armuchee-Frog-Mountain-Maecurú faunas. On the other hand, this southern Oriskanian has *Spirifer* of the *S. macropleura* type, *Amphigenia*, *Tropidoleptus* (one species has been found in Maryland), *Vitulina*, *Productella*, many pelecypods strongly reminding one of the American Middle Devonic faunas, and *Styliolina*, that either do not occur in the northern Oriskanian or make their appearance with the pronounced southern invasion of Onondaga time. In other words, the Oriskanian of the United States is not only an outgrowth of the Helderbergian fauna, but also has received many migrants from the southwest Brazilian-Pacific region and from the North Atlantic (Gaspé) along a path not

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*Either the same or a very closely related species also occurs in Brazil.

yet clearly made out, but seemingly more probably down the St. Lawrence-Connecticut depression than by way of the St. Lawrence-Champlain troughs.

The Ereré fauna is a direct outgrowth of the Maecurú and probably follows it without a time break. It seems to hold the horizon of the American Onondaga, hardly that of the Hamilton, and certainly there is nothing in it that indicates the Genesee fauna. The connection existing between Brazil and the lower Mississippi embayment during the Maecurú was destroyed during Ereré time, as all of the guide fossils of the Onondaga and Hamilton fail of representation in the Amazon formations.

CURUÁ FORMATION OF DERBY

Above the Ereré formation occurs a series of "black [lower 300 feet] and red shales, passing at times into a shaly sandstone" (Derby **6**:170). Their thickness is estimated to be about 600 feet. This formation occurs on the rivers Maecurú, Curuá, Trombetas, and Tapajos, and near Ereré.

"In both the black and red shale, near the junction of the two," Derby (**16**:171) found *Spirophyton typum* Hall and the sporangia *Protosalvania braziliensis* and *P. bilobata.* The relation of these beds to the Devonic and Carbonic is not yet established, according to Katzer, and he refers them provisionally to the Carbonic, as did Hartt. Derby and Clarke, however, place them in the higher Devonic. Clarke also reports the presence of the Ereré species *Nuculites ererensis.*

Katzer states that *Spirophyton* is found with *Productus cora* and *P. sublaevis* in the Carbonic limestones of Dompierre. In the Flysch of Europe this fucoid or "hieroglyph" (=a burrow probably of a polychaete worm) is widely distributed. As the occurrence of *Spirophyton* has no satisfactory time value, Katzer refers these black and red shales with concretions to the Carbonic.

GENERAL DISCUSSION

The older Devonic deposits of the Amazon region are also known in the Brazilian states Matto Grosso and Parana; also in Bolivia, Peru, Argentina, and apparently also in Paraguay and the Falkland

Islands. Everywhere the petrographic character of these deposits is similar and points to littoral conditions. Katzer states that this distribution forces the conclusion that in the north and east, in the region of Guiana-Cegra, there was a bordering Archean continent, to the south of which lay the sea in which the Amazon sandy deposits were laid down. The land was actually but the western end of the *Atlantic-Ethiopian continent.* A second continent in the southwest extended from southern Chili and Patagonia westward over a portion of the present Pacific Ocean and probably beyond southern Georgia. This Katzer has named the *Southern Pacific Continent.*

The Brazilian Devonic sea, the author continues, is connected on the one side with that of New York (it would be better to say North America), and on the other with South Africa (Cape Colony), because the faunas of these two areas are to a great extent harmonious.[1] Less decided, but still surprisingly great, when one takes into consideration the long distances, is the harmony between this older or Lower Devonic fauna and those of Australia, Asia, and Europe.

The Lower Coblenzian faunas of Rhenish Germany remind one forcibly of American Oriskanian. To bring out this fact more clearly in this place, but a short account of the Siegen fauna can be given, the following being the more important forms: *Craniella*, *Orbiculoidea anomala* (like American *O. ampla*), *Schizophoria provulvaria*, *S. personata* (like *S. oriskania* soon to be published), *Leptostrophia explanata* (like large Oriskany species). *Stropheodonta sedgwicki* (type of *S. demissa* now known in Maryland Oriskanian), *Schuchertella gigas* (often reported as a *Hipparionyx*), *Eatonia*, *Rhynchonella papilio* (type of *Plethorhyncha barrandei*), *Rennselaeria* (?)

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[1] The lower Devonic fauna of South Africa has recently been described by Reed (*Annals of the South African Museum*, Vol. IV, Pts. III and IV, 1903–4). These Bokkeveld beds are faunally very closely related to the Amazonian, and especially to the Falkland Islands faunas. Common to two or more of these areas may be mentioned the following: *Orbiculoidea baini*, *Schuchertella sulivani*, *Chonetes falklandicus*, *Spirifer orbignyi*, *S. lauro-sodreanus*, *Ambocoelia umbonata*, *Leptocoelia flabellites*, *Vitulina pustulosa*, *Tropidoleptus carinatus*. Nearly all the gastropods and pelecypods of the Bokkeveld beds are compared by Reed with Amazon species. There are at least fifteen such forms. "The presence of a true *Cryphaeus* and of spiny forms of *Homalonotus* indicates that the beds may be referred with certainty to the Devonian, and it is probable that they belong to the lower division of that formation" (Reed, Vol. IV, p. 202).

crassicosta (these shells look more like *Plethorhyncha speciosa*) *Trigeria* (?) *oehlerti* (*Leptocoelia* with excessive fold and sinus), *Tropidoleptus carinatus rhenanus*, *Megalanteris*, *Spirifer primaevus* (type of *S. murchisoni*). The following remind one strongly of the Maecurú facies: *Actinodesma*, *Cypricardella*, *Leptodomus*, *Goniophora*, *Grammysia* (large forms), *Modiomorpha* (large forms), *Sphenotus*, *Pteronites*, *Limoptera*, *Cryphaeus*, and *Homalonotus*.

For a modern work on this fauna, see Dreverman, *Palaeontographica*, Vol. L (1904), pp. 329–87, 5 plates. Even a glance at these plates will lead American workers to see an earlier development of their Hamilton fauna. European stratigraphers invariably regard the Siegan as Lower Devonic.

Compared with North America, the Amazon Devonic, according to Katzer, proves to be a mixture of Oriskanian, some Helderbergian and more especially New York Hamilton. Formerly Katzer regarded all the Devonic of the Amazon as Middle Devonic. He now considers that the Hamilton cannot be considered as uppermost Middle Devonic, but that part of it must be referred to the Lower Devonic—a view in which he will have few, if any, followers. This conclusion is largely based on the early occurrence in South America (Maecurú) of *Vitulina pustulosa*, *Tropidoleptus carinatus*, large *Grammysia*, *Leioptera*, *Actinoptera* of the *boydi* type, and the high or Hamilton occurrence of these types in North America.

Katzer's difficulties would have vanished if he had correlated the Maecurú and Curuá deposits with the Oriskany of the Lower Devonic. That this correlation is a more accurate one is borne out by the fauna, as has been shown by the present writer.

It has also been shown that the Ereré fauna has not the facies of the Onondaga nor of the Hamilton. This dissimilarity is partially explained by the Amazon coarse littoral deposits, an unnatural habitat for an extensive coral fauna as that of the American Middle Devonic. However, the Ereré fauna is wholly a direct outgrowth of that of the Maecurú, while the Onondaga (Corniferous) is a development out of the Oriskanian of the type of the northern province plus an eastern North Atlantic invasion (the *Spirifer cultrijugatus* fauna of the Rhine at the base of the Middle Devonic), and another from the south through the Mississippi embayment bringing in some of the prolific coral faunas so abundantly developed about Louisville, Kentucky.

The reason why the Lower Devonic faunas of northern Europe, North America, and South America have so much that closely binds them together is because the oceans of these areas were in communication. This is strikingly shown in the great pelecypod development of the Coblenzian of the Rhine region—genera upon genera almost unknown in the Oriskanian making their first appearance in some force in the Onondaga, and being in full development in the Hamilton. The Coblenzian pelecypod development in Europe is very largely wiped out or changed by the great Euro-Asiatic invasian coming in just above the *Spirifer cultrijugatus* fauna, which is known as the Calceola fauna holding the horizon of the Onondaga in this country. This fauna continues without very great change into the Stringocephalus fauna holding the horizon of the Hamilton. While this great invasion of Middle Devonic Euro-Asiatic faunas was proceeding normally in Europe, the North American Middle Devonic had but little connection with that region, and the fauna of a lower Devonic facies was continued to the end of Hamilton time, when another great physical change occurred, and northern Europe and America were once more in communication.

CARBONIC

The marine Carbonic of the Lower Amazonas is divisible into two divisions—a lower consisting essentially of sandstone, and an upper of limestone. Of each division about 10^{m} thickness is known. The limestone is locally very rich in well-preserved, often silicious fossils, and these indicate that it is of Permo-Carbonic age. The sandstone is devoid of fossils and of coal-beds, and, further, as the stratigraphic relation to the limestone is nowhere clearly shown, its actual age remains undetermined. The best exposures are those of the Tapajos. Beneath the sandstone is a series of shales and shaly sandstone—the Curuá group of Derby, and referred by him and Clarke to the Devonic (see statement under Devonic), but provisionally referred by Katzer to the Carbonic.

During the time of limestone deposition there were effusions of diabase and porphyry, giving rise to hornstones and dark limestones with the fossils transformed into silicious pseudomorphs.

Much of this fauna remains unworked. Some of the leading fossils are: *Lophophyllum* near *proliferum*, *Lonsdaleia rudis*, *Rhipidomella penniana*, *Orthotichia morganiana*, *Schuchertella tapajotensis*, *Streptorhynchus hallianus*, *Orthotetes correana*, *Chonetes glaber*, *Strophalosia cornelliana*, *Productus semireticulatus*, *P. lineatus*, *P. cora* and seven other species, *Spirifer cameratus*, *S. condor*, *S. rockymontanus*, *Spiriferina transversa*, *S. spinosa*, *Reticularia perplexa*, *Ambocoelia planoconvexa*, *Hustedia mormoni*, *Seminula argentea*, *Cleiothyris royssii*, *Aviculopecten occidentalis*, *A. herzeri*, *Lima retifera*, *Pinna peracuta*, *Myalina kansasensis*, *Allorisma subcuneata*, *Platyceras nebrascensis*, *Pleurotomaria speciosa*, *Euphemus carbonarius*, *Bellerophon crassus*. (For a complete list, see Katzer, pp. 162–67.)

Another well-known area for Carbonic is that of the Trombetas. The observed thickness is a little over 6^m. The fauna here is a smaller one (seventeen species) than that of the Tapajos (115 species), but the species are the same in both areas.

Katzer regards the Tapajos faunas as highest Upper Carbonic, and not of Lower Permic age as did Waagen. Derby (**6**:173) states:

> The fauna shows the closest relationship to that of the Coal Measures of the Western States, more than half of the species being identical. I have already shown that the Bolivian and Peruvian Carboniferous faunas, as far as they are known, are equivalent to the Brazilian, and to that of the North American Coal Measures.

To the north of the Amazon River the Carbonic is known along the river Curuá and in the region north of Alemquer (Katzer). It consists here of sandstones and gray sandy-calcareous shales with a thickness estimated at 200^m. The fauna obtained here Derby regards as of the same age as that of the Tapajos.

> Of all the Palaeozoic deposits of the Amazonas, those of the Carboniferous occupy the most extensive area and, at the same time, present the greatest difficulties to study. Composed for the most part of soft beds, they suffered extensive denudation, during the interval between the close of the Carboniferous and the beginning of the Tertiary, during which time they were, for the most part, exposed above the level of the sea. . . . . Mr Smith, who has best studied these deposits, is of the opinion that their total thickness is not less than 2,000 feet, and, although the data for the calculation is very defective, I cannot say that it is exaggerated (Derby, **6**:171).

TABLE OF DEVONIC FAUNAS

(Unidentified species and species without decided value are not listed here. c=common; r=rare.)

	Lower Maecurú Formation	Upper Maecurú Formation	Rio Curuá	Ereré Formation Zone 2 of Section
CORALS				
Pleurodictyum amazonicum Katzer	c			
BRYOZOA				
Rhombopora ambigua Katzer	c			
Reptaria stolonifera Rolle	x			
Chaetetes carvalhoanus Katzer	x			
BRACHIOPODA				
Lingula spatulata (not *L. spatulata* Hall)				x
" ererensis Rathbun				x
" rodriguesii Rathbun (from zone 3 at base of Ereré)				r
" stauntoniana Rathbun (from zone 3 at base of Ereré)				x
" gracana Rathbun (from zone 3 at base of Ereré)				r
Orbiculoidea lodensis Hall variety (from zone 3 at base of Ereré)				c
Dalmanella nettoana (Rathbun)	c		x	x
Rhipidomella hartti (Rathbun)	c		x	
" musculosa (Hall)	x			
Leptostrophia perplana (Conrad)	c		c	
Stropheodonta (?) hoeferi (Katzer)	x			
Tropidoleptus carinatus (Conrad)				r
" " maecuruensis Katzer	c		c	
Vitulina pustulosa Hall	c		r	c
Schuchertella agassizi (Hartt)	c		x	c
Chonetes comstockii Hartt	c			c
" onettianus Rathbun (related to *C. scitula*)				x
" herbert-smithi Hartt	x			c
" freitasii Rathbun	c		x	?
" curuaensis Rathbun	?		r	
Anoplia nucleata (Hall); identified by Clarke	x		x	
Productella maecuruensis Rathbun	r			
Rhynchonella ererensis Rathbun (not figured; based on one dorsal shell)				r
Camarotoechia dotis (Hall) ??	c	c		r
" cf. sappho (Hall)	x		x	
Amphigenia elongata Hall	c		c	
Spirifer buarquianus Rathbun	c			
" " var. contracta Katzer	c			
" " " alata Katzer	c			
" coelhoanus Katzer	c			
" clarkei Katzer	r			
" duodenarius Hall ? (probably not this species)	c			
" derbyi Rathbun (related to *S. murchisoni*)	r			
" hartti Rathbun	r			

TABLE OF DEVONIC FAUNAS—*Continued*

	Lower Maecurú Formation	Upper Maecurú Formation	Rio Curuá	Ereré Formation Zone 2 of Section
BRACHIOPODA—*Continued*				
Spirifer lauro-sodrianus Hartt (related to *S. macropleura*	r			
“ pedroanus Hartt	r	x	r	c
“ valenteanus Hartt (not figured; a poor species)				r
Cyrtina (?) curupira Rathbun				r
“ maecuruensis (Rathbun)	r		x	
Anoplotheca flabellites (Conrad)	x			
Terebratula rathbuni Clarke	x		x	
“ derbyana Hartt				c
Trigeria (?) jamesiana (Hartt)	c			c
“ “ wardiana Hartt	r		r	c
Oriskania (?) navicella Hall & Clarke (identified by Katzer)	r			
This is no Oriskania, nor is it H. & C. species				
PELECYPODA				
Actinopteria eschwegii Clarke (related to *A. boydi*)	c		r	
“ humboldti Clarke	c			
Leiopteria browni Clarke	r			
“ sawkinsi Clarke			r	
Aviculopecten coelhoanus Katzer	r			
Modiomorpha helmreicheni Clarke (of the early depressed type)	c			
Modiomorpha sellowi Clarke (related to *M. complanata* of the Onondaga)	c			
Modiomorpha pimentana Hartt & Rathbun				c
Nucula bellistriata parvula Clarke (a Hamilton form)	r			
“ kayseri Clarke				r
Nuculites ererensis Hartt & Rathbun (also in higher “ Curuá)				r
“ majora Clarke				c
“ branneri Clarke				c
“ smithi Clarke	x			
Palaeoneilo sulcata Hartt & Rathbun	x			
“ pondiana (Hartt & Rathbun)				r
“ (?) simplex Hartt & Rathbun				r
“ orbignyi Clarke	c			
Leda diversa Hall (a New York Hamilton species)				r
Guerangeria (Nyassa ?) ortoni Clarke	r			
Goniophora woodwardi Clarke				r
Toechomia rathbuni Clarke	c			
“ freitasi Clarke	c			
Sphenotus gorceixi Clarke				c
“ bodenbenderi Clarke	r			
Cimitaria karsteni Clarke	r			
Cypricardella hartti Clarke	c			
“ (?) pohli Clarke	r			
Pholadella parallela Hall (a New York Hamilton species)				r

TABLE OF DEVONIC FAUNAS—*Continued*

	Lower Maecurú Formation	Upper Maecurú Formation	Rio Curuá	Ereré Formation Zone 2 of Section
PELECYPODA—*Continued*				
Grammysia ulrichi Clarke				r
“ pissisi Clarke	c			
“ burmeisteri Clarke	r			
“ lundi Clarke	c			
“ gardeneri Clarke	r			
Edmondia sylvana Hartt & Rathbun				r
GASTROPODA				
Bellerophon stelzneri Clarke			r	
“ morganianus Hartt & Rathbun				c
Bucaniella coutinhoana (Hartt & Rathbun)				c
“ reissi Clarke	x			
Bucania freitasi Clarke	r			
Plectonotus derbyi Clarke	r			
“ (?) salteri Clarke	x			
Ptomiatis forbesi Clarke	r			
Platyceras whitei Clarke	r			
“ “ curua Clarke			r	
“ hussaki Clarke	r			
“ steinmanni Clarke	r			
Platyceras hartti Clarke (related to *P. ventricosus*)	x			
“ symmetricum Hall ?				r
“ “ maecuruensis Clarke	r			
“ meerwarthi Katzer	r			
“ tschernyschewi Katzer	r			
“ coutoanus Katzer	r			
“ gracilis Katzer	r			
“ subconicum Katzer	c			
Diaphorostoma furmanianum (Hartt & Rathbun)				x
“ darwini Clarke	x		c	
“ (?) agassizi Clarke	r			
Strophostylus varians Hall	x			
Tropidocyclus gilletianus (Hartt & Rathbun)				c
Pleurotomaria rochana Hartt & Rathbun				c
PTEROPODA				
Tentaculites eldredgianus Hartt & Rathbun	c	x		c
“ stübeli Clarke	c			
“ tenellus Katzer	r			
“ osseryi Clarke			c	
Styliolina clavulus (Barrande); according to Katzer	x			
TRILOBITES				
Homalonotus (Trimerus) derbyi Clarke	c			
“ (?) acanthurus Clarke	r			
“ (Dipleura) oiara Hartt & Rathbun				r
Phacops brasiliensis Clarke	c			
“ menurus Clarke	r			

TABLE OF DEVONIC FAUNAS—*Continued*

	Lower Maecurú Formation	Upper Maecurú Formation	Rio Curuá	Ereré Formation Zone 2 of Section
TRILOBITES—*Continued*				
Phacops scirpeus Clarke	r			
“ (?) pullinus Clarke	c			
“ goeldii Katzer	r			
“ (?) macropyge Clarke	c			
Dalmanites (Odontocheile) maecurua Clarke	c			
“ “ australis Clarke	r			
“ (Acaste) galea Clarke	c			
“ (Hausmanni) infractus Clarke	r			
“ “ tumilobus Clarke	c			
“ “ gemellus Clarke	r			
“ “ ulrichi Katzer				r
Cryphaeus paituna (Hartt & Rathbun)				c
Species in each horizon	92	3	22	45
Restricted species	71	0	5	35

Common to Maecurú and Curuá	16
Common to Ereré and either of the others	10
Common to Ereré and Maecurú	10
Common to Ereré and Curuá	5
Entire Devonic fauna	131

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THE RELATION OF RADIOACTIVITY TO VULCANISM

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Within the last year or two those working in the rapidly growing science of radioactivity and sub-atomic systems have discovered a number of properties and relations that bear strongly on earth processes and theories, and that are of daily increasing interest to the geologist, many of whose problems are being made to assume a new light. Very recently (April, 1906) Major Dutton[1] presented a paper to the National Academy of Sciences in which the results of the investigators of radioactivity have been brought into relation with geological phenomena to construct a definite explanation of volcanic action.

In discussing the competency of radioactivity to produce the local high-temperature effects which are essential to volcanic action, it is desirable to consider first the relationship of radioactivity to the general thermal condition of the earth's interior. Since Major Dutton's paper was prepared, R. J. Strutt[2] has published an account of some tests made on various igneous rocks from different parts of the world, with the result that the earlier conclusions as to the relation of earth heat to radioactivity are made much more secure and definite. In general it may be said that all the igneous rocks examined (they were selected to represent different parts of the earth and different rock types) show distinct radioactivity, the most active being the more acid granites and syenites; the least active, basalts and various ultrabasic rocks. Division into more active and less active specimens does not correspond absolutely to rock types, but very generally so. The range in content is calculated at from 1.84×10^{-12} to 25.5×10^{-12} grams of radium per cubic centimeter of rock, or

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[1] See *Popular Science Monthly*, June 1906, pp. 542–50; also *Journal of Geology*, Vol. XIV, pp. 259–68 (June, 1906).

[2] R. J. Strutt, "On the Distribution of Radium in the Earth's Crust, and on the Earth's Internal Heat," *Proceedings of the Royal Society*, Ser. A, Vol. LXXVII (1906), pp. 472–85.

0.613×10^{-12} to 9.56×10^{-12} grams of radium per gram of rock. All samples showing above 3.37×10^{-12} grams of radium per gram of rock are granites or syenites; the basalts and peridotites are all below 1.86×10^{-12}.

Strutt shows that if the interior of the earth be considered at thermal equilibrium, and if the whole amount of heat is due only to radium (part must be due to uranium and other active elements), and "always supposing that the heat production of radium is not materially diminished, under conditions prevailing inside the earth;" if, further, the radium be considered evenly distributed throughout the earth mass, it cannot much exceed 1.75×10^{-13} grams per cubic centimeter. Rutherford,[1] using somewhat different values for temperature gradient, etc., calculates the equivalent in radium bromide as 2.6×10^{-13} grams per cubic centimeter or 1.52×10^{-13} grams radium. But the weakest rock examined (Disco Island basalt) gives tests over ten times this amount, and the granites 240 or 250 times! The question becomes, then, why is the interior so cool? Strutt offers the explanation that only the external or crustal portions of the earth are radioactive. Taking the moderate value of 5×10^{-12} grams radium per cubic centimeter as representing the average rocks of the crust, radioactive rocks need extend only 45 miles below the surface to establish the present temperature gradient. If we assume that the granites represent the constitution of the outer crust, 5 or 6 miles are sufficient; if basalts of the weakest activity so far examined, only 96 miles are necessary.[2]

As supporting his assumption of a crustal layer of 45 miles or less in thickness and of different constitution from the interior, Strutt refers to the conclusions of Professor Milne that a study of the propagation of earthquake waves through the earth's interior indicates a rather abrupt change at about 30 miles' depth, the material below that being rather uniform throughout the globe.

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[1] Rutherford, *Radioactivity*, 2d ed. (Cambridge, 1905), p. 494.

[2] To account for the greater density of the interior of the earth, and from the hint given by the constitution of meteorites, we may suspect that the inner parts of the earth are of "basic" materials. The limit of basic materials tested is found in meteoric iron, which gives no measurable radioactivity. We may well suspect, then, that the radioactive crust is rather thin, the amount of activity not being constant to a certain definite point, but gradually decreasing toward a zero value at somewhere between 30 and 90 miles in depth.

There are other highly suggestive features to Strutt's paper, but let us consider the geological bearing of those already presented. First, it seems probable that we have a hitherto unconsidered supply of heat capable of maintaining for an exceedingly long period the known temperature gradient within the earth, and, in fact, necessitating the introduction of restrictions as to interior distribution in order to account for the lack of a higher than the observed gradient. As Strutt suggests, an assumption that the earth is getting hotter is "not likely to be regarded with favor." But that we have a condition of equilibrium seems quite possible, and, if not equilibrium, there must at least be a condition of very much slower cooling than the calculated loss by conduction to the surface would indicate. In this latter case we may still assume that the earth's heat has been derived from two groups of sources: one, the initial condition and relative positions of its constituent atoms, molecules, and masses, acting as outlined by one of the nebular or solid accretion hypotheses; the other, radioactivity or, more broadly, sub-atomic changes. This latter has probably varied but little for a long period of time.[1] If the condition at present is one of practical equilibrium, or not far removed therefrom, it means that the effects of any original high temperature (such as assumed by the nebular hypotheses) are now exceedingly slight, and as, if such original temperature ever existed, it must have died out with a gradually decreasing rate, its effects must have been slight for a long period of time. It would seem, therefore, that the utmost caution should be used in any attempt to explain characteristics of the geological record, especially in its later part, in terms of any cosmic hypothesis assuming initial high temperatures.

The folding of zones of the earth's crust into mountain ranges or mountain systems and certain other diastrophic changes, in particular those giving rise to earthquakes, are very commonly referred, in whole or in part, to the contraction of the earth as it cools. But the indica-

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[1] It is supposed on very suggestive evidence that uranium is the parent of radium. Geologically considered, radium has a comparatively short life, breaking down with a velocity that decreases according to an exponential law and reaching half value in 1,300 years. The supply of radium is apparently maintained by the transformation of uranium, which is an exceedingly slow process, varying in velocity similarly to radium and reaching half value, according to Rutherford's calculation (*loc. cit.*, p. 458), in about 600,000,000 years or more.

tions from Strutt's measurements are to the effect that the earth is either not appreciably cooling or is doing so with excessive slowness. Post-Tertiary foldings can hardly be referred to such a cause, and probably early Tertiary and even Mesozoic movements should be excluded. On account of the fundamental similarity of the geological history of the steps leading to the formation of the systems of folds produced at different periods, it would seem reasonable to assume very similar causes and to believe that, at least since the opening of the Paleozoic,[1] contraction due to cooling is as unnecessary to explain the earlier as the later foldings.

If radioactivity may be accepted as a sufficient cause for the present thermal gradient, we must also conclude that no major contractional movements under the influence of self-gravitation have taken place in recent geological time of such magnitude as to give rise to any great addition of heat of mechanical origin.

Leaving now the general aspect and turning to the particular subject of volcanoes, we may accept radioactivity as the cause of the major part or all of the general internal heat, at least in late geologic time, and still have all of the special problems of vulcanism to face that have confronted those who assume other origins for the temperature gradient, and the same explanations might do equally well irrespective of the type of general hypothesis.

But Major Dutton[2] has put forward a more particular hypothesis to the effect that volcanoes are caused by local excessive radioactivity which melts small areas of rock near the surface and allows the expansive force of "water vapor to lift its covering and force a way to the surface." The rest of this communication is devoted to a discussion of the points involved in this very interesting and ingenious hypothesis.

The first point is the shallowness of the reservoir. Dutton estimates that "most of the volcanic eruptions originate at depths between one mile and two and one-half miles." The bearing of this point on the local-radiation hypothesis of volcanoes is that at such shallow depths the general earth heat cannot be invoked to produce the tem-

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[1] The post-Archean (pre-Paleozoic) foldings are sufficiently different—especially in their incomparably wide distribution and almost universal association with abundant plutonic intrusive masses—to invite a special treatment.

[2] *Loc. cit.*

peratures involved, and we must therefore assume some special heating agent in the cooler portions of the earth's crust. For by the normal temperature gradient 1,000° C. would be reached at not much less than about twenty miles[1] below the surface.

It would seem that the general chemical characters of lavas would be fatal to this contention. If the material extruded from volcanoes was chiefly derived from the melting of rock at the depth of from one to two and one-half miles, or even considerably deeper, the reservoirs would be largely within the zone of sediments, and lavas should frequently have a composition derivable from the major sedimentary types alone or mixed in various ways. But igneous rocks have a rather definite range in chemical composition, and there are general and important differences between igneous types and at least the major sedimentary types. The chief reasons for these differences are easily explained by the nature of the processes leading up to sedimentation. The materials of the igneous rocks are worked over and sorted on lines of mechanical and chemical resistance, etc., and from them are leached much or all of the more soluble materials, a large part of which passes down and becomes a permanent constituent of the waters of the sea, a corresponding deficit appearing in the composition of the sediments.

Petrologists have recognized for some years that lavas in general cannot be considered as derived from molten sediments, and yet, if the reservoirs were limited to the first few miles of the crust, a large proportion of them should have such origin. The abundant evidence gathered along this line demands that lavas be derived entirely from below the zone of sedimentary rocks.

Volcanoes which arise from the deep sea cannot be considered as affected one way or the other by this line of argument, for we know nothing of the chemical nature of even the shallow layers of the suboceanic crust. Furthermore, there are continental volcanoes that do not occur in sediment-covered provinces. Of these probably the most common are found on granitoid bedrocks. Many of the Tertiary volcanoes of the Sierra Nevada were of this type, the lavas over considerable areas breaking through granitoid rocks, with only here and

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[1] According to Strutt's curve, based on a uniformly radioactive crust 45 miles deep overlying a non-radioactive interior, 1,000° C. would be reached at about 18 miles, 1,200° at about 23 miles.

there patches of metamorphosed sediments. If the lavas coming up through such rocks were chiefly rhyolites or dacites, with perhaps complementary types derivable from these by differentiation, they might be considered to have been formed by melting of the granitic or granodioritic bedrock material; but we find a great profusion of andesites during the later Tertiary—hornblende andesites, pyroxene andesites, hypersthene and other basic andesites (and latites), and finally basalts rich in olivine. This phenomenon of basic rocks breaking through and pouring out over granites is not uncommon in other regions.

Can we reasonably imagine that in a great batholitic mass of granite, several or many hundred square miles in area, the granitic material is only a mile or two thick, and there changes into basic diorite or gabbro? Many granitic areas occur in the western United States through which basic lavas in abundance have broken, yet erosion, which has in many cases deeply dissected such masses shows nowhere such an internal structure.[1]

Further information as to depth of focus may be derived from sedimentary districts where, after the extrusion of lavas, the rocks have been uplifted, tilted, and eroded. The thickness of sediments necessarily traversed by a lava in rising to the surface at some definite stratigraphic horizon can frequently be calculated closely enough for our present purpose. In the Coast Ranges of California the late Tertiary lavas have often had to make their way through several miles of Mesozoic and Tertiary rocks to reach the surface. These volcanic rocks do not show the characteristics of melted sediments; nor have the exceedingly active earth processes at the end of the Tertiary, which have uplifted and folded and eroded the rocks in such a way as to expose frequently the whole Tertiary and Cretaceous series—not rarely 20,000 to 30,000 feet in thickness[2]—brought to light any of the reservoirs formed by the melting of rock *in situ*. They frequently testify to the fact that the sources were still lower, by the dikes found cutting across the oldest layers.

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[1] It is not to be denied that the later lavas breaking through earlier instrusives frequently show striking chemical relationships, and this is true of the province above referred to—but in general not such as could be explained by a remelting of the granitic magna a short distance below the surface. The chemical relationships may show consanguinity, but far from identity.

[2] These numbers are not sums of maxima—such would be much greater.

The zone of rock flowage, the characters of which have been so well set forth by Van Hise, is probably not completely established until we get considerably below the depths where Dutton would place lava reservoirs. One indication of this is that earthquakes have their foci at those and apparently often at considerably greater depths. Earthquake foci must be limited to the zone of fracture, for when with increasing "hydrostatic" rock pressure and temperature the strength of the harder rocks is well passed, we can hardly imagine a dislocation or other diastrophic movement that would be accompanied by seismic jars.

The depth to which certain sediments can be buried and then deformed without metamorphism—several miles, as shown by the thick Cretaceous formations of California and Oregon—indicates that the zone of chemical plasticity, as we may call it—the zone where readjustments take place by molecular (or atomic) interchange and recrystallization without rupture and yet without melting—is considerably below the limit set for volcanic reservoirs. But sediments and intercalated lavas have not uncommonly descended into this zone of chemical plasticity (as, for example, the Paleozoic-Mesozoic Bedrock complex of the Sierra Nevada, and other "regionally metamorphosed" formations), and indeed many thousands of feet below the upper limits of this zone, representing a burial beneath the surface of probably from 5 to 10, or possibly more, miles, and while there they are sometimes invaded by intrusive rocks from still farther down—rocks of a batholitic character, rising from a region wherein all of the necessary heat may easily be derived from the general interior supply. For, according to the curve presented by Strutt, 500° C. would be reached at about 8 miles, 600° at about 11 miles; and these temperatures are quite probably sufficient for granitic aqueo-igneous fusion. But, after these beds have been brought up again and exposed by deep erosion, we see no evidences of local reservoirs formed within them, though they may be cut through to their bases by various, often basic, dikes which may also cut down to an undeterminable depth through the granites.

Dutton suggests that, if an eruption occurred from a depth of 5 or 6 miles, "the temperature of the lava would be very high—probably a white heat—and the mass would be very great. Its consequences might be disastrous beyond all precedent." He also doubts the possibility of a magma at 5 or 6 miles erupting at all. It seems, as stated above, that many Tertiary volcanoes received their material from beneath that depth of sediment. With present volcanoes it is impossible to say from what depth their magmas arise. One might be inclined to suspect, for example, that Mauna Loa and its companions, arising in a regular curve from the flat floor of the sea, received their molten rock from below the level of the ocean bottom, and, if so, as the mass rises 30,000 feet above this base, a lift of over 6 miles, followed by extrusion, would seem possible without any terrific outbreak. But Major Dutton explains this by considering that while the lavas were piling up the whole mass has been rising,[1] and the reservoir is in the protruded mass and considerably above the sea-floor.

The chief argument put forward for the shallowness of lava reservoirs is that volcanic earthquakes always have shallow foci. This is probably true. But whether they be due, as Dutton supposes, to the "fracturing or sudden yielding of the rock masses imediately above the lava reservoir," or whether they be due to gas or steam explosions, as commonly believed, we would expect them to be shallow. For the conditions which would make explosions possible (such as sudden relief of pressure by fracturing of solid obstructions and the consequent explosive expansion of water vapor, etc.) would probably only be found near the surface, however deep the magma originated, and fracturing could only take place in that superficial zone suggestively named the zone of fracture. The occurrence of such phenomena at slight depths seems therefore to have no bearing on the depth of the lava reservoir.

While the above considerations are believed to be incompatible with the particular form of volcanic theory under discussion, and with any theory postulating such shallow reservoirs, and while a pushing-down of the reservoirs toward the 15 or 20-mile limit makes less urgent and soon unnecessary the demand for a local special heat supply, the possibility of local radioactivity as an explanation still remains. But there are some considerations which appear to make improbable any theory of local strong radioactivity.

[1] See U. S. Geological Survey, *Fourth Annual Report*, p. 195 (1884).

The most striking phenomenon of recent vulcanism is the peculiar distribution of volcanoes. It is well known that the great majority of active volcanoes lie along two immense circles—the one encompassing the Pacific Ocean, and the other cutting this at an angle and passing through the Mediterranean region, the Himalayan region, and the West Indies. Many volcanoes occur outside of these two great belts, but in such cases are usually related to mountain chains either continental or submerged in a long line of islands, or to steep (generally rising) coast lines, or to long submarine plateaus or ridges. Without entering into any detailed discussion of these major volcanic lines, it may be asked: Why are there so many spots of local radioactivity —in other words, of peculiar chemical constitution—arranged at short intervals along these lines? A mere statement of the question shows that our theory demands too special and peculiar conditions. These same belts are well-known zones of seismic activity, but they are most fundamentally zones of diastrophic activity, and are closely related, commonly as bounding or separating tracts, to the earth's greater morphological units. Judged from the crustal evidences of earth movements and of the volcanic activities of the earlier periods, this relationship of volcanoes to critical morphological lines—belts of earth movement or diastrophic activity—has held throughout recorded geological time. If earthquakes, lines of upheaval, or other major movements and volcanoes are all dependent for their localization on the greater diastrophic activities, this striking association and alignment of them all would naturally be expected; but if the volcanoes depend for their origin on some irregular distribution of small patches of radioactive matter, this association and alignment are hard to understand.

Another characteristic of volcanoes which is considered a strong argument for a special theory of radioactivity is the repetitive nature of volcanic eruptions. The melting of rock by radioactive processes may easily be imagined to give rise to periodic outbursts of lava; but, even if the details of the process cannot be figured, would we not expect the same periodic character if volcanoes were an expression of diastrophic activity?

Earthquakes are commonly caused by movement along a "fault" plane; and this movement is apparently usually repetitive. The topographic peculiarities along the rift line of the recent great California earthquake indicate that faulting has taken place in recent time along the same line, and probably several times. In the great faults along the fronts of faulted ranges (the so-called Basin range type) the evidence is to the effect that the movements were repetitive and of moderate extent. Why should these phenomena take place in small spurts, with perhaps several years or even centuries of quiescence between? Why should not the mountain blocks rise, or the valley blocks fall at once with a great crash?

For a long period (post-Pliocene, however) a large part of the California coast (several hundred miles in extent) has been rising with respect to the sea. Its upward progress is marked by raised beaches and sharply incised terraces traceable to about 1,500 feet above the present sea-level. At San Pedro Hill Professor Lawson identified eleven terraces between sea-level and 1,240 feet. On San Clemente Island he determined eighteen between sea-level and 1,500 feet.[1] The upward movement has evidently not been uniform, but periodic, periods of activity being followed by periods of quiescence. And this is apparently true of all similar crustal disturbances.

Furthermore, the progress of older earth movements as preserved in the records of sedimentation, deformation of strata, and unconformities, shows that discontinuous movements and periodicity have characterized diastrophic history from the earliest geological times.

We should naturally expect, then, that vulcanism, if it is simply one phase or accompaniment or result of diastrophism, would partake of that universal and perhaps most striking characteristic of diastrophic processes, the alternation of periods of visible activity with periods of apparent rest, and the accomplishment of any general change by successive small increments, rather than by one great catastrophic effort.

What success shall we have if we try to get a concrete conception of a series of eruptions from a reservoir caused by locally concentrated radioactivity? A cubic mile of radium, or perhaps of pure pitchblende, if properly blanketed with rock, would probably in the course of time melt itself and its immediate surroundings, but we should have an eruption largely of radium or of pitchblende. How

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[1] Lawson, "Post-Pliocene Diastrophism of the Coast of Southern California," *Bulletin of the Department of Geology*, University of California, Vol. I, pp. 115–60.

are successive eruptions to be brought about? We cannot reasonably imagine a solid mass of highly radioactive material melting a shell of rock about it and continually erupting that shell, the core remaining intact. We cannot reasonably imagine a great vessel with walls of a highly radioactive material melting its contents and erupting that, the walls remaining practically intact. The radioactive material must be largely scattered through the mass, and must therefore be in part erupted during the volcanic action. But is there enough radium or like material in lavas to melt them, if they were placed at a moderate distance beneath the surface, even taking the normal rise and surrounding active rocks into consideration? Apparently not. Have any large masses of pitchblende, or other possible especially radioactive material, ever been observed thrown out during volcanic eruptions? On the theory of local radioactivity they should be common.

It is well known that the basic lavas are highly heated when erupted. Granites are probably molten and active under hydrothermal conditions at a few hundred degrees Celsius; their structures and metamorphic effects demand but a moderately high temperature, possibly the least of any of the igneous rocks. Basalts flowing out on the surface require 1,000° or 1200° C., and are often at a higher temperature. But the remarkable fact is that basalts show the lowest radium content of any igneous rocks examined, while granites show the highest.

It is the writer's opinion that, while radioactivity may possibly explain a large part, perhaps all, of the present interior heat of the earth, it is incompetent to explain the special phenomena of volcanoes, although as an important general source of heat it may supply its share of the heat which figures in volcanic action.

It may some time be shown that certain peculiarities of some volcanoes as compared with others may be due to varying local radioactivity, but it would not seem that the characteristics of volcanic regions as compared with non-volcanic regions could be so explained. It appears that volcanoes must be looked upon as one type of results of the major normal diastrophic processes developed along the earth's critical mechanical lines, and that each volcano is not dependent for its general activity upon the special chemical composition of the crust immediately below its locus of eruption.

Reviews

An Introduction to Chemical Crystallography. By P. GROTH. Translated by HUGH MARSHALL. New York: John Wiley & Sons, 1906.

A short treatise on the relations between the properties of crystals and their chemical constitution, with special reference to the structure of crystals. The treatment assumes a knowledge of the laws of crystallography as set forth in such works as Groth's *Physikalische Krystallographie.* No attempt is made to review the history of the development of chemical crystallography; the subject is taken up in its present stage of advancement and the relations so far established are stated in principle and illustrated by specific examples.

The chief phases of the subject which are discussed may be briefly mentioned: crystal structure and its possible varieties, involving ideas of polymorphism or physical isomerism, pseudosymmetry and polysymmetry, as well as those of the crystal molecule; special consideration of polymorphism; a comparison of the crystal structures of chemically allied substances—morphotrophy; isomorphism, including a discussion of the similarity of crystal structure in substances possessing analogous chemical constitution; the relations between crystals and solutions of isomorphous substances, and isomorphous mixtures; and so-called molecular compounds.

Chemical crystallography, while essentially a part of physical chemistry and of special interest to the chemist, is of such fundamental importance in the study of minerals and rocks that this translation of the treatise by Professor Groth will be particularly acceptable to the mineralogist and petrologist. J. P. I.

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