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No. 1. — *Contributions from the Petrographical Laboratory of the Harvard University Museum, in Charge of* J. E. Wolff.

I.

On the Petrographical Characters of a Dike of Diabase in the Boston Basin. By William H. Hobbs.

In the region north of Boston occurs a most interesting series of massive rocks, which break through the slates and sandstones, and include granite, quartz-porphyry, quartzless-porphyry, elæolite-syenite, diorite, porphyrite, diabase, augite-porphyrite, and gabbro. They have been studied in greater or less detail by many observers, prominent among whom are W. O. Crosby, M. E. Wadsworth, and J. S. Diller.

The rocks which have afforded material for the present study belong to a single dike, and may be seen in a series of exposures in Medford and Somerville. They are coarsely crystalline rocks, and have borne the names "syenite" and "diorite." They have in general been carefully distinguished from similar rocks of finer texture known as "greenstones," which were shown by Wadsworth in 1877 to have about the same composition as the coarser rock, and were considered by him as identical with it. The finely crystalline rock seems to be more widely distributed than the coarse variety. In the present paper it has been studied only at a few localities, where there was some promise of deciphering its relations with the "diorite."

The age of these rocks has not been accurately determined, though they have generally been considered post-triassic on account of their lithological resemblance to the diabase of the Connecticut Valley. The slates through which they have broken are probably identical with the Lower Cambrian argillite of Braintree. Diller has furnished evidence to show that the finely crystalline diabase ("greenstone") is the youngest of the eruptives of this region, its dikes cutting those of the other rocks.[1]

Many mistakes have been made in determining the composition of both the so-called "diorite" and "greenstone." The "diorite" was long

[1] Bull. Mus. Comp. Zoöl. at Harvard College, VII. 179.

ago described from the Granite Street locality in Somerville by J. F. and S. L. Dana,[1] and by J. W. Webster,[2] as made up essentially of the minerals feldspar and hornblende. This was supported by Professor Hitchcock, in his Survey of Massachusetts.[3] The mistake, which consisted in taking augite to be hornblende, was further repeated by W. W. Dodge[4] and W. O. Crosby.[5] Professor Wadsworth[6] was the first to apply the microscope to the study of this region, and was enabled to determine correctly the general composition of the rocks. His study included all the eruptives exposed in Somerville, and part of those outcropping in Medford, Malden, Brighton, and Brookline. He pointed out the connection of the outcrops, and indicated their general trend. He showed that the feldspar is plagioclase, and that the prevailing non-feldspathic constituent is augite. On the basis of an observed identity in mineral composition he concluded that the fine-grained "greenstone" is identical with the coarser "diorite." Professor Crosby, in his "Contributions to the Geology of Eastern Massachusetts,"[7] has quite accurately outlined on his map the area in which these rocks are exposed.

The present article, being restricted mainly to the coarsely crystalline diabase, repeats to some extent the work of Professor Wadsworth. While the results are in the main confirmatory, there are still important points of difference, and some new facts have been determined.

Leaving out of consideration the vicinity of the Old Powder House in Somerville, the field study has yielded but little. The attempt has been mainly to add something to our knowledge of the petrographical characters of the so-called "Mesozoic diabase of the Atlantic border." Those who desire a full literature of the subject treated in this paper should refer to the above-cited work of Professor Wadsworth.

Field Notes.

The dike of diabase which is here considered extends from Granite Street in Somerville to Spot Pond in Stoneham, and probably beyond, although no examination in the field was carried beyond that point.

1 Memoirs Amer. Acad., 1st series, IV. 163 (1818).

2 Boston Jour. Phil. and Arts, II. 282 (1824).

3 Final Rep. Geol. of Massachusetts, 640–663 (1841).

4 Proc. Boston Soc. Nat. Hist., XVII. 415 (1875).

5 Occasional Papers of Boston Soc. Nat. Hist., Vol. III.

6 Notes on the Petrography of Boston and Vicinity, by M. E. Wadsworth. Proc. Boston Soc. Nat. Hist., XIX. 217 (1877).

7 Occasional Papers of Boston Soc. Nat. Hist., Vol. III.

No outcrops of the coarse rock have been found south of the Granite Street quarry. Professor Crosby has included the fine-grained diabase which crops out at the Pumping Station in Brighton, and similar rocks in Brookline and Newton, as a part of this dike; but the great change of strike required, and the long intervening distance without exposures, are opposed to the supposition. From the Granite Street quarries to the Old Powder House in Somerville, (a distance of about one and a half miles,) the strike of the exposures is N. 25° W. From that point to Spot Pond, the trend is N. 10° E. In Medford and Somerville the country rock is argillite, which has been thrown into gentle folds, the dips of which seldom exceed 35°. A notable exception to this statement is seen at the old slate quarry on Professor's Row, College Hill, where beds strike ± N. 95° E. and dip ± 72° to the south. The area of coarse diabase, which has an average width of about two thousand feet, is never found in contact with the slate. The exposures of diabase almost invariably show the well-known weathering to boulders *in situ*, though this is best observed at Pine Hill. North of High Street in Medford the areal geology is complicated by the occurrence of granite and felsite, for the mapping of which very detailed field-work will be necessary.

The arrangement of exposures of coarse and fine grained diabase in the vicinity of the Old Powder House seems to show a gradual passing of one rock into the other. In the immediate vicinity of the Powder House is an extensive outcrop of coarse rock, like that at the Granite Street quarries and Pine Hill. About four hundred feet northeast of the Powder House on Harvard Street the texture is much finer, though not sufficiently fine to be ranked with the normal "greenstone." About six hundred feet S. 20° W. of the Powder House the rock is somewhat finer than at the last-mentioned locality. Again, at the corner of Elm and Morrison Streets, which is about one thousand feet west-southwest of the Powder House, the normal "greenstone" occurs in slate. Moreover, on Willow Avenue, about fifteen hundred feet along the strike to the south from the Harvard Street locality, the rock is practically identical with that at the latter place. From this it seems probable that the coarsely crystalline rock at the Powder House is near the middle of the dike, where the cooling was slow, and that the gradual diminution in the size of the grains in going from that point is owing to more rapid cooling near the contact.

The wide distribution of the "greenstone" has made it impracticable for me to make a complete examination of it, but the few localities which have here been studied agree so well with each other, and with Professor Wadsworth's notes on the other localities where the same rock is exposed, that a complete study of it seems unnecessary to prove its identity with the "diorite."

Petrographical Notes.

Having shown by field observations that the so-called "diorite" is equivalent to the so-called "greenstone," the rocks will be distinguished according to their mineral composition, without regard to coarseness of texture. Microscopic examination shows the rock to be either a diabase or diorite. The diabase is the principal rock, being found at the quarries on Granite Street (Nos. 207, 209, 209 a, 214), and at the very extensive quarries on Pine Hill (No. 222). The exposure on Harvard Street in Somerville is also of this rock (No. 210). The diorite forms a facies of the diabase, and includes all the outcrops in the vicinity of the Old Powder House (Nos. 208, 216, 218) except No. 210, already mentioned as belonging to the diabase, and the hill north of High Street and east of Highland Avenue (No. 203). Aside from the amphiboloid mineral, the two rocks appear to be almost identical.

Diabase. — This rock is quite uniform in character, and occupies a large part of the area of the dike. A macroscopic examination shows that it is composed mainly of a plagioclase feldspar, and an amphiboloid mineral with more or less biotite and pyrite. The proportions of these minerals vary considerably, causing the specific gravity to range from 2.98 to 2.65. In weathering, the amphiboloid mineral is first decomposed, causing a complete disintegration of the rock to a coarse feldspathic sand. The rock does not show the slightest evidence of lamination, and the feldspars, which have been little interfered with in crystallizing, illustrate well the *divergent strahlig-körnig* arrangement of Lossen, the remaining space being largely occupied by hypidiomorphous crystals of augite. The feldspar grains are more or less lath-shaped; of a white, pink, or green color; generally striated; and have an average length of about 8 mm. The specific gravity of cleavage pieces from No. 222 was found to be 2.638 and 2.643 by determinations with the Thoulet solution, though these results are probably much affected by an incipient alteration. In a single specimen (No. 214), the cleavage of the amphiboloid mineral is so well developed that the mineral can be identified as augite in the hand specimen.

Under the microscope, feldspar and augite are found to be always present. The feldspar is shown by twinning striations to be plagioclase, which exhibits when fresh beautiful zonal phenomena. In a number of sections the method of Professor Pumpelly [1] or M. Michel Lévy [2] was applied for the determination of this feldspar. As is well known, this method consists simply in a determination of the maximum extinction angle in the zone of the macro-pinacoid and base, sections which are in this zone being characterized by symmetrical positions of extinction in the two sets of twins, with reference to the twinning plane. Results were obtained as high as 27°, requiring the presence of a feldspar as basic as labradorite. In the classical work of Pumpelly above cited, crystals of feldspar from the Granite Street locality were determined by this method, combined with a modification of Des Cloiseaux's method for determining the size of the basal extinction angle. The highest result obtained by the first method was 16°, and by the second 3° to 4°, though, owing to the sections being inclined to the base, the latter results were more or less unreliable. He concluded that the feldspar was probably albite or oligoclase.

Mechanical separations of the constituent minerals have been made in a number of cases by the Thoulet solution. In every case feldspar was removed with each separation between the specific gravity limits 2.76 and 2.6, and often a considerable portion came below the inferior limit. The grains were found to be seldom pure, and the wide range in specific gravity is doubtless, in part, to be referred to decomposition products. The portion separated below the limit 2.6 was in several cases subjected to microchemical tests by both Boricky's [3] and Behrens's [4] methods, after careful washing to remove all iodide of potassium. Potassium as well as calcium being always detected in this powder, that derived from No. 222 was subjected to quantitative chemical determination, which yielded 4.16% of oxide of potassium. The products of alteration of the feldspar are calcite, and a mineral which is probably kaolin. Considerable green chlorite-like material is often contained in the feldspar grains; but it has apparently been derived from the biotite or augite by alteration, and has found the way to its present position in the feldspar through the cleavage cracks. This substance is the viridite of Professor Wadsworth, which he considered an incipient alteration of the feldspar.

[1] Metasomatic Development of the Copper-bearing Rocks of Lake Superior. Proc. Am. Acad., XIII. 253.

[2] Minéralogie Micrographique, p. 227.

[3] Archiv der Naturw. Landesdurchforschung von Böhmen, III. Band, 5 Abth., Prag, 1877.

[4] Mikrochemische Methoden zur Mineral Analyse, Amsterdam, 1881.

From what has now been said, it seems certain that a feldspar as basic as labradorite exists in the rock. This is attested both by the high extinction angles in the zone of oP and $\infty \mathrm{P}\bar{\infty}$, as well as by the presence of calcite as a significant product of alteration. That a feldspar less basic than oligoclase, and probably as acid, is present also, is shown by the zonal structure and wide range in specific gravity. The potassium obtained from No. 222 may be derived either from alteration products (muscovite?) or from the feldspar itself. The analysis of this rock *in toto*, which may be found in the sequel, shows by the small amount of hydration that little alteration has taken place. It therefore seems to be certain that the potassium is derived from the feldspar itself, either from orthoclase or from a potash plagioclase.

The principal non-feldspathic constituent is augite, which is much broken up by feldspar crystals, though rarely the feldspar is penetrated by augite, showing the nearly contemporaneous formation of the two minerals. The augite, which has generally a rose color, displays a faint dichroism, the ray parallel to $\mathfrak{b}$ being pink, and that parallel to $\mathfrak{a}$ pinkish yellow. Both prismatic cleavages are generally well developed, and intersect on the basal plane with the pyroxene angle 87°. Parting parallel to $\infty \mathrm{P}\bar{\infty}$ and occasional twins according to the same plane, though not constant features, are observed in the rock from some localities. Zonal structure is not uncommon, and rarely the *hour-glass* structure is well developed. The principal alteration is to uralite, which is found in rims completely surrounding many grains, while with others it has gone farther, and found its way to the centre along the cleavage cracks. This mineral occurs in its usual form in scales or sheaves, and is easily distinguished by its high double refraction, small extinction angle, and strong pleochroism, the ray vibrating parallel to the long axis being dark green, while that vibrating perpendicular to this direction is either green or bright yellow. It is probable that the uralite further changes to chlorite; but since biotite was generally to be found in the vicinity passing into chlorite, it could not be definitely determined. The distribution of the calcite shows that it is derived from the pseudomorphism of the augite, as well as from the decompositon of the feldspar.

Compact green and brown (basaltic) hornblende, though noticed once or twice, are extremely rare.

The biotite when present is generally either in plates, from its penetration of feldspar and augite, clearly original, or in fine scales or aggregate masses in association with augite. The former variety contains inclusions too small to be determined, with the characteristic pleochroic zones about them. Both varieties have suffered alteration to the ordinary product, chlorite.

Professor Wadsworth considered the biotite secondary to the augite, chlorite being an intermediate stage in the process of alteration. It seems, however, much more probable that this form of the biotite, if indeed secondary, is derived directly from the augite, and that the further alteration of biotite to chlorite sufficiently explains the occurrence of the latter between biotite and augite. The occurrence of biotite as a pseudomorph after augite has been described by Blum,[1] Richthofen,[2] Tschermak,[3] Rohrbach,[4] and Brauns.[5] On chemical grounds, without assuming a high degree of metamorphism, the change from chlorite to biotite is difficult to conceive. In some sections, particularly No. 207, a large part of the chlorite can be referred to the diabantite of Hawes.[6] In many slides chlorite occurs in clearly defined hexagonal sections surrounded by one, or more frequently four or five, concentric rims of magnetite. In other cases biotite can be seen in these basal sections in the act of changing to chlorite, the centre of the crystal being biotite, about which is a wide or narrow rim of chlorite. Figure 1 is taken from sections No. 202 and No. 203, and shows the different stages in this process of pseudomorphism.

Apatite is found as a constant constituent, in unusually large clear crystals, cutting all other minerals. A very small amount of quartz is present, which, in some cases at least, is of secondary origin. Pyrite, magnetite, and ilmenite are present in varying amounts. Magnetite is either in hexagonal sections or more or less irregular masses. These masses are often elongated parallel to blades of chlorite, and are then evidence of secondary origin. A case of this kind is shown in Figure 2. Ilmenite appears in sections, generally hexagonal, like the magnetite, but is easily distinguished by its change to leucoxene or titanite. In a section from the Granite Street quarries (No. 207) this change has been complete and the only vestiges of ilmenite are the masses of white, more or less opaque, highly refracting leucoxene. In other specimens (Nos. 202, 208, 209 a) the decomposition has been less complete, but has taken place in bands, which have three directions parallel to the sides of the rhom-

[1] Pseudomorphosen, I Nachtrag, p. 30; III Nachtrag, p. 93.
[2] Wien Akad., XXVII. 335. Blum, Pseudomorphosen, III. 96.
[3] Porphyrgesteine Oesterreichs, Wien, 1869.
[4] Min. u. petr. Mitth., VII. 27.
[5] Neues Jahrbuch, V Beilage Bd., 275.
[6] Mineralogy and Lithology of New Hampshire, p. 120.

bohedral sections. (See Figure 2.) This structure has been described by many observers and figured by De la Vallée Poussin and Renard,[1] and by Teall.[2] The structure has been explained by Teall as due to intergrowths of magnetite and ilmenite, according to the fundamental rhombohedron. Since the *Gleitfläche* of ilmenite is R, which is also the normal-solution plane,[3] these may be due to decomposition along the normal-solution plane. From No. 222 the heavy portion separated in the Thoulet solution was subjected to treatment with the electro-magnet. Material was thus obtained so magnetic that, when removed from the poles, the grains clung to each other like magnetized iron filings. Treated with concentrated hydrochloric acid, this material was strongly attacked, but did not entirely dissolve even by continued digestion.

Professor Wadsworth has described the occurrence of prehnite as a common product of the alteration of the feldspar and augite. This mineral occurs in veins at the Granite Street quarries, and to determine its characters a section was made from the mineral obtained from one of these veins. The columnar crystals by macroscopic examination seem to have their vertical axes, in general, perpendicular to the walls of the fissure. In the slide, sections parallel to the long axis (*c*) always showed a sheaf-like grouping of individuals having perfect cleavage, both parallel and perpendicular to the vertical axis. These sections afforded no interference figure. Another series of sections (basal) had nearly equal dimensions, with two equally perfect cleavages (∞ P) cutting each other at about 100°. These sections gave also, in converging polarized light, a very perfect biaxial interference figure, with high positive double refraction and orthorhombic dispersion. The optic angle when measured in air was found to be 83° 30′, which is much smaller than the results obtained by Des Cloiseaux with prehnite from other localities. The plane of the optic axes bisects the obtuse angle between the cleavages. The prismatic cleavage is very perfect, hardly less so than the basal. No evidence of twinning like that noticed by Des Cloiseaux[4] in some specimens, or that found by Professor Emerson[5] in the prehnite of the Deerfield dike, was observed.

The only section of rock from the region under consideration in which

[1] Mémoires sur les Caractères minéralogiques et stratigraphiques des Roches dites Plutoniennes de la Belgique et de l'Ardenne française. Mém. Couronnés de l'Acad. Roy. de Belgique, XL. 50, 74.

[2] Quart. Journ. Geol. Society, XL. 640.

[3] Cf. Judd, On the Relations between the Solution Planes of Crystals and those of Secondary Twinning. Min. Mag., December, 1886.

[4] Manuel de Minéralogie, p. 430.

[5] Am. Journ. Sci., (1882,) XXIV. 270.

prehnite was discerned is No. 215 (Bell Rock, Malden) where it was found filling a minute fissure vein. The chalcodite which Professor Wadsworth has described was not noticed in any of the slides, and it seems certain that the important part which he assigned it, of completely taking the place of both feldspar and augite, is wrong.

A typical and unusually fresh specimen of the diabase (No. 222, Pine Hill, Medford) has been subjected to a quantitative chemical analysis by R. C. Sweetser, B. S., Assistant in Chemistry at the Worcester Polytechnic Institute, to whom I would here express my great obligation. Though fully engaged with other duties, he kindly offered to do the work and obtained the results given below in column I. Column II. contains the results of an analysis of a diabase from the Lenneschiefer at Böchtenbeck by Schenck, which shows considerable more decomposition, but is otherwise nearly identical.[1] Column III. is an analysis of diabase by Teall from Cauldron Snout, Durham, in the Whin Sill.[2]

	I.	II.	III.
SiO_2	48.75	48.42	51.22
Al_2O_3	17.97	17.59	14.06
Fe_2O_3	0.41	1.05	4.32
FeO	13.62	8.36	8.73
CaO	8.82	7.73	8.33
MgO	3.39	4.30	4.42
MnO	0.91	——	0.16
K_2O	2.40	3.07	1.25
Na_2O	1.63	5.15	2.55
H_2O	0.60	2.24	1.28
TiO_2	0.99	2.23	2.42
P_2O_5	0.68	0.28	0.25
CO_2	tr.	0.08	0.19
FeS_2	tr.	0.15	0.49
	100.17	100.65	99.67
Sp. Gr.	2.985	2.919	

Schenck considered orthoclase as probably present in II. The analysis as well as the extinction angle shows the feldspar to be more acid than that of I. Augite is changed to viridite, and ilmenite occurs and alters to leucoxene along the *Gleitflächen.* The rocks I. and II. are thus shown to be very similar. The mineral composition as well as the chemical composition of III. is also nearly identical with that of I.

[1] Adolf Schenck. Die Diabase des oberen Ruhrthals und ihre Contacterscheinungen mit dem Lenneschiefer. Diss., Bonn, 1884, p. 20.

[2] Teall. Quart. Journ. Geol. Soc., XL. 640.

Augite Diorite.—This rock, though quite similar to the diabase, differs from it in a loss of the ophitic structure, and in the appearance of brown (basaltic) hornblende as the principal non-feldspathic constituent. In some sections augite does not appear, owing to complete uralitization. At other localities it comes into prominence, and there the rock may be known either as a diorite or a diabase.

The hornblende is for the most part the massive brown variety, which is well characterized by its color, perfect cleavage, large optical angle, and strong pleochroism. The absorption may be written $\mathfrak{c} = \mathfrak{b} \gg \mathfrak{a}$. The sections have in general distinct outlines parallel to the fundamental prism and the clino-pinacoid. A common feature of the hornblende crystals is the occurrence within them of cores of augite, which seem to show either that the hornblende is derived from the augite by pseudomorphism, or that the two minerals crystallized originally in their present relations. Such pseudomorphism was first noticed by Streng [1] in 1877, and subsequently by Hawes,[2] Irving,[3] Van Hise,[4] Sjögren,[5] and Von Lasaulx.[6] Remarkable instances of this change have been described by Professor Williams,[7] from the Cortlandt Series on the Hudson River, and by Schenck,[8] from the diabase of the Upper Ruhrthal in Westphalia. The former has shown the gradual passing of the augite into brown hornblende. The latter has described a further change of the brown to green hornblende, while Von Lasaulx found in the diabase of Kürenz that the change of the augite was first to uralite, then to brown hornblende. In the diorite which we are considering, the contact of augite and hornblende is a sharp line. No evidence of a gradation from one mineral to the other was anywhere observable. The hornblende is in general very fresh, while the augite alters readily to chlorite, so that in many cases only a few scattered fragments of augite can be seen (Figure 2). It seems probable, therefore, that these combinations are the result of parallel growth. Teall [9] has figured such growths in the Whin Sill, and Rohrbach [10]

[1] A. Streng. Neues Jahrbuch für Mineralogie, etc., 1877, p. 133.

[2] G. W. Hawes. Mineralogy and Lithology of New Hampshire, pp. 57, 206, Plate VII. Fig. 1.

[3] R. D. Irving. Geology of Wisconsin, III. 170.

[4] C. R. Van Hise. Am. Journ. Sci. [3], XXVI. 29.

[5] H. Sjögren. Neues Jahrbuch für Mineralogie, etc., 1884, I. 82 (Ref.).

[6] A. v. Lasaulx. Verh. d. Naturh. Vereins d. pr. Rheinl. u. Westf., 1878, p. 171.

[7] G. H. Williams. Am. Journ. Sci. [3], XXVIII. 259.

[8] A. Schenck. Die Diabase des oberen Ruhrthals, etc. Diss., Bonn, 1884.

[9] Quart. Journ. Geol. Soc., XL 653, Plate XXIX. Fig. 3.

[10] Min. u. petr. Mitth., VII. 1, Plate I. Figs. 1–7, 1886.

in the Cretaceous formation of Silicia. The figures of the latter show a sharp line of contact between the two minerals. He was also able to show that, in the majority of cases at least, the minerals were in parallel position. Chemical analysis showed an essential difference in the composition of the augite and hornblende. It was also observed that decomposition had seldom progressed to the same point in both minerals when together, though neither seemed to offer in all cases more resistance to decomposition than the other.

A remarkable instance of mechanical deformation is exhibited in section No. 202. A large crystal of brown hornblende has been bent until it has the shape of a letter S. The optical properties are anomalous, as would be expected, and a crystal of apatite has been bent about the hornblende crystal, which has been attended with crushing, and optical disturbances, so that the apatite crystal is extinguished in a mosaic. This must be referred, however, to motions which existed in the partially consolidated magma, as we would expect to find anomalies in the optical behavior of the plagioclase grains if it were due to the action of orographic forces.

Section No. 208 (corner Elm and Morrison Streets) is porphyritic, the base being difficult to resolve. The porphyritic crystals are feldspar and parallel growths of augite and hornblende.

The chlorite of No. 202 is often filled with belonites of a green color, arranged in three parallel directions, cutting each other very precisely at angles of 60°.

Summary and Conclusions.

What has been noted in the preceding pages may be summed up in the following statements.

The dike under consideration includes, not only the exposures of so-called "diorite," but outcrops, in the vicinity of the Old Powder House in Somerville, of rock intermediate in texture between the normal "diorite" and normal "greenstone," as well as the "greenstone" itself. The coarseness of texture is in general dependent only on the position of the specimen in the dike, the fine-grained rock being naturally found near the contact. The general composition of the rock is that of a diabase, though facies of augite-diorite occur.

The diabase has in general a more or less ophitic structure, and is characterized by the original constituents, plagioclase, augite, biotite, apatite, ilmenite, and magnetite; apatite and the ore minerals comprising the first generation, while feldspar, augite, and biotite crystallized nearly contemporaneously and form the second generation. The secondary minerals are uralite, chlorite, biotite (in part?), leucoxene, kaolin (?), magnetite (in part), calcite, pyrite, and quartz. The plagioclase is somewhat variable in composition, owing to zonal structure, but has probably an average composition corresponding to andesine. It is also probable that orthoclase is present, though the potash obtained in the analyses may be derived from a plagioclase containing a considerable per cent. of potassium. The augite-diorite differs from the diabase in that the ophitic structure is wanting, and that the brown hornblende, which now comes into greater prominence than the augite, is generally in idiomorphous crystals. The diorite is characterized by very perfect instances of the parallel intergrowth of augite and hornblende.

In both the diabase and diorite the change of the augite has been uralitization, though in the diorite it has in many cases changed directly to chlorite.

In conclusion, I have to acknowledge obligation to my instructors, Mr. J. E. Wolff, of Harvard University, and Dr. George Huntington Williams, of the Johns Hopkins University. The greater part of the microscopical examination in connection with this paper was made in the laboratory of Mr. Wolff, and I am indebted to him for much advice and suggestion. Dr. Williams has examined most of the slides, and assisted me in countless ways in the preparation of this paper. I am also much indebted to Mr. R. C. Sweetser, of the Worcester Polytechnic Institute, for a complete chemical analysis.

November, 1887.

EXPLANATION OF PLATE.

Fig. 1. Illustration of the change of hexagonal plates of biotite to chlorite, with separation of magnetite in concentric rims. From sections No. 202 and 203.

Fig. 2. Illustration of the intergrowth of augite and brown hornblende, and alteration of the former to chlorite. The alteration of ilmenite to leucoxene along the *Gleitflächen* is also shown. From sections No. 202 and 208.

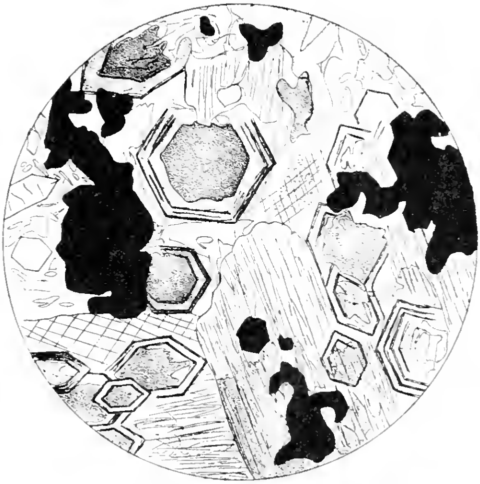

Fig. 1

Fig. 2.

B Meisel lith

No. 2. — *On the Geology of the Cambrian District of Bristol County, Massachusetts.* By N. S. Shaler.

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Preliminary Note.

For a number of years I have been engaged in an incidental manner in studying the geological structure of the great synclinal district to which I have given the name of "the Narragansett Basin." This geological field, extending from the southern part of Narragansett Bay in Rhode Island to the region of the granitic hills which includes the Blue and Sharon Hills of Massachusetts, and eastwardly to the region occupied by the town of Hanover in Massachusetts, is mainly underlaid, as is well known, by rocks of Carboniferous age. My principal aim has been to determine the geological history of this Carboniferous section. Incidentally, it has been necessary to make some study of the deposits which lie below the level of the Millstone Grit. In these latter inquiries I found it necessary to do a good deal of work on the extensive series of more or less metamorphosed ancient rocks which lie between the western border of Rhode Island and the western edge of the Coal Measures, from Greenwich, R. I., to Wrentham, Mass. This inquiry, although incomplete, has developed certain facts of considerable interest, which it appears to me should be made public before the preparation of my final report on the Narragansett Basin, which cannot be finished for some time to come. The most interesting of the many results which I have obtained in this Pre-Carboniferous series of rocks consists in the discovery of an extensive series of Cambrian deposits, containing a tolerably abundant and fairly determinable set of fossils. The discovery of these beds not only enables us to fix the age of an extended section of rocks, but to ascertain a number of facts which have a great importance with reference to the general history of this portion of the continent.

Several geologists have observed the fact that between Providence, R. I., and Wrentham, in Massachusetts, we have an extensive development of interbedded conglomerates, shaly slates, and sandstones, the whole separated from the other detrital deposits of this region by peculiarities of color. While the Coal Measure conglomerates have generally a grayish or blackish hue, these more western deposits of puddingstone are generally of a red color, while the intercalated shales vary in hue from a brilliant red to an olive-green. Various conjectures have been made as to the age of these deposits. They have been thought by one observer to resemble the Trias, while others, owing partly to their position, have assigned them to the Devonian age. Until I began my studies upon this district, the strata had afforded no fossils, and the determinations above noted were purely conjectural.

As it appears to me that there is a lesson of some value afforded by the conditions of my inquiry, I venture to set forth the methods under which it was pursued. After carefully traversing all the roads in this district, with the hope of obtaining geological data on those lines, I became convinced that results of value could not be yielded by tracking these paths, for the reason that here as elsewhere in an accidented country the public ways avoid the outcrops. Inspecting a portion of the field, I found that almost all the available exposures were covered by brushwood, and thus hidden from a hasty glance. I therefore resolved to trace the country on foot in such a manner that I should obtain sight of every exposure. A preliminary inquiry showed that, even where the rocks were covered by drift, a careful consideration of the fragmentary matter in the glacial deposits would give very clear evidence as to the nature of the deposits below the covering. Pursuing this latter inquiry in a methodical way, I found that at any point whatsoever the boulder clay as distinguished from the kame deposits was to the extent of at least three fourths its mass composed of material which had not been carried for a greater distance than half a mile. Pursuing my further inquiries in this close manner, I found in a very short time that these apparently barren deposits of shales and conglomerates afforded at certain points a good number of fossils. Within an area of a single square mile, three important localities have already been discovered from which, as will be seen in the sequel, we have obtained over a score of recognizable fossils. It is likely that further research on these beds will increase the list of organic remains to thirty species or more.

My studies on the Narragansett field were begun in 1865. The first of the fossil localities was not found until 1883. The pressure of other work and the lack of good topographic maps made it impossible to work up this field at an earlier date. In 1884, my service as Geologist in the United States Geological Survey enabled me to command more time for these explorations, and the rapid advance of the topographic work in this area done by that Survey in co-operation with the State of Massachusetts has afforded a sufficient topographic basis for the inquiry.

I am indebted to my assistant, Mr. August F. Foerste, for a certain amount of aid in the preparation of this report. He has worked out a part of the boundaries which are delineated in the accompanying map, and has collaborated with me in the preparation of the descriptions contained in the second part of this report.

General Structure of the Field.

The area indicated in the first of the accompanying sketch maps evidently contains two distinct series of stratified rocks, besides the numerous and peculiar injected materials, which are not to be discussed here. On the east we have the Coal Measures of the Narragansett basin. The western boundary of this series cannot be exactly traced, for the reason that it is altogether hidden by drift deposits mostly belonging to the class of kame and terrace accumulations, and therefore unfit to afford the basis of any determinations as to the subjacent beds. West of this border, the position of which cannot be at any point fixed within the limits of some hundreds of feet, we have the area of Cambrian deposits. This strip has an average width of not far from two miles. Although its contact with the Carboniferous deposits is not seen, it is likely that it belongs to the class of erosion overlies, that is to say, the Carboniferous rests upon the worn surface of the steeply inclined Cambrian beds. Evidence in favor of this supposition is also afforded by the conglomerates of the Coal Measures, which contain more or less detrital material brought from the Cambrian series, which was evidently exposed to erosion at the time when the lower portion of the Coal Measure deposits were formed. Moreover, as my extensive studies on this district have adequately shown, few faults occur in the field. The habit of accident is that of folding rather than faulting.

On the west of the Cambrian lies another field of rocks, which I am compelled at present to consider as of Pre-Cambrian age. The deposits in this section consist in the main of gneissoid rocks of varying composition and a great area of dark greenish chloritic deposits which appear in part at least to be metamorphosed conglomerates and shales. In the region west of Pawtucket and Valley Falls on the south side of Blackstone River these rocks contain a number of areas of crystalline limestone. As yet it has proved impossible to determine the sections in this district with any satisfactory degree of definition. At Mannville on the eastern or right bank of the river, about two hundred feet in thickness of these supposably Pre-Cambrian rocks appear as rather distinct beds of what seems originally to have been clay slate, now changed to a gneissoid material. In these gneissoid rocks near Cumberland Hill there are extremely interesting mineralogical localities. The remarkable deposit of ilmenite, the iron ore composing Iron Hill, has long received much attention from mineralogists. The hill near Sneech Pond is said to have yielded a certain amount of metallic copper in the various explorations which have been made upon it. Near by, and in the same district, is an interesting and extensive vein of pyrolusite.

The imperfect sections of this district which have thus far been obtained indicate that the total depth of the deposits probably amounts to more than five thousand feet, and may attain to twice that amount. However, as the region has been much affected by mountain building forces, and as the metamorphism has gone so far that little trace of the original bedding is now discernible, it is very difficult to obtain a satisfactory account of the series. The nature of the contact between these evidently ancient rocks and those of Cambrian age has not yet been well determined. There are some reasons to suppose that it may be by faulting, but the fact that pebbles of the supposed Pre-Cambrian series are found in the rocks of Cambrian age is rather against this supposition. Actual contact is at no point traceable, the surface being too deeply covered with detrital materials. It may be noted, however, that the line between the two formations is much more direct than that which separates the Cambrian from the Carboniferous, and we are therefore more justified in supposing that faulting may have taken place at this point.

Whatever be the age of these strata we have termed Pre-Cambrian, it is evident that they were formed long before the Cambrian deposits themselves, and this for the reason that the measure of metamorphism which has affected the two regions is extremely diverse. The Cambrian rocks exhibit very little sign of metamorphic action. The shales indicate a slight amount of infiltration, and in the conglomerates the pebbles all retain essentially their original character, save that they are sometimes slightly indented one into the other. The cement of the mass is not more altered than is usual with our unchanged conglomerates. Its general character, save for its reddish color, is undistinguishable from the deposits of Millstone Grit age in the neighboring coal-field. This wide difference in the measure of metamorphism of the rocks which are traced almost in contact with each other is of itself sufficient evidence of great disparity in age. Too much importance, however, should not be given to this consideration, for the reason, as I shall have hereafter occasion to show in the final report on the Narragansett field, that the Carboniferous rocks in the southern portion of the basin appear to have undergone a very extensive regional metamorphism in which the sandstones have taken on a gneissic shape, the black shales been converted into otrolitic schists, and the conglomerates also metamorphosed, the cement taking on a gneissoid form, and the composition in many of the pebbles being similarly changed. This alteration, however, seems to come about gradually as we go from the north southward, while the corresponding change in passing from the Cambrian to the subjacent rocks is of a sudden nature.

The rocks of apparently Pre-Cambrian age, possibly to be assigned to the Huronian period, which lie to the west of the Cambrian field, differ in their attitudes from those of the Carboniferous as well as the Cambrian series. The prevailing strikes in the valley of the Blackstone are from northwest to southeast. There are some local variations which give other directions, but there can be no question that, considered as a field, the highly tilted rocks pretty regularly extend in a northwest and southeast direction. Thus the limestone belt which extends from near Valley Falls to Harris's Quarry, about four miles west of that point, has a tolerably uniform trend in the above-mentioned direction. At the Dexter Quarry they are locally thrown from the prevailing strike, so that the axis is nearly north and south; but the general direction of the limestone belt is nearly that above described. On the other hand, the rocks of the Cambrian, as well as those of the Carboniferous, have a tolerably uniform northeast and southwest trend, the strikes varying from north to north 45° east, thus following the general course of the dislocations along the Atlantic coast. It therefore appears that there must have been a change in the character of the tension and consequent disruption which have affected this country in Pre- and Post-Cambrian times, the more ancient rocks having undergone extensive displacements in a peculiar axis before the later deposits were accumulated.

In this connection it may be interesting to note that the beds of Tertiary age on Martha's Vineyard, about fifty miles to the southeast of

Attleborough, also exhibit northwest and southeast strikes. This matter I have considered in some detail in my Report on the Geology of Martha's Vineyard, now in press in the United States Geological Survey.

The age of the rocks which I have termed Pre-Cambrian must for the present remain doubtful. The absence in the section of any beds like those containing the Paradoxides of Braintree raises the presumption that they do not belong in the Braintree Cambrian series. The massive limestones which occupy a portion of the section are also to a certain extent evidence to the same effect. As a whole this section reminds me more of that which occurs at Rockport, Maine, than any other deposits known to me on the coast; still I think there is nothing which can be evidence to prove the likeness in age of these beds.

General Character of the Cambrian Rocks.

As the object of this paper is to set forth the phenomena of the Cambrian series with no other attention to other deposits than is necessary to make them comprehensible, I shall now proceed to give in some detail an account of the deposits which appear to belong in this portion of the section. So far fossils have been found in rocks of this section which probably do not in the aggregate include more than one hundred feet or so of the total section of the Cambrian series. However, as these deposits are of the same aspect as all the red slates and conglomerates of the area, it appears at present reasonable to include all rocks of this description with the above-mentioned series. The total thickness of the section which I have termed Cambrian is not accurately determinable. It probably amounts to not far from two thousand feet. In the main it consists of thin-bedded shaly layers which occasionally pass into moderately thick fine-grained greenish and reddish slates. Intermingled with these in several levels we have a number of layers of conglomerate, perhaps as many as half a dozen distinct beds, varying in thickness from two hundred to three hundred feet. In all cases these conglomerates are frequently interrupted by thin layers of shale or sandstone. The pebbles are mostly of small size; none have been observed exceeding a foot in diameter, and few above six inches in thickness. The pebbles are in most cases rather angular. At certain points they have a very high degree of angularity, so that they assume the form of a breccia. The rocks from which the pebbles were taken are mainly identifiable in the western portion of the field before described. No distinct traces of cross-bedding have been observed in the deposit. Indeed, in the layers of conglomerate a thickness of from twenty to thirty feet may often be found in which only slight evidences of bedding are ascertainable.

This section has been subjected to two classes of accidents. One has resulted in the general tilting of the deposits in an easterly direction, the angle of inclination not usually exceeding about 20° of slope. At certain points in the field there have been disruptions of the rocks, with possible faulting on the lines of breakage, attended by the extrusion of massive dikes of hornblendic granite, which appear in the form of elongated somewhat lenticular-shaped ridges, which taper abruptly at either end. These ejections vary in diameter from a few hundred feet to as much as a mile, and their greatest length in one or two cases may amount to three miles or more. On either side of the injected syenite (or hornblendic granite) the bed rocks are folded abruptly upward into vertical attitudes, which sometimes continue for a considerable distance from the face of the dike material.

It is an interesting feature connected with these intrusions of granitic matter, that in no case do they appear to have brought about any very conspicuous metamorphism in the sedimentary deposits with which they have come in contact. The change is rarely apparent at more than two or three feet from the dike. Actual contact has been seen but at one point, southeast of locality No. 3 on the map, where the slates are found in almost immediate juxtaposition with the hornblendic granites. At locality No. 1 we have an extensive area exposed within one hundred feet of the contact with the hornblendic granite mass, more than half a mile in diameter. At this point we find no perceptible metamorphic influence on the sedimentary strata.

The topographic features within the limits of the Cambrian field are in a large measure determined by the resistance to erosion afforded by these elongate domes of ejected matter. In a less determined way the ridges of conglomerate influence the shape of the country. The hornblendic granites are but rarely exposed to the eye, for the reason that, wearing evenly, they form a uniform surface on which the drift material rests as a blanket. The conglomerate ridges, wearing irregularly, often appear as sharp peaks too steep to retain any considerable coating of glacial detritus.

It is probable that these granitic ejections took place before the deposition of the Carboniferous rocks, for, although a very marked feature in the Cambrian district, they have nowhere been observed penetrating through or into the coal measures which overlie them. Indeed, as I shall hereafter note in the discussion of this district, one of the most remarkable features in the Coal Measures is the entire absence of dike materials in this wide area, a feature in which it is in sharp contrast with all the neighboring portions of New England. The fact appears to be that the dikes which intersect the rocks of Southern New England were formed before the Carboniferous age, or if formed after for some reason never penetrated the deposits of the Coal Measure series.

Although the intrusive rocks of this area are a baffling element in the effort to unravel its structure, the principal difficulty arises from the drift coating which covers at least ninety-five per cent of the surface. In passing over the country, the student is, on account of the distribution of this drift coating, led to give too great structural importance to the conglomerates and to the hornblendic granites. The fact is, that the softer shales almost always occupy the lowest parts of the area. Almost all the stream beds course upon them, and it is only by a careful study of the drift materials that the preponderance of these slates becomes evident.

Origin of Sediments, and Conditions of Deposition.

The sediments composing this Cambrian section appear to have been derived from rocks substantially the same as those which now lie in the field west of the area. Although fossils have been found in a small part of the section, close study makes it plain that by far the greater portion of the strata are clearly azoic. The frequent return of conglomerate layers and the coarseness of the pebbles show that during most of the time when the beds were accumulating the region was near shore; so, too, the large amount of sandy matter even in the slates affords a presumption that the region was not remote from the coast line. About one hundred feet of shale beds have been subjected to a very careful search for organic remains. The total thickness of the deposits in which any trace of life has been found probably does not exceed one hundred feet, and even in this section only a small part of the rocks actually contain fossils. As before remarked the rocks of this Cambrian series are very little metamorphosed. We therefore cannot attribute the absence of life to secondary changes, but must regard it as an original characteristic of these sediments. The great abundance of conglomerates, the considerable size of their pebbles, the fact that none of these have a beach-worn character, but are in general form like the pebbles contained in the neighboring glacial deposits of a stratified character, afford a basis for the presumption that these rocks were accumulated during an ice epoch.

The glacial origin of these sediments is made more probable by the fact that they contain a large amount of ferruginous material. My observations on the recent drift of New England show that at a hundred localities, representing all the States except Vermont, the drift contains a large amount of such material. The conditions of glacial erosion, the rapidity with which the process goes on, and the absence of acids produced by decaying vegetation in the rocks, cause glacial deposits formed of detrital materials originating in crystalline rocks to contain large amounts of iron, which under ordinary conditions of decay would be oxidized and borne away in the dissolved state.

The distribution of Cambrian fossils in these beds, where they occur in thin layers, appears to indicate that life was present in the sea at some distance from this shore line, and that it occasionally, in the interruption of the conditions which made the rest of the beds non-fossiliferous, won its way to this field. Precisely similar invasions of life took place during the last glacial period along the shores of this part of the continent.

Characteristics of Life.

The organic fossils obtained from the Cambrian beds of Attleborough show very clearly that the section in which they lie belongs in the earlier divisions of that age. This is indicated by the general correspondence of the organic forms with typical sections elsewhere, particularly those in the region about the Hudson valley. It will be noted that no trilobites of the Olenellus group have been found in this section, though the total number of specimens of this order observed is considerable. The fact that one species of Paradoxides occurs in these beds appears to indicate that the fauna has rather close affinities with the Braintree Cambrian horizon. It is interesting to note that this surviving member of the Paradoxides series is very small. I believe it to be one of the most minute forms which has yet been described. Although this fossil is so far represented by a single specimen, it affords ground for the presumption that the group was at this time imperfectly developed.

The most interesting feature connected with these fossils is the ample representation of the group to which Salterella and Hyolithes belong. By far the greater number of the individual fossils which were found at the three localities belong to one or another of five species described in the following account of the fossil remains. Indeed, at locality No. 1, at least ninety-five per cent of the recognizable fossils are members of this group. Some of the layers at that locality which have an aggregate thickness of half a foot are in good part composed of these remains. It is interesting to note the fact, that certain of these species appear to have found lodgment in the empty shells of their predecessors. In no other way can we so well explain the fact, that from one to four of the cones are often found packed into the larger shells in the manner indicated in the diagrams of the descriptions of fossils from this section. If this view of the relations of these included cones be correct, we have in this horizon perhaps the first evidence of a habit of a somewhat intellectual nature which is known through the history of the rocks.

It is perhaps worth while to note that one of the Ptychoparias found in this section is clearly rolled, as is the fashion with many of the forms, such as the Calymenes, in higher horizons. This peculiar habit has been supposed to be of a protective nature, the trilobite thereby securing immunity from danger when assaulted by enemies. This indeed seems at first sight a very probable interpretation of this habit, and of the peculiarities of form which make the means of rolling the body into a ball possible. The difficulty, however, is to see what was the nature of the enemies from which the creature had to defend itself. The rocks of this horizon are not known to contain any creatures capable of threatening the safety of the trilobites. So far as our knowledge goes, they were themselves the only highly organized forms in this horizon. The other creatures appear to have been relatively weak; none of them, so far as we know, were able to menace the trilobites, nor does it seem likely that the trilobites could have assailed each other in a serious manner.

Relation of this Deposit to Cambrian Problem.

The position of these Attleborough beds with reference to the fauna of the Paradoxides section is one of extreme interest. As yet these two horizons have never been found in definite relations with each other, so that it may be affirmed which of the two is the earlier. The Scandinavian geologists claim that in their country the Paradoxides zone occupies a higher position than that of the Olenellus group. On this account I have taken much pains in seeking for any indication of beds which could be referred to the Paradoxides zone. So far, I have not succeeded in finding any trace of rocks which would serve to establish the relation between the two horizons. As is well known, a considerable mass of strata, having an aggragate thickness of some hundreds of feet, belonging to the Paradoxides section of the Cambrian, exists on the southern shore of Massachusetts Bay in the township of Braintree. This deposit probably extends, as a continuous mass or as an isolated section, as far as the Neponset River in Quincy, a distance of about four miles. Although no distinct fossils have been found, save at Braintree, a number of distinct remains occur near the Neponset River, in beds having much the same aspect, and apparently at about the same distance from the syenites, as those at Braintree. It therefore, on account of the large extent of the Paradoxides section about Massachusetts Bay, seems possible that the Braintree section may be represented somewhere in the Attleborough Cambrian district.

Although I spent a good deal of time searching for rocks which should have a physical likeness with those at Braintree, I have not yet been able to discover any such in the Narragansett field. The conditions under which the search was made render it difficult to make sure that such deposits may not yet be found in that vicinity. A search for the Attleborough series in the Boston synclinal and in the neighborhood of the Braintree beds has likewise been unavailing. No deposits of conglomerates or sandstones having the peculiar hue of that series have been found in any part of the Boston basin. I therefore regretfully conclude that the probability of determining the relative position of these two sections in this field is small. The absence of one of these members of the Cambrian series from the Boston basin and from that of Attleborough may be fairly attributed to the large amount of erosion to which both regions have been subjected. The Paradoxides beds of Massachusetts Bay are evidently a mere remnant of a sheet which once overspread a large part of that area. The extensive conglomerates belonging to the Roxbury series, with their associated slates and the argillaceous deposits of Cambridge and Somerville, are probably of Cambrian age, and may possibly belong to the lower portion of that section, along with the Paradoxides bearing strata. But it is barely possible that they may represent the same age as the conglomerates and shales which lie above the level of the Attleborough fossiliferous horizon. The wide difference in the mineralogical character especially of the slates makes this view, however, improbable.

Although the relation of these two horizons is not determinable by a comparison of the Massachusetts Bay and Narragansett deposits, it is possible that it may be elsewhere determined. Fragments of sections containing these horizons may well be found along other portions of our Atlantic coast.

Discussion of the Evidence afforded by the Attleborough Series.

The facts as given above concerning the rocks of the Attleborough section and the neighboring parts of Rhode Island carry our information concerning the condition of the Atlantic coast line much further than might at first sight be supposed. In the first place, they prove that the Atlantic coast line was during the Cambrian period not far removed from its present position. The great thickness and general character of the conglomerates appear to me to be abundant evidence on this point. Whether the formation of these conglomerates was due to glacial action or not, it is clear that they were deposited near the coast line. Only by the action of water moved by strong currents could we have had the stratification induced which appears in many of these pebbly sections. Such rapid movements of water are only possible in shoal regions. The fact that the pebbles have apparently all been derived from rocks in the immediate neighborhood, those which lie to the westward of the Cambrian deposits, indicates that, while the Cambrian region was sea, the neighboring district was in a condition to yield detritus to erosive forces, and was therefore presumably land. We thus fix the marine shore line of the continent in this area close to the present coast.

It may be here remarked, in passing, that we have now determined four stages in the history of this part of the continent, in which the coast line was near its present position. These are as follows: the Cambrian, which we are now considering, the Carboniferous, which immediately succeeds it in the same field, the Triassic conglomerate of the Connecticut valley, and the probable Miocene conglomerates which appear at Gay Head on Martha's Vineyard. There are two other horizons pretty well determined in which fragmental materials formed along the coast line exist, viz. that of the Roxbury puddingstone, which probably belongs in the Cambrian age, possibly in the horizon of the Paradoxides beds, and the coarse sandstones of Cretaceous age which appear on Martha's Vineyard. If we add to these the glacial conglomerate of the last ice period, we have a total of seven stages in the earth's history from the Lower Cambrian to the present day, in which the shore of the continent has appeared near its present position. When we remember the amount of evidence going to show great erosion in this field since the earliest geological ages, an erosion which may have removed the evidence of coast line deposits of many different ages, we are struck with the fact that we have here proof as to the permanence in the relation of the continent to the sea in this portion of the earth's surface.

The same evidence which enables us to affirm the frequent presence of the coast line at this point, serves also to indicate that this portion of New England has from a very early date possessed and retained its present mineralogical character. The conglomerates of this Cambrian horizon contain substantially the same kinds of rocks as make up similar detrital deposits of the drift period. So far, I have been unable to discover any varieties of rocks in the one which are not contained in the other, with the single exception of the hornblendic granites, such as are intruded in the form of dikes amid the Cambrian deposits. It appears likely that these materials did not appear in this district until after the Cambrian had been deposited.

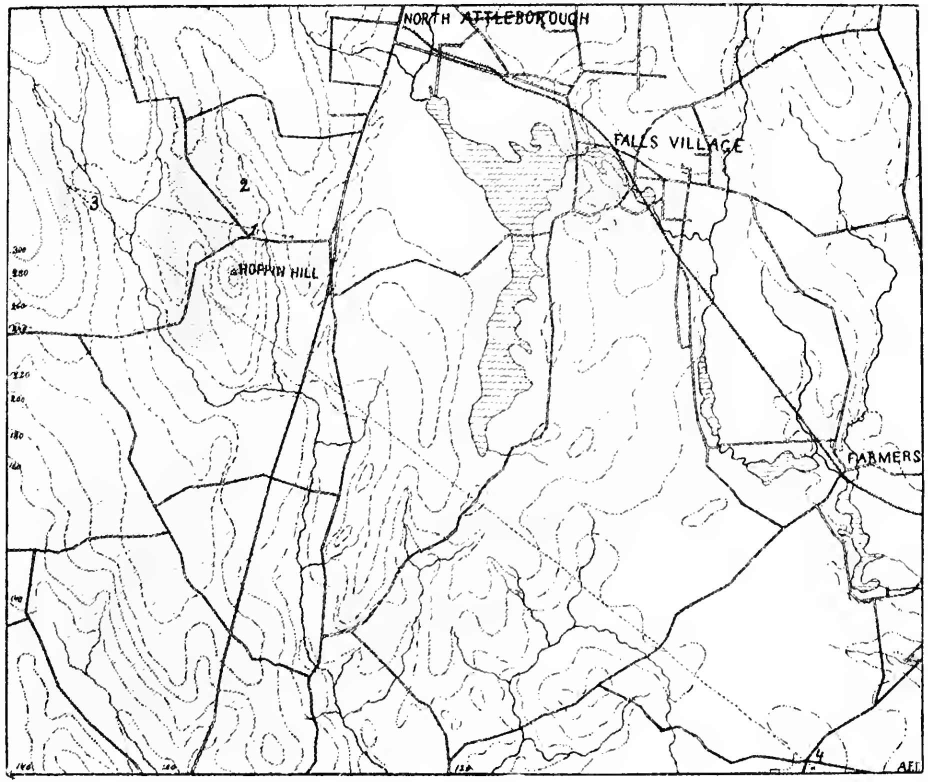
The hornblendic granites which are intruded into the rocks of this Cambrian field have a general likeness to those which appear in the region of the Sharon and Blue Hills. Although in the form of detached masses, they are scattered in a somewhat linear fashion, as in those fields of granite. It is not improbable that their ejection may be of the same date as that of the similar rocks to the northward, but as yet there is no sufficient evidence to make any affirmation in the matter.

The evidence afforded by the Attleborough series as to the history of the Narragansett Basin, taken in connection with the other facts which I have ascertained in my study of this district, is of a very interesting nature. On the eastern side of the Narragansett synclinal, north of Fall River, the Carboniferous deposits lie immediately upon syenites. On this side of the field the Lower Carboniferous strata are composed, to the thickness of a hundred feet or more, of consolidated waste derived from these crystalline rocks. This waste is so little changed, that at first sight the section appears to be composed of decayed granitic matter. It was only on finding fossils in the deposit at Steep Brook, Mass., where it is quarried for fire-clay, that I became convinced of its Carboniferous age. It thus appears that while on the western part of the basin the Carboniferous series rested upon the great section of Cambrian and Pre-Cambrian rocks, it was bounded on the east by ejections of crystalline materials.

This fact enables us in a general way to determine something concerning the time when these granitic deposits appeared on this part of the continent. They evidently were injected after the formation of the Cambrian, and before the formation of the Carboniferous. At the time when the Coal Measures were deposited these hornblendic granites had been worn down to something like the form in which they now appear. If we are ever able to determine the age of the Roxbury conglomerate, we can place the period of the extrusion of some of these hornblendic granites in a yet more accurate manner, for it is evident that those of the Blue Hill region, as before remarked, were subjected to erosion before the deposition of those conglomerates.

The foregoing account of the Cambrian localities of the Attleborough district will, it is hoped, be sufficient to attract the attention of geologists to this important district. Although this report is in its nature preliminary, enough has been set forth to show the importance of the field with reference to many problems in American geology.

Plate I.


NORTH ATTLEBOROUGH
FALLS VILLAGE
FARMERS
HOPPIN HILL
2
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300
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140
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Preliminary Description of North Attleborough Fossils. By N. S. Shaler and August F. Foerste.

1. Obolella crassa, Hall, var.

Plate I. Fig. 1.

Shell oval or sub-circular, the beak projecting a little beyond the general outline of the shell. The surface is marked by numerous concentric, lamellar striæ, and also by rather strong radiating striæ. The latter, although usually continuous throughout their whole length, frequently become more or less disjointed and laterally displaced in passing across certain of the more marked concentric striæ. The radiating striæ also vary at such points in their relative prominence and distinctness.

The interior of the shells differs considerably from that of typical specimens of this species. The cast of the interior of the dorsal or anterior valve exhibits two short triangular elevations at the beak, which represent the cardinal area, and a depression between which corresponds to the cardinal tooth. On either side are additional larger elevations, this pair representing the scars of the cardinal muscles. Immediately above the second pair, the general surface of the casts is strongly elevated, the elevation decreasing in distinctness towards the margin. That part of this elevation which lies nearest to the hinge margin is quite abrupt, and marks the position of the lateral muscular scars. Along the median line of this elevation is a depression extending to above the middle of the shell, the more or less distinct sides of which are known by some writers as central muscular scars.

The cast of the ventral valve shows a median elevation, narrow and prominent, at the beak, which represents very likely a notch in this part of the cardinal area of the original shell. On either side of this elevation are two laterally directed notches, in front of which is an elevation representing cardinal muscular scars, and the elevated portions immediately behind represent lateral scars. No satisfactory central markings could be distinguished. Where it seemed that these could be detected, closer examination has shown them to be too faint for determination.

Locality and position. — Stations Nos. 2 and 3, North Attleborough, Mass., Cambrian, 160 specimens; also at Troy and Schodack Landing, N. Y.; St. Simon and Bic Harbor, Canada.

2. Obolella ?

Plate I. Fig. 2.

Shell almost circular in outline, moderately convex, with no prominent beak. The exterior surface is marked by concentric (exfoliated) striæ of growth, a moderate distance apart, and distinct. The interior cast of the dorsal valve is in general moderately convex, at the edges being more finely and less distinctly striate than the exterior surface. The margin along the beak is flat. The cardinal scars in the cast follow the outline of the shell, and are well defined along their exterior outline, but not along their interior. The reverse is true of the casts of the lateral scars. The lateral scars unite with the central scars, forming a figure comparable with that of a reversed W, which is distinctly outlined along the outline facing away from the beak, but is indistinct along the outline facing the cardinal scars. The diameter of the shell is 5 mm.

Locality and position. — Station No. 2, North Attleborough, Mass., Cambrian, one specimen.

3. Fordilla (Troyensis, Barrande?).

Plate I. Fig. 4.

Cast of left valve 7 mm. long and 4 mm. broad, moderately convex along the border, quite strongly convex near the hinge line. The broadest part of the shell is slightly anterior to the middle of the length of the shell. Posteriorly the shell decreases rapidly in breadth. The posterior extremity is rounded, but more attenuate than in specimens figured by Walcott. Anteriorly the border of the cast is narrowly indented; in consequence of the indentation, the border is produced as a small lobe, and forms the anterior extremity of the shell. A rather broad, shallow groove runs along the shell near the margin. The cast shows no striæ.

Compared with typical specimens of this species, the North Attleborough form is larger, more attenuate posteriorly, and more strongly arched near the hinge line. Walcott, in his Second Contribution to Cambrian Faunas,* figures, on Plate XI. fig. 3 b, a cast which forms a connecting link between the form here described and the typical forms, which have a broader posterior outline.

Locality and position. — Station No. 1, North Attleborough, Mass., Cambrian, one specimen; also at Troy and Schodack Landing, N. Y.

4. Lamellibranch?

Plate I. Fig. 5.

A single specimen of entirely unknown relations has at least the general outline of a Lamellibranch. It is 9.5 mm. long and 3.7 mm. wide. The border is gently curved; the hinge line almost straight. Along the hinge line is a flat, strongly inclined narrow field, with fine striæ almost perpendicular to the hinge line. The rest of the shell forms a surface almost perpendicular to the hinge area. It is finely striated, the curved striæ following the outline of the border. The broadest part of the shell is about one third the dis-

* Bulletin U. S. Geol. Survey, No. 30.

tance from the anterior extremity of the shell. If indeed a Lamellibranch, the specimen is the left valve of the shell.

Locality and position. — Station No. 1, North Attleborough, Mass., Cambrian, one imperfect specimen.

5. Scenella reticulata, Billings.

Plate I. Fig. 6.

Shell small, conical. The aperture is almost circular; but there is a great convexity of curvature on one side, giving rise to a low, indistinct carina, and to a slightly oval outline at the aperture. The apex of the shell is slightly incurved towards the carinated side. The length of the aperture is 6.5 mm., the breadth 6 mm.; the height of the shell is 3.9 mm. The surface is faintly wrinkled transversely. True concentric and radiating striæ are not shown in the specimen. The absence of radiating and concentric striæ would at once separate this specimen from the types of the species, but the markings are so delicate that their preservation in this decayed rock would be extremely improbable. In other respects, however, it is very much like the type specimens.

Locality and position. — Station No. 2, North Attleborough, Mass., Cambrian, one specimen; also at Topsail Head, Conception Bay, Newfoundland.

6. Stenotheca rugosa, var. pauper.

Plate I. Fig. 7.

Shell small, decreasing rapidly in size towards the apex. Apex strongly incurved. Shell corrugated into from five to eight rounded ridges, passing transversely around the shell. These are crossed by very fine, closely set striæ, passing longitudinally along the shell. In the casts, the transverse ridges are less distinct, and the longitudinal striæ are not seen at all. When not crushed, the apex is broad oval in outline. Diameter of the aperture 2.5 mm.; height, the same. Specimens are often smaller.

Locality and position. — Station No. 1, North Attleborough, Mass., Cambrian, 20 specimens. It is of some interest to note that this form does not occur at Station No. 2, where two other varieties are found.

7. Stenotheca rugosa, var. abrupta.

Plate I. Fig. 9.

Shell small, decreasing rapidly in size towards the apex. The apex never strongly incurved; usually within a moderate distance of a line vertical to the base at its centre. Shell never more than slightly curved. Shell corrugated into four or five rounded ridges, passing transversely around the shell, very strong below, decreasing rapidly in size towards the apex. Greatest diameter of the aperture, 4 mm.; height of the shell, the same. Longitudinal striæ very fine and closely set.

Mr. Walcott's note on the type of *Stenotheca pauper* recalls this variety; but our specimens are larger than is indicated by the original description of Billings, and the apex can scarcely be said to be incurved. The ridges are coarse, and not small.

Locality and position. — Stations No. 2 and 3, North Attleborough, Mass., Cambrian, 30 specimens; also at Troy, N. Y., and Bic Harbor, Canada? Varieties *pauper* and *abrupta* are not found connected by intermediate forms at North Attleborough, and may be distinct species.

8. Stenotheca curvirostra, sp. n.

Plate I. Fig. 8.

Shell small, rather elongate; the lower part gently curved, the curvature more marked, especially at the beak; the beak always considerably elevated above the aperture of the shell. The transverse ribs are narrow and sharp; from ten to eighteen are found on a single shell; the interspaces are broad and flat. The longitudinal striæ are fine and closely set. Diameter of the aperture of the shell in the largest specimen found, 4 mm.; height of the shell 5 mm.

Locality and position. — Station No. 2, North Attleborough, Mass., Cambrian, 5 specimens.

9. Platyceras primævum, Billings.

Plates I. and II. Fig. 10.

Shell very small, whorls two in number. Seen from above, the whorls lie very nearly in the same plane; they increase rapidly in size, the second becoming comparatively very large, and all being throughout evenly rounded. Seen from below, only the last whorl is visible, and the whorls have a somewhat spiral form; the ascent of the spire increases rapidly towards the aperture, at that point partly overlapping the first part of the whorl. There are faint traces of transverse striæ; this characteristic ornamentation of the species would not be well preserved in the decomposed material in which the North Attleborough specimens occur. Width of the shell 2.8 mm.; height, 1.5 mm.

Locality and position. — Station No. 2, North Attleborough, Mass., Cambrian, a dozen specimens; also at Troy, N. Y., and Bic Harbor, Canada.

10. Pleurotomaria (Raphistoma) Attleborensis, sp. n.

Plate II. Fig. 11.

Shell small, flattened, composed of three whorls. The first whorl is very small; the succeeding ones increase rapidly in size. The surface in general slopes at a low angle from the apex of the shell to the sides. In the last whorl of the cast, the outside margin of the coil thickens a little, forming an indistinct border along the margin of the shell, which becomes more evident as it approaches the orifice. The edge of the whorl is compressed and rather narrowly rounded. The surface of the shell is marked by fine, transverse, closely set striæ, which apparently are directed backward towards the earlier formed parts of the shell, but in reality indicate various stages of growth of the shell. The internal cast does not show these fine striæ; but broader and more widely separated elevations, having the same direction as the striæ. The diameter of the shell is 3.2 mm.; the height is a little less than 1 mm. Owing to the shape of the shell it is difficult to measure its height accurately.

Locality and position. — Station No. 1, North Attleborough, Mass., Cambrian, one specimen. The discovery of another coiled gasteropod in this division of the Cambrian of America is of interest, and makes the sudden influx of coiled genera in the Upper Cambrian less inexplicable.

11. Hyolithes quadricostatus, sp. n.

Plate II. Fig. 15.

Shell straight, elongate, tapering gradually to an acute point; apical angle 17°. The external cast of the type specimens is 20 mm. long; including an additional length represented by an internal cast of the same specimen, but extending farther from the apical extremity, it is 25 mm. long. As the end of cast is broken, a length of 30 mm. may be presumed for the entire specimen. The supposed dorsal side is broad and flat or slightly concave along the centre; when depressed, a low elevation may occur along the median line; in all cases, the surface retains a rather flat appearance. The lateral angles are rounded. The supposed ventral side is as usual flattened along the median line for about half the width of the shell. The sides of this flattened surface are more or less elevated, giving it a slightly concave appearance along the median line. Immediately beyond the flattened surface on either side is a more or less distinct groove. The result is, that, in addition to the two lateral angles, there are two angles or ridges on the ventral side, giving the entire shell the quadricostate appearance indicated by the specific name. The two ventral ridges increase in distinctness as they recede from the apical extremity, and are usually more distinct, or at least less rounded, than the lateral angles. At a distance of six or seven millimetres from the apical extremity, the shell is crossed by an apparently imperforate septum. The cast of this septum from the upper side had the appearance of a flattened surface with a slightly elevated border around the margin. The surface of the shell is marked by fine transverse striæ. The longitudinal ridges are less prominent on the interior cast of the shell than on the exterior.

Taken by itself this species would appear to be very distinct from the usual forms of Hyolithes, but in reality it forms only the extreme of a series of intermediate species, which begins with specimens characterized by numerous fine longitudinal striæ, these striæ increasing in size and diminishing in number until we have such forms as *Hyolithes hexagonus*, Barrande, with only four ridges in addition to the normal two lateral angles. In the specimens here described, this number is reduced to two additional costæ. The character of the variation is quite distinct from that afforded by a more acute or salient ventral median line alone.

Locality and position. — Station No. 2, North Attleborough, Mass., Cambrian, rare.

12. Hyolithes communis, var. Emmonsi, Ford.

Plate II. Fig. 17.

Shell slender, straight, gradually tapering. In the specimen here described, the part from the apical extremity to the imperforate septum is lost. It is fair to presume that the length of this unseen part was about 15 mm.; the remainder of the specimen is 38 mm. long, so that an occasional total length of 55 mm. or 60 mm. would not be too high an estimate. The apical angle is 11°. The dorsal side is flattish, more or less depressed along the median line, the depression becoming more distinct at a distance from the apical extremity. The ventral side is quite evenly rounded, and is strongly convex; the lateral angles are also rounded, their position chiefly defined by the depression along the median line of the dorsal side. The cast of the septum warpedly curved; the convexity turned towards the apex of the shell; otherwise smooth, with a faint, raised margin. The surface of the shell is ornamented by fine transverse striæ.

This species varies greatly in size, and the specimen here described is one of the largest forms. The depressed median area of the dorsal side is most characteristic.

Locality and position. — Station No. 2, North Attleborough, Mass., Cambrian, one specimen. The type specimens were found near Troy, N. Y.

13. Hyolithes Americanus, Billings.

Plate II. Fig. 16.

Shell straight, triangular, tapering gradually to an acute point. There is no trace of a septum in the specimen at hand. The apical angle is 20°. The dorsal side flattened or gently convex, with a slightly increased curvature at the lateral angles. The lateral angles are but slightly rounded. The ventral side is composed of two flat surfaces, which meet each other at the median line, giving a triangular outline to the cross sections of the shell. The angle formed at the median line is in type specimens never rounded; but there is a slight tendency in some specimens to form a more or less distinct elevation or incipient wing along this line. The flattened surfaces of the ventral side, meeting sharply at the median line, are characteristic of this species. The character of the ornamentation of the surface cannot be determined from the specimens at hand. Mr. Billings describes them as being finely striated, "the striæ curving forwards on the dorsal side, then passing upwards on the sides at nearly a right angle, curve slightly backwards on the ventrum." The specimen described here is 11 mm. long, and is one of the smaller specimens of the species.

Locality and position. — Station No. 2, North Attleborough, Mass., Cambrian, one specimen. It occurs also at Troy, N. Y., and at Bic and St. Simon in Canada.

14. Hyolithes princeps, Billings.

Plate II. Fig 25.

Shell large, straight, gradually tapering, very thin. The shells occur in large numbers throughout the section at Locality No. 1. Their outline is readily seen on almost any fracture of the rock in the bed in which the species is found; but owing to the irregular fracture of the rock and the large size of the species, as well as to the very frail nature of the shell, entire specimens are not found. The following description is drawn up from abundant fragmentary material.

The shells vary greatly in size, reaching at maturity a diameter of 9 or even 11 mm. and a length of 100 mm. or more. The dorsal side is flattened or moderately convex. The ventral side is decidedly convex; usually the convexity is more marked on one side of the ventral surface than on the other, the latter side being often almost flat. The median line is rounded, yet usually distinct enough to be recognized. The apical angle is very moderate. In some specimens it is as low as 6°. In the original description of the species, it is said to be as high as 15°. The lateral angles are also more rounded than in typical specimens. The surface is marked by fine transverse striæ.

It will be noticed that the specimens here described do not closely accord with the type. The lateral angles are not prominent enough, and the apical angle is lower; but they agree with those forms in size and in general appearance. At any rate, the amount of variation seems insufficient to be ranked as specific. One interesting feature of these specimens is the frequency with which the shells of different individuals are found loosely inserted in each other so that three or four shells are successively sheathed one within the other, or they may be inserted side by side in a large individual. Small slender shells apparently belonging to *Hyolithellus micans* also occur in this position. Whatever may be the conditions of this sheathing, it does not suggest any structural connection between the different shells at the time of fossilization.

Locality and position. — Station No. 1, North Attleborough, Mass., Cambrian, 200 specimens.

15. Hyolithes Billingsi, Walcott?

Plate II. Fig. 20.

Shell small. The dorsal side flattened; the lateral edges distinct, but narrowly rounded. The ventral side moderately convex or composed of two flattened surfaces meeting along a rounded median line. Shells are often triangular in cross section and are then distinguished from *Hyolithes Americanus* by the rounded character of the median line on the ventral side, and their smaller size. In the specimens figured by Walcott, the dorsal side is slightly curved, this concavity being almost filled up again by a low, broad, median elevation. This feature has not been detected in the North Attleborough specimens. The identification of this form is entirely unsatisfactory, owing chiefly to the imperfect material at command.

Locality and position. — Station No. 1, North Attleborough, Mass., Cambrian, 6 or 7 specimens. Also at St. Simon and Bic Harbor, Canada, and Silver Peak, Nevada.

16. Hyolithellus micans, Billings.

Plate II. Fig. 23.

Shell very slender, often 22 mm. long, tapering gradually to a pointed extremity. Cross-sections are circular, unless disturbed by pressure. The surface is marked by fine transverse striæ. These striæ may be either of approximately equal size or at more or less regular intervals may have intercalated single striæ of larger size. The apical angle is 4° or 5°.

The identification here made is based chiefly upon the slender form and circular outline of the shell. The operculum has not been found.

Locality and position. Station No. 1, North Attleborough, Mass., Cambrian, 400 or 500 specimens. Also at Bic and St. Simon, Canada, and Troy, N. Y.

17. Salterella curvatus, sp. n.

Plate II Fig. 22.

Shell short, curved, rather rapidly tapering. Cross-sections circular. The curvature of the shell can usually be referred to one plane, but sometimes it is slightly irregular, having what might be called an incipient spiral structure; the apical angle varies from 8° to 12°. The surface is smooth, or ornamented by faint, scarcely visible transverse striæ, in no manner comparable with the much stronger striæ of *S. pulchella*, Billings.

Locality and position. — Station No. 1, North Attleborough, Mass., Cambrian, 20 specimens. Also at L'Anse au Loup, Labrador, and Point Levis, Canada.

18. Aristozoë?

Plate II. Fig. 18.

What appears to be a hinge line is quite straight, 4.3 mm. long; valve oblique, the longest diameter from the anterior end of the hinge line to the opposite border is 7.6 mm, and is inclined to the hinge line at an angle of about 50°. A large tubercle with broad base and almost pointed extremity is situated at a slight distance from the middle of the valve, being closer to the posterior extremity of the hinge line than to the opposite parts of the valve. Between the tubercle and the hinge line is a depression. A slight depression is found between the tubercle and the posterior border of the shell. A strong groove borders the tubercle along its anterior border and extends along its side in the direction of the longest diameter of the valve. Half-way between the tubercle and that part of the border directly opposite to the posterior extremity of the hinge line is a ridge which is well defined towards the border by a depression. Two low grooves cross this ridge transversely, connecting with the groove at the base of the tubercle. The valve is in a fair state of preservation. The affinities of this form are very doubtful.

Locality and position. — Station No. 2. North Attleborough, Mass., Cambrian, one specimen.

19. Microdiscus belli-marginatus, sp. n.

Plate II. Fig. 19.

Head semicircular, 4.3 mm. long and 5 mm. broad. The glabella is oblong, strongly convex, slightly narrowed in front. It is well defined by a deep, distinct groove, which continues around the sides and anterior part of the glabella; it is not connected at the front with the groove which lies along the border of the head and within the rim. The marginal groove is deep, broad in front, gradually growing narrower towards either side; it gives a high relief to the rim. The marginal rim has very nearly the same breadth throughout its length; it is beset with small tubercles, usually sixteen or eighteen in number, which lie near the interior margin of the ridge. The tubercles directly in front of the glabella are often indistinct or obsolete. The occipital furrow behind the glabella is low, and not very distinct. It serves chiefly to bring into greater prominence a tubercle on the middle of the occipital ring. This tubercle is directed backwards, varies in size, and is often low, and again may become a large sharp-pointed tubercle in the form of an incipient nuchal spine. The extension of the occipital furrow along the posterior part of the cheeks is very deep and marked, giving high relief to the cheeks. The posterior rim is very narrow, but sharp and distinct, and the postero-lateral extremities of the head have very small acute terminations, without which they would appear somewhat rounded. The cheeks are connected in front by a narrow, sharply rounded ridge, which lies a short distance from the glabella, along its anterior border.

The pygidium is of an oval form, and is about 5 mm. broad and 4.3 mm. long. The middle lobe is strongly divided from the side lobes by grooves. It is very convex, and is also curved antero-posteriorly, giving the pygidium a strongly convex outline from front to rear as well as from side to side. It is divided into nine or ten segments ; along the median line is a series of tubercles, very distinct on the anterior segments, diminishing in size near the posterior extremity. The sides show no traces of segmentation. They are connected posteriorly by a narrow ridge similar to that connecting the cheeks. The rim is sharp and distinct, being well defined by a furrow which lies between it and the side lobes. The specimens are usually of the size above noted, but one almost entire pygidium found at locality No. 2 must, when perfect, have been at least 8 mm. long.

Locality and position. — Stations No. 2 and 3, North Attleborough, Mass., Cambrian, thirty specimens.

20. Microdiscus lobatus, Hall.

Plate II. Fig. 13.

Head minute, 2.2 mm. long. The glabella is cut transversely by two furrows, giving rise to three lobes, of which the anterior one is considerably larger than the rest. From the occipital ring to the first lobe the glabella grows narrower. The first lobe itself is again larger. The occipital groove is also well marked and the occipital ring has the effect of another lobe to the glabella. The grooves separating the glabella from the cheeks are deep and distinct. The cheeks are prominent and strongly convex, bordered distinctly by the deep continuation of the occipital furrow. Anteriorly the border is rather broad, becoming narrower along the sides. A moderate groove defines the interior of this border anteriorly ; it decreases much in breadth along the sides.

Locality and position. — Station No. 2, North Attleborough, Mass., Cambrian, one specimen.

21. Paradoxides Walcotti, sp. n.

Plate II. Fig. 12.

A single specimen was found showing the under side of the integument which covered the head, 2.8 mm. long, and 3.8 mm. broad. The cheeks are in position, and the facial suture is barely indicated by a faint line running from the anterior extremity of the palpebral lobe forward, bending at first a little outward, then more rapidly inward near the margin, which it cuts; posterior to the palpebral lobe it almost immediately cuts the margin in a slight outward curve. The outline of the head forms a curve, which would be semicircular were it not for its disproportionate breadth. There are faint indications of a spine at the postero-lateral extremities. The glabella is broad in front, the posterior half with incurved sides, narrowing to half its anterior width. The occipital furrow is distinct, and the occipital ring has a distinct tubercle at the middle. The glabella is marked by three pairs of shallow furrows, with perhaps a fourth scarcely discernible pair. The second and third pairs are not seen to meet across the median line; but owing to the position of two very low and rather indistinct tubercles, one anterior and one posterior to the first or posterior pair of furrows along the median line, these furrows seem to meet in a curve bending slightly backwards along the middle of the glabella. The palpebral lobes are large and prominent, beginning a little anterior to the third pair of furrows, and curving around to within a very short distance of the extension of the occipital furrow across the cheeks. The curve along the anterior border of the head is regular. A shallow groove runs within a short distance of the anterior border, gradually becoming deeper and broader and receding more from the border on the sides of the head, so that the rim here becomes broader. A faintly discernible shallow pit near the anterior extremity of the glabella may in this case be only accidental.

Paradoxides tenellus, Billings, is in size like this species, but otherwise very distinct. It is interesting to find a Paradoxides in the Olenellus Cambrian, since its occurrence there diminishes the importance of the Paradoxides Cambrian as a Paradoxides division.

Locality and position. — Station No. 2, North Attleborough, Mass., Cambrian, one specimen.

22. Ptychoparia mucronatus, sp. n.

Plate II. Fig. 21.

Glabella in small specimens very convex, the degree of convexity decreasing with the increase of size; general form oval, the anterior part becoming somewhat narrowed. The occipital furrow is always well defined. There are three pairs of glabellar furrows. These vary greatly in distinctness, being as a rule less prominent in young individuals and more marked in large specimens. The anterior pair is also usually much less distinct than the other two. The occipital ring is well rounded, except where interrupted by the nuchal spine, which is generally present, but usually small, being a mere terminal tubercle directed backwards and often more prominent in young specimens than in older individuals. From this are all variations to that of a moderate-sized spine. In one specimen, a fragment, the head of which may possibly have been 14 mm. long, the spine extended for a distance of 3.2 mm. beyond the general outline of the occipital ring, the base being broad, narrowing suddenly to a short slender spine. Many large specimens are found in which this nuchal spine is not seen. Examination, however, always indicates that in these cases the posterior extremity of the occipital ring has been injured, so that the absence of a nuchal spine cannot be definitely asserted. They agree perfectly in every other respect with the spined forms. Considering that we have positive evidence of large forms with spines, the absence of the same in specimens all apparently more or less injured seems to mean little. One specimen 15 mm.

long has a process of the usual type, namely, a small mucronate tubercle or spine at the posterior extremity. The species occasionally attains a length of head of 20 mm. The average size is within 10 mm. Anterior to the glabella is a groove which separates the anterior border of the head from the glabella and the ocular ridges. Within the border is a broad, shallow groove. It is of medium size, rounded and curved. The distance between the extremities of the border, at the facial suture, is slightly less than the distance between the grooves defining the palpebral lobes. In line with the anterior margin of the glabella, or slightly behind the same and parallel with the anterior border, are the ocular ridges, increasing in prominence with the size of the individual, joining laterally the anterior end of the palpebral lobe. The groove which more or less distinctly defines the posterior margin of the ocular ridge joins the more distinct groove which separates the palpebral lobe from the fixed cheeks. The palpebral lobes are obliquely curved, having a postero-lateral direction. The facial sutures anterior to the palpebral lobes bend slightly outwards to meet the anterior margin of the head. Posteriorly they curve towards the side and backwards, cutting the posterior edge within the postero-lateral angles. The cheeks are more convex in young specimens; in larger individuals they are only moderately curved. The extension of the occipital groove over the sides of the head is quite deep and distinct. Numerous specimens of free cheeks show that the postero-lateral extremities of the head were quite strongly spined.

Three specimens have been found preserving most of the segments of the thorax, the posterior ones being more or less injured. One of these specimens shows thirteen segments, but there may have been fourteen or fifteen in the complete individual. The pygidium, judging from the specimens at hand, must have been relatively very small, perhaps about the size of that of *Ptychoparia Piochensis*. The pygidium has not been found.

The side lobes of the thorax are moderately broader than the axial lobe. The middle lobe is strongly convex, and marked with a median row of mucronate tubercles, or small spines. These in the individual best preserving them were more prominent along the middle segments, being of moderate size anteriorly and practically obsolete in the last three or four segments. The species, as already noted, is quite variable; but the variations are none of them of any marked character, and all are abundantly connected by intermediate specimens. It takes the place of the series of species from the Vermont sections known as *Ptychoparia Adamsi*, *P. Teucer*, *P. Vulcanus*, and the type of fossils in which the border is separated only by a short interval from the glabella, as figured by Walcott under *P. Adamsi* (Bulletin U. S. Geol. Survey, No. 30, Pl. XXVI. fig. 1 c). These specimens would have been placed under *P. trilineata*, Emmons, had not such a good observer as Walcott decided, from a personal observation of the types, that the species was properly a *Conocoryphe*, which our specimens decidedly are not.

Locality and position. — Stations Nos. 2 and 3, North Attleborough, Mass., Cambrian, 300 specimens.

23. Ptychoparia Attleborensis, sp. n.

Plate II. Fig. 14.

Head small, often minute; in the largest specimen, 4 mm. long. The usual size is about 2.6 mm. The glabella is oblong or slightly attenuate anteriorly. The occipital groove is low or indistinct. The occipital ring extends beyond the general posterior outline of the head, and apparently forms part of the glabella before it. The glabella is sometimes intersected by faint lateral grooves, of which there are three pairs, the anterior pair scarcely visible. Oftener these grooves are obsolete, and the glabella may, in case the occipital groove is very slight, appear as a continuous undivided body as far as the posterior margin of the head. The glabella is always convex, and considerably elevated above the general level of cheeks. There is in some specimens a very slight trace of an ocular ridge, which runs from the anterior end of the glabella laterally, and slightly posteriorly, joining a similar slight trace of the palpebral lobes. The most marked feature of the fixed cheeks is the existence of a depression along their postero-lateral outline. The anterior border is proportionately very broad. About the character of the rim little can be said. Near the lateral margin of the border, or rather near the facial suture, there are sometimes two or three low tubercles visible. There is also in some specimens a faint trace of a sufficient elevation of the border to indicate an incipient marginal rim. A careful comparison of these specimens with published figures of *P. subcoronata*, Hall and Whitfield, a specimen of similar size, shows numerous differences, which are too marked to permit the Attleborough specimens to be placed under the same species.

Locality and position. — Station No. 2, North Attleborough, Mass., Cambrian, 20 specimens.

EXPLANATION OF PLATES.

PLATE I.

Fig. 1. *Obolella crassa*, Hall, var.; *a*, dorsal valve; *b*, interior cast of the same, the features of the central area exaggerated to explain theoretical views; *c*, the same, in its normal state; *d*, the interior surface of the dorsal valve diagrammatically represented; *e*, the interior cast of the ventral valve; *f*, the interior surface of the ventral valve diagrammatically represented.

In the diagrammatic figures: *x*, cardinal area; *a*, cardinal muscles; *d*, lateral muscular scars; *c*, central muscular scars; *p*, a notch in the cardinal area.

Fig. 2. *Obolella*; *a*, ventral valve; *b*, interior surface of the same; *c*, a diagrammatic representation of the same.

Fig. 3. Probably a cast of an operculum of some species of *Hyolithes*.

Fig. 4. *Fordilla Troyensis*, Barrande?

Fig. 5. *Lamellibranch?*

Fig. 6. *Scenella reticulata*, Billings; *a*, lateral view; *b*, outline of base.

Fig. 7. *Stenotheca rugosa*, var. *pauper*.

Fig. 8. *Stenotheca curvirostra*, sp. n.

Fig. 9. *Stenotheca rugosa*, var. *abrupta*; *a*, normal type; *b*, a single larger specimen.

Fig. 10. *Platyceras primævum*, Billings; *a*, seen from above; *b*, an umbilical view of the same, specimen laterally compressed.

PLATE II.

Fig. 10. *Platyceras primævum*, Billings; *c*, a specimen of normal type.

Fig. 11. *Pleurotomaria* (*Raphistoma*) *Attleborensis*, sp. n.

Fig. 12. *Paradoxides Walcotti*, sp. n.

Fig. 13. *Miscrodiscus lobatus*, Hall.

Fig. 14. *Ptychoparia Attleborensis*, sp. n.

Fig. 15. *Hyolithes quadricostatus*, sp. n. Ventral view; a section near its larger extremity, and a basal view of the septum.

Fig. 16. *Hyolithes Americanus*, Billings; ventral view, and cross-section near its larger extremity.

Fig. 17. *Hyolithes communis*, var. *Emmonsi*, Ford; dorsal view, with cross-section of its larger extremity, and basal view of the septum.

Fig. 18. *Aristozoë?*

Fig. 19. *Microdiscus belli-marginatus*, sp. n.; *a*, head; *b*, pygidium.

Fig. 20. *Hyolithes Billingsi*, Walcott ? three specimens with cross-sections.

Fig. 21. *Ptychoparia mucronatus*, sp. n.; *a*, glabella, with very marked terminal spine, smaller type; *b*, glabella, larger type; *c*, movable cheek associated with the same; *d*, specimen preserving thoracic segments.

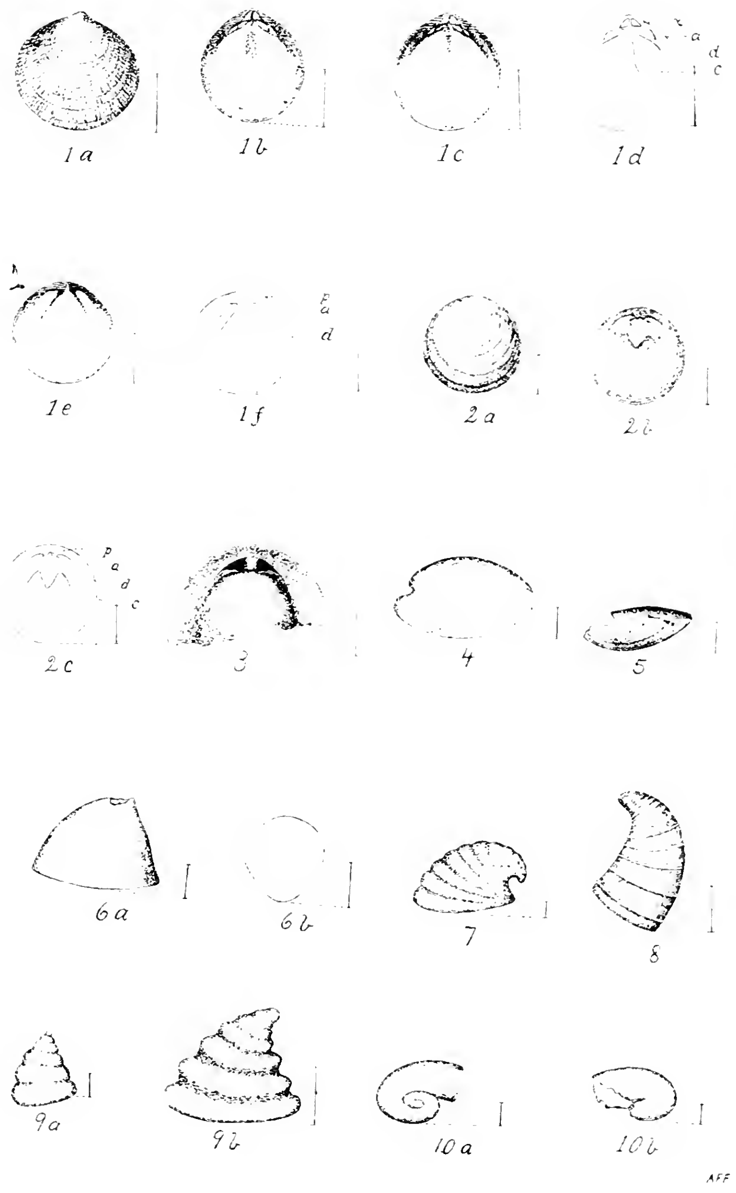
Fig. 22. *Salterella curvatus*, sp. n.; two specimens, the lower slightly coiled.

Fig. 23. *Hyolithellus micans*, Billings.

Fig. 24. Not numbered in the plate, a movable cheek, relationship unknown.

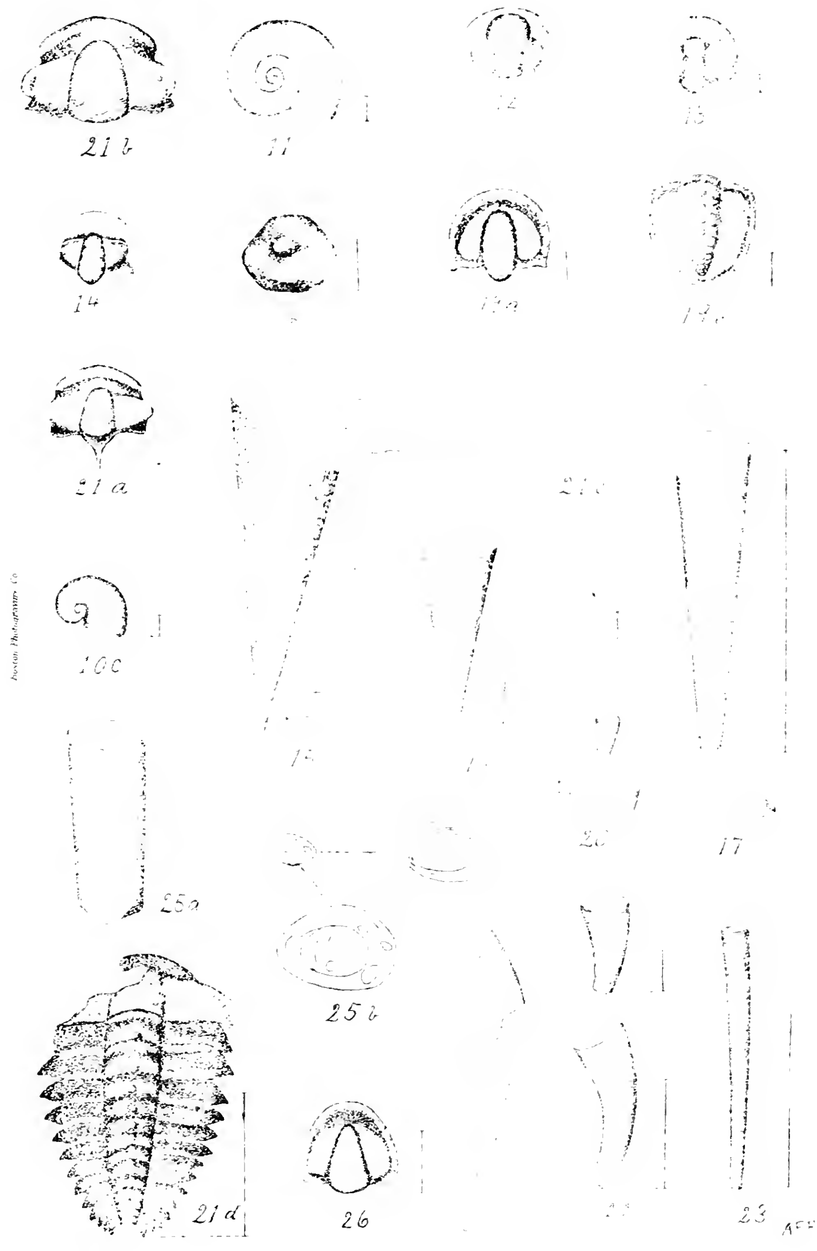
Fig. 25. *Hyolithes princeps*, Billings; *a*, ventral view; *b*, sections showing invagination of different individual shells of same species; some of the smaller with more circular outlines may also be those of *Hyolithellus micans*, Billings.

Fig. 26. *Microdiscus speciosus*, Ford; head; figure introduced as a means of comparison with *M. belli-marginatus*. From Olenellus Cambrian of Troy, N. Y.


1a
1b
1c
1d
a
d
c
1e
1f
p
a
d
2a
2b
2c
p
a
d
c
3
4
5
6a
6b
7
8
9a
9b
10a
10b
AFF

Shaler & Foerste.
Attleboro Fossils.

Plate 2.



No. 3. — *Specimens of Fossil Plants collected at Golden, Colorado, 1883, for the Museum of Comparative Zoölogy at Cambridge, Mass., examined and determined by* Leo Lesquereux.

[Returned to the Museum, July 17, 1884.*]

CRYPTOGAMOUS PLANTS.

Lycopodiaceæ.

1. *Selaginella Berthoudi*, Lx. 2 specimens.

Filicaceæ.

2. *Sphenopteris Lakesii*, Lx. 62 specimens.
3. *Sphenopteris membranacea*, Lx. 2 specimens.
4. *Hymenophyllites confusus*, Lx. 5 specimens.
5. *Pteris pseudopennæformis*, Lx. 2 specimens.
6. *Pteris subsimplex*, Lx. 20 specimens.
7. *Pteris erosa*, Lx. 1 specimen.
8. *Pteris undulata*, sp. nov. Leaves large, linear-lanceolate, regularly deeply undulate-crenate especially in the upper part; secondaries thin, distant, declined in joining the rachis, open in passing toward the borders; forking once at base, sometimes once again near the borders, very distinct.

Much like *P. subsimplex*, Lx., U. S. Geol. Surv. of the Terr., VII. p. 52, Pl. IV. fig. 5; but with the secondaries thinner and the borders undulate. The leaves, about 12 cm. long, $3\frac{1}{2}$ cm. broad, are coriaceous with polished surface. The angle of divergence of the veins is more acute, 45° to 50°, and their distance $1\frac{1}{2}$ mm. 2 specimens.

9. *Woodwardia latiloba*, Lx. 53 specimens.
10. *Gymnogramma Haydenii*, Lx. 8 specimens.

Equisetaceæ.

11. *Physagenia*, species. Tubercles attached to filaments diverging in rows from a central point, composing the rhizoma of some *Equisetaceæ*. Central point exactly round, 2 mm. in diameter; tubercles oval, 12 mm. long, 6 mm. broad in the middle, strangled to 2 mm. at the point of union, and forming a chain of which two of the tubercles are seen in close connection. They are

* The manuscript of this memoir, as it was delivered in 1884, is copied without any correction. — Editor.

deeply irregularly wrinkled lengthwise, of the same size and aspect as those of *P. Parlatorii*, Heer, Fl. Tert. Helv., p. 100, Plate XLII. figs. 6 a and 13. A large number of fragments of stems are mixed with the tubercles distributed in most of the specimens. 21 specimens.

PHANEROGAMOUS PLANTS.

Palmæ.

12. *Geonomites Goldianus*, Lx. 10 specimens.

13. *Geonomites graminifolius*, sp. nov. Broken or separated rays of Palm, varying in width from 5 to 10 mm., marked in the middle by a broad nerve, the borders thinly regularly striate by 10–15 thin veins scarcely distinct even with a lens. These fragments may belong to leaves of *Calamopsis Danai*, Lx., or to a species much like it. One leaf in a better state of preservation has the rays narrowed to a point of connection to a broad thinly lineate rachis, united 3 to 5 together, either connate part of their length, or disconnected to the base, like the fragments described above. Though the likeness to *Calamopsis Danai*, figured and described in Trans. Am. Phil. Soc., XIII. p. 411, Plate XIV. figs. 1–3, is marked, I have never seen the rays divided in narrow laciniæ as in this species, generally found in small narrow linear segments. 7 specimens.

14. *Geonomites*, species undet. 1 specimen.

15. *Palmocarpon commune*, Lx. 13 specimens.

16. *Palmocarpon lineatum*, sp. nov. Seeds small, oval or oblong, obtuse at apex, subtruncate at base, regularly thinly but distinctly striate.

The seeds 4 mm. long, 2½ mm. in diameter, are very numerous, apparently derived from racemes. 8 specimens.

17. *Palmocarpon truncatum minor*, Lx. 8 specimens.

Piperaceæ.

18. *Piper Heerii*, sp. nov. Leaves subcoriaceous, round or oval, very entire, palmately nerved from the base; lateral nerves very curved, the outer following the borders up to the middle of the leaf, the inner acrodrome.

The fragment, the half of one leaf cut lengthwise or along the medial nerve, is, in all its characters, identical with the leaf described by Heer as *Piper antiquum*, Beitr. zum Foss. Fl. v. Sumatra, p. 11, Plate I. fig. 7. As the leaf is fragmentary, the petiole being absent, I cannot well identify it with that of the Miocene of Sumatra, though I am unable to see any marked difference. The leaf described by Heer is unequilateral and long petioled, and none of these characters can be seen from the American fragment. The nerves are distinct; the outer primary follows the borders at a small distance, its branches, nearly at right angles, forming, by anastomosing curves, a series of areoles along the borders from the middle downward, and the areas are traversed by nervilles at right angles. 1 specimen.

AMENTACEÆ. (APETALEÆ.)

Betulaceæ.

19. *Betula fallax*, sp. nov. Leaves rhomboidal-ovate, cuneate to the base and narrowed in the same degree from the middle to the apex, penninervate; lower pair of secondaries attached to the midrib above the base of the leaves and opposite, the others, 5–6 pairs, parallel, at variable distance, at an acute angle of divergence, somewhat curved in passing toward the borders; border distantly dentate in the upper part of the leaves, the teeth short and turned up, being marked only at the apices of the lateral nerves which are mostly simple, the lower ones only with few branches. The species resembles in the form of the leaves *Betula nigra*, Linn. The leaves vary from $3\frac{1}{2}$ to $5\frac{1}{2}$ cm. in length; from $2\frac{1}{2}$ to $3\frac{1}{2}$ cm. in width in the middle. The angle of divergence of the nerves is only 30°, and therefore the leaves are only dentate in the upper part, at the points entered by the secondaries. 32 specimens.

20. *Betula Schimperi*, sp. nov. Leaves small, as broad as long, round or subcordate at base; ovate, acute, simply or doubly dentate; lateral nerves thick, 5 pairs, the three lower opposite, the lowest more or less branching outside, all craspedodrome, as well as the divisions, entering the larger teeth directly when simple, and the intermediate short ones by branches; curved in traversing the areas at a broad angle of divergence. The leaves measure 2 to 3 cm. across, both ways, and are deltoid-acute at the apex. The teeth, like the veins, are somewhat distant, turned outside, sharply pointed, triangular. The base of the medial nerve is pressed into the stone, and thus the leaves appear subcordate; but the base is really rounded and abruptly turned down to the pedicel. The surface is rugose by the deep impression of the nerves and nervilles, these being simple or branching in the middle. The relation of the species is with *Betula angulata*, Goepp., Shoss. Fl., p. 10, Plate III. fig. 3. 2 specimens.

21. *Betula*. Species not determinable. 1 specimen.

22. *Alnus rugosa*, sp. nov. Leaves membranous, elliptical-ovate, narrowed to the base, undulate on the borders, pinnately nerved; lateral nerves equidistant, parallel, straight, craspedodrome, with few branches; surface rugose. The leaves are about of the same size as those of *A. nostratum*, Ung., as figured, Chlor. Protog., Plate XXXIV. fig. 1, and the nervation is of the same type; but the leaves are narrowed, not rounded to the base. 2 specimens.

23. *Alnus carpinifolia*, sp. nov. Leaves comparatively small, ovate-acute, narrowed and abruptly short-decurring to the petiole, entire to the middle, denticulate above; lateral nerves equidistant, the lower pair much branching, all parallel, at an acute angle of divergence, craspedodrome.

The relation of the leaf is with that of *Alnus cycladum*, Ung., Fl. v. Kumi, p. 23, Plate III. fig. 19, differing essentially by the base which is rounded, and abruptly turned down to the petiole. The lower lateral nerves are joined to the midrib a little above the base of the leaf. 1 specimen.

Cupuliferæ.

24. *Quercus Haydingeri*, Ett. 2 specimens.

25. *Quercus straminea?* Lx. The leaf which I refer to this species is oval, apparently denticulate near the apex, and narrower than those figured in the U. S. Geol. Surv. of the Terr., VII., Plate XIX. figs. 6, 7. It may therefore belong to a different species. The facies and nervation are the same, and in these last two leaves the upper part is destroyed. 2 specimens.

26. *Quercus viburnifolia*, Lx. 11 specimens.

27. *Quercus pseudo-alnus*, Ett. 1 specimen.

28. *Quercus celastrifolia*, sp. nov. Leaves subcoriaceous, oval, equally narrowed at both ends, obtusely pointed; secondaries very oblique, distant, parallel from the base, curving in passing toward the borders, ascending along them, nearly simple, passing upward under the teeth and joined to them by short branches.

The teeth are acute, turned upward, one at the end of each of the secondaries which are subopposite in 5 or 6 pairs; nervilles thin, at right angles to the medial nerve, except near the borders, where they turn upward like thin tertiary nerves. The leaves are 5–6 cm. long, 3–3½ cm. broad, the angle of divergence 30–35°. 3 specimens.

29. *Quercus coloradensis*, sp. nov. Leaves subcoriaceous, entire, oblong, obtuse, rounded at the base and abruptly decurring in joining the petiole (broken); secondaries 5–6 pairs, at an acute angle of divergence, camptodrome, the lower ones branching, all connected by distinct though thin nervilles and running high up along the borders which are parallel in the middle. By the size and form of the leaves, 5 to 6 cm. long, 3 to 4 cm. broad in the middle where they are somewhat contracted, the species is related to *Quercus Oreadum*, Sap., Fl. de Cumi, Ann. Soc. Nat., Plate II. fig. 11. 2 specimens.

30. *Quercus Whitei*, sp. nov. Leaves of medium size, membranous, ovate-lanceolate, cuneiform to the base, short-petioled, regularly more or less deeply dentate; secondaries straight, oblique, equidistant, simple, parallel, each entering one of the teeth which are gibbous on the back.

This fine species is closely allied to *Q. clymodrys*, Massal., Foss. Fl., Pl. XXII., XXIII., fig. 10, 12, especially with the variety described as *Castellinensis* by Capellini, Form Gessosa, p. 52, Plate V. fig. 1. It is also allied to *Q. furcinervis*, Rossm., differing from both by the subdentate or umbonate teeth, resembling those of *Q. platonia*, Heer. The secondaries at an angle of 40° are straight, the upper ones only slightly curved. The teeth, short upon some leaves, as long as ½ cm. upon others, are always distant and bossed on the back. The leaves average 7 cm. long, and 4 cm. broad in the middle. 6 specimens.

Salicineæ.

31. *Populus Ungeri*, Lx. The specimen referred to this species is a fragment, the lower half of a leaf, apparently round, entire on the borders and

with the nervation of the species as figured in U. S. Geol. Surv. of the Terr., VII., Plate XXIV. fig. 5. The size is also the same. In this fragment the basilar border is abruptly turned downward, and slightly decurrent to the petiole, as in *P. subrotundata*, fig. 8 of the same plate. The petiole is inflated below the border, as in some species of Ficus. But that is apparently a result of compression. 3 specimens.

32. *Populus monodon*, Lx. 1 specimen.

33. *Populus mutabilis*, Hr. 1 specimen.

34. *Populus Gaudini*, Heer. A small leaf, ovate in outline, narrowly long-acuminate, truncate at base ; pinnately nerved ; nerves thin.

The leaf is of the same size as that of the species in Heer, Fl. Tert. Helv., Plate LXIV. fig. 3. It has also the same form ; except that it is narrowly acuminate, like fig. 6 of the same plate and same species. The leaf is 5 cm. long, $3\frac{1}{2}$ cm. broad near its base, and abruptly curved to the slender petiole. 1 specimen.

35. *Populus Zaddachi*, H. 1 specimen.

36. *Populus arctica*, Heer. The species is represented by a number of specimens, all small leaves, 2 – 4 cm. long, crenulate on the borders, more or less enlarged transversely, five-nerved from the base, coriaceous.

Except that the leaves are generally more distinctly crenulate, nothing in the characters indicates a difference from those which I have figured in U S. Geol. Surv. of the Terr., VII., Plate XXIII. and Plate XLVI., or of those in Heer, Fl. Arct., I., Plate IV. fig 6 a. The nervilles are generally strongly marked. 15 specimens.

37. *Populus Nebrascensis*, Newby. The species is represented by a very large number of specimens, some of them with the characters indicated by the author in "Illustrations and Notes on the Extinct Flora of North America," p. 62, Plate XII. figs. 4, 5, while others are definite varieties, which could be considered as species closely allied to *P. arctica*, *P. Zaddachi*, and *P. Richardsoni* of Heer. I have separated the varieties by short diagnoses. The true *P. Nebrascensis* of Newberry has the teeth of the borders unequal, always obtuse. It differs from *P. arctica* by the absence of transverse nervilles, and the leaves longer, generally ovate-lanceolate, nerved to the base. 145 specimens.

38. *Populus Nebrascensis*, var. *grandidentata*, Lx. Leaves broader, rounded and undulate toward the base ; borders cut from the middle upward in large deltoid obtuse gradually longer teeth. Some of the leaves are subtruncate at apex with long irregular teeth ; others are rapidly narrowed to an obtuse apex. The nervation is the same in the varieties as in the normal form, 3 – 5 palmate from the base, with the inner pair of primary nerves curved inward and ascending to near the apexes and the secondary ones at a great distance from the base. 85 specimens.

39. *P. Nebrascensis*, var. *rotundata*, Lx. Much like the preceding, differing from it by the broader leaves, broadly round and enlarged at the base. The teeth are obtuse and large. 48 specimens.

40. *P. Nebrascensis*, var. *acute-dentata*, Lx. Leaves oval, narrowed at base,

lanceolate above, generally palmately trinerved, teeth of the borders large, equal, sharply pointed. 13 specimens.

41. *P. Nebrascensis*, var. *longifolia*, Lx. Leaves large, oblong-ovate, rounded at base, five-nerved ; lateral primary nerves ascending to above the middle, scarcely curved inside, much branching ; secondary nerves three or four pairs, at a great distance from the base, camptodrome or craspedodrome, with their divisions effaced at the borders which are cut in obtuse large teeth. The leaves are longer, lanceolate from below the middle, 7½ to 11 cm. long, 4 to 7 cm. broad below the middle ; the teeth are large, round, equal, marked from near the base ; the petiole is long and slender. 15 specimens.

42. *Populus tenuinervata*, sp. nov. Leaves comparatively small, round or ovate, broadly cuneate or rounded at base, palmately five-nerved ; inner primary nerves curving inward and ascending near the apex ; those of the outside also curving and ascending to the middle, all camptodrome, thin but distinct ; borders irregularly dentate, the teeth unequal and pointed ; nervilles distinct, obliquely joined in the middle.

The leaves resemble those of a *Ficus*, being, in their facies, like those of *Ficus crenata*, Ung., which, however, has not distinct nervilles. They have a still more marked likeness to those of *Populus latior-transversa*, Heer, as figured by Ludwig in Paleont., V., Plate XXVI. fig. 3. The petiole is thick. 34 specimens.

43. *Populus crenata*, Ung., considered by Schimper a var. of *P. mutabilis*, Heer. The leaves are referable to the species as it is figured by the author, Fl. of Sotzka, Plate XV. fig. 6, being small, oval, rounded, and trinerved at base, the primary lateral nerves at an acute angle of divergence, not much curved inward, the borders with large unequal teeth, the substance coriaceous and the surface polished. 17 specimens.

44. *Populus attenuata*, Al. Br. 2 specimens.

Plataneæ.

45 and 46. *Platanus Guillelmæ*, Goepp., and *P. aceroides*, Heer. It is extremely difficult to separate the species. The description of Heer, Fl. Alask., p. 473, merely defines the leaves of *P. Guillelmæ* as undivided or merely sublobate, acutely dentate, narrowed into a short petiole; secondary nerves at an acute angle of divergence ; and he remarks in the explanation, that the leaves of Disco which he refers to the species are tapering to the petiole, slightly lobed or not at all, and have short teeth. According to this, most of the very numerous specimens obtained at Golden are referable to *P. Guillelmæ*. I refer to *P. aceroide* those with more open primary lateral nerves and of a more solid consistence. The determination is rendered more uncertain by the generally fragmentary state of the specimens. 76 specimens.

47. *Platanus Haydenii*, Newby. A beautiful specimen, No. 508 of the list, appears referable as a variety to this species. The leaf is oval in outline, trinerved from above the decurring base ; the lobes, five, short, obtuse at the apex

of the three primary nerves and of the two lower secondary ones which come out of the midrib very obliquely, far above the base of the primary nerves or nearly in the middle of the leaf. The borders of the leaf are obtusely dentate between the lobes, the teeth being short, turned outside, separated by flat sinuses. The leaf is 9 cm. long, without the petiole, of which only 1 cm. is preserved and 5 cm. broad in the middle, cuneiform to the base, decurring under the primary nerves, and tapering upward in narrowing about in the same degree. This fine leaf is apparently of the same kind as that in Newberry. "Illustrations," Plate XIII. fig. 1, named *Populus nervosa*, var. *elongata*. It is however distinctly trilobate, and referable to *Platanus*, on account of the decurring base of the leaves under the lateral primary nerves. 16 specimens.

48. *Populus Raynoldsii*, Newby. 23 specimens.

49. *Populus rhomboidea*, Lx. 6 specimens.

50. *Populus*, species undeterminable. 7 specimens.

Urticaceæ. — Ulmaceæ.

51. *Ulmus quercifolia*, Ung., Iconogr., p. 43, Plate XX. fig. 23. The specimen merely differs from the European species as figured by Unger in the narrower more elongated base of the leaves. The borders are sharply dentate, the lateral nerves distant, oblique, parallel from the base, passing in a curve toward the borders, where they become effaced. 1 specimen.

52. *Ulmus antecedens*, sp. nov. Leaves small, thickish, oblong-lanceolate, acute, subcordate and subequilateral at base, doubly or triply dentate ; teeth short, curved upward ; secondaries thick, parallel, strong and straight, generally simple, sometimes forking in the middle, with thick oblique nervilles.

The leaf has the same character as those of *Ulmus crassifolia*, of Texas. The substance is thick, the size is the same, 4 cm. long, 2 cm. broad in the middle, the widest part: the lateral nerves 12 or 13 pairs. 1 specimen.

Moreæ.

53. *Ficus (Dombeyopsis) grandifolia*, Ung. Considered by Schimper a synonym of *Ficus tiliæfolia*, Al. Br., differs by the coarser texture of the leaves and the larger size. Of the leaves which represent this species, one, preserved entire, is 15 cm. long from the base of the petiole, 18 cm. broad in the middle, with the base prolonged downward into two auricles, descending 4 cm. lower than the base of the medial nerve. 8 specimens.

54. *Ficus tiliæfolia*, Al. Br. 18 specimens.

55. *Ficus Berthoudi*, sp. nov. Leaves thick and coarse, broadly cordate at base, ovate-lanceolate, acuminate above, entire, enlarging toward the base and rounding to the petiole, descending lower than its top, sometimes auriculate, the basilar border in one leaf overlapping the top of the petiole ; primary nerves deep and broad ; lower lateral nerves opposite, the upper alternate, all very deeply curving toward the borders and following them in a series of

areoles; nervilles deep, close, parallel, cut by branches at right angles, forming a square distinct areolation. 4 specimens.

56. *Ficus asarifolia*, Ett. 1 specimen.

57. *Ficus Andræi*, sp. nov. Leaves subcoriaceous, long petioled, elliptical-oblong, slightly emarginate at the rounded base, lanceolate above, crenulate on th eborders ; palmately five-nerved ; lower lateral nerves with fewer branches following the borders, the inner ascending the borders, near the apex somewhat incurved, much branched outside, camptodrome; secondaries three pairs, at a great distance from the base; nervilles strong, at right angles to the nerves.

The leaf resembles in shape and size some of those of *Populus Richardsoni*, Heer. It differs essentially by a strongly fibrillose nervation, the narrowly oval oblong shape, not enlarged, but subcordate at base. The leaf broken at apex is 8 cm. long, 5 broad in the middle. The preserved part of the petiole is 2 cm. long. 4 specimens.

58. *Ficus auriculata*, Lx. 8 specimens.

59. *Ficus subtruncata*, Lx. 4 specimens.

60. *Ficus spectabilis*, Lx. 7 specimens.

61. *Ficus occidentalis*, Lx. 5 specimens.

62. *Ficus irregularis*, Lx. 2 specimens.

63. *Ficus protogea ?* H. A fruit. 2 specimens.

64. *Ficus*, species undeterminable. 4 specimens.

65. *Protoficus Zeilleri*, sp. nov. Leaves of medium size, coriaceous, rugose on the surface, enlarged and round-cordate at base, deltoid at the acute apex, palmately three- or five-nerved from the top of the petiole; lateral nerves much branched; borders crenulate. The leaves, deeply rugose by the impression of strong nervilles, are 6 to 7 cm. long, 5 to 5½ cm. broad below the middle; primary nerves 3 or more, generally 5, the lower at a broad angle of divergence, following the borders, the inner ascending in a curve somewhat inclined to the midrib; secondaries two or three pairs at a great distance from the base. The borders, mostly destroyed, are seen crenulate, at the few places where they are preserved. 5 specimens.

Lauraceæ.

66. *Laurus socialis*, Lx. 6 specimens.

67. *Laurus primigenia*, Ung. 4 specimens.

68. *Laurus Smidtiana*, Heer, Fl. Shakal, p. 51, Plate XV. fig. 8. Leaves petiolate, coriaceous, obovate, very entire; secondaries camptodrome, dissolved in the reticulation. The fragments which I refer to this species are not quite satisfactory for positive determination, though the outlines of the leaves, their size and nervation, fully agree with the description and figures of the author. The areolation is peculiar, composed of thin close nervilles, crossing the areas at right angles to the midrib, or obliquely to the lateral nerves, as in some species of *Pyrus*. But one of the leaves preserved nearly entire has the base

decurring to a short petiole, and is evidently a *Laurus*. That leaf is oval, nearly obtuse. 3 specimens.

69. *Laurus*, species undeterminable. 1 specimen.

GAMOPETALEÆ.

Lonicereæ.

70. *Viburnum marginatum*, Lx. 15 specimens.

71. *Viburnum anceps*, Lx. 5 specimens.

Oleaceæ.

72. *Fraxinus denticulata?* Heer. A fragment only, the upper part of a small oblong oval leaf, with borders slightly denticulate, the lateral nerves mostly craspedodrome, entering the teeth. By the form, the size of the leaf, and the nervation, the fragment is similar to that described by Heer, Arct. Fl., II. p. 118, Plate XLVII. fig. 2. The identity is not positively ascertained. 1 specimen.

Sapotaceæ.

73. *Styrax ambra*, Ung. Leaves membranous, broadly ovate, round-truncate at base and abruptly attenuated to the petiole, entire, pinnately nerved; secondary nerves curved, following the borders, camptodrome, branching at the apexes, the lower pair following the borders, joined to the medial nerve at a short distance from the base; nervilles transverse, oblique, continuous.

One of the leaves referred to this species is preserved whole, except the apex, and is conformed in all its characters like that figured by Unger, Sillog., III. p. 34, Plate XXIV. figs. 19, 20. 2 specimens.

74. *Styrax Laramiense*, sp. nov. Leaf subcoriaceous, smooth on the surface, oval, very entire, equally narrowed in rounding downward from the middle to a short petiole and upward to the point (broken), pinnately nerved; medial nerve straight, narrow; secondaries at an acute angle of divergence, a little curved in passing to the borders, which they follow in areoles.

One leaf only 5½ cm. long, 4 cm. broad; the lateral nerves at an angle of divergence of 30°. It is related to *S. officinale*, Linn. 1 specimen.

POLYPETALEÆ.

Araliaceæ.

75. *Aralia notata*, Lx. 2 specimens.

76. *Aralia Hercules?* Ung. 1 specimen.

Ampelideæ.

77. *Cissus tricuspidata*, H. 3 specimens.

78. *Cissus primæva?* Sap. A fragment, the upper part of one leaf, deltoid acuminate, with four pairs of opposite lateral nerves diverging from a thick

midrib, representing, in shape at least, the figure of that species in Saporta, Sezanne Fl., Plate XI. fig. 2. The sandstone is coarse and hard, and no trace of areolation is distinguishable. 1 specimen.

79. *Cissus parrotiæfolia*, Lx. 6 specimens.

80. *Cissus lobato-crenata*, Lx. 1 specimen.

81. *Cissus corylifolia*, sp. nov. Leaves thickish, ovate, blunt at apex, simply or doubly short dentate, strongly pinnately nerved; lateral nerves at an acute angle of divergence, close, parallel, scarcely curved in passing to the borders, the lowest much branched on the under side, the upper ones branching near their ends, craspedodrome; nervilles at right angles to the nerves, simple or branched in the middle, deeply impressed.

The leaves, finely preserved, vary in length from 6 to 9½ cm. and from 4 to 7½ cm. in width, being broadest a little below the middle. They have a degree of likeness to *Parrotia pristina*, Ett., as figured in Fl. v. Bilin., Plate XXXIX. fig. 23. 3 specimens.

82. *Cissus duplicato-serrata*, sp. nov. Leaves of various size, subcoriaceous, ovate, taper-pointed, rounded at base, palmately three, more generally five nerved; primary lateral nerves diverging from the midrib at acute angles, scarcely curving or not at all, entering the teeth which are prolonged into short lobes at a distance below the apexes, much branched outside: borders doubly irregularly dentate, the teeth pointed: all the nerves and their divisions distinctly craspedodrome.

The leaves are referable to *Cissus*, though they have a degree of affinity with some varieties of *Populus Nebrascensis*. They differ essentially by the primary lateral nerves not incurved, much branched, all the divisions, craspedodrome, the teeth acute, the substance of the leaves thick. 7 specimens.

83. *Cissus spectabilis*, Heer. Fl. Schakal., p. 45, Plate III. fig. 3 b. Leaves oblong-ovate, subcordate-emarginate at base, unequally dentate on the borders, very entire at and toward the base: lateral nerves branching.

The above description is that of Heer, which fully agrees with the characters of the leaf which I refer to the species. The leaf is merely smaller; the teeth though unequal are not distinct, but mere crenulations, the same as seen in the figure of Heer. 1 specimen.

84. *Vitis*, species undeterminable. 1 specimen.

Hamamelideæ.

85. *Parrotia fagifolia*, Ett. Leaf broadly oval, irregularly undulate on the borders; lateral nerves simple, alternate, distant, oblique, running straight to the borders as in a leaf of *Fagus*, which it resembles. The leaf has the characters of the species, as figured in Fl. v. Bilin., Plate XL. fig. 24, and is positively identified. 1 specimen.

Corneæ.

86. *Cornus Studeri*, Heer. 2 specimens.

Nysseæ.

87. *Nyssa Europæa*, Ung. A fragment of a leaf which by its form, the lower part of it especially, its nervation, and the thick curved petiole, is remarkably similar to the figure of that species in Ung. Sillog. Pl. Foss., III. p. 73, Plate XXIII. figs. 6, 7, 10. 1 specimen.

Magnoliaceæ.

88. *Magnolia tenuinervis*, Lx. 3 specimens.

Nelumboneæ.

89. *Nelumbium Lakesii*, Lx. 2 specimens.

Malvaceæ.

90. *Pterospermites grandidentatus*, sp. nov. Leaves large, sometimes very large, somewhat like leaves of Platanus, palmately sub-five-nerved; the outer lateral nerves being generally thin and shorter, much divided outside; lower secondary nerves opposite, at a distance from the base; borders sharply dentate, the teeth acute, turned upward, entered by the primary nerves and their branches, while toward the apex the secondaries curve in festoons along the borders, joined to the teeth by small anastomosing branches; nervilles strong, at right angles to the nerves.

This definition is about the same as that given by Saporta of *P. inæquifolius*, Sez. Fl., p. 402, Plate XII. figs. 3–5. One of the leaves of Golden is well preserved, and merely differs from those described by the French author in the lateral primary nerves somewhat incurved not quite straight. Two other specimens represent merely the base of two leaves with five primary nerves around the point of attachment of the petiole and two smaller ones declining downward to the cordate base, as in the leaves of *Ficus* (*Dombeyopsis*) *grandifolia*, Ung. 3 specimens.

91. *Pterospermites*, species. A mere fragment, the lower half of an oblong ? comparatively small leaf, membranous, rounded and slightly emarginate at the base, palmately nerved, with two pairs of more slender nerves under the base of the primary ones. The nervation is the same as in *P. spectabilis*, Heer, Arct. Fl., II. p. 480, Plate LIII. figs. 2, 3; but the species apparently differs by the nerves being more straight and the leaf apparently smaller. 1 specimen.

Tiliaceæ.

92. *Tilia antiqua* ? Newby. Probably the species, though the areolation and nervation of one of the leaves are much like that of *Greviopsis sidæfolia*, Sap., Fl. Foss. de Sezanne, p. 407, Plate II. fig. 10. There are only two leaves, upon the same specimen, and both are fragmentary, the borders being mostly

destroyed. The teeth appear rather short, turned outside as in *Greviopsis;* but the transverse nervilles, much more distinct, have the character of those of *Tilia*. 1 specimen.

93. *Grewia crenata*, Ung. Leaf nearly round, subcordate at base, obtusely and obscurely crenate; palmately five-nerved; nervation camptodrome.

The leaf is like that in Ett. Fl. v. Bilin., Plate XLII. fig. 7. The marginal or lower pair of primary nerves is only less marked, though distinct enough. The leaf is 4 cm. in diameter. 1 specimen.

94. *Grewiopsis tenuifolia*, Lx. 1 specimen.

Aceraceæ.

95. *Negundo decurrens*, sp. nov. Leaves compound, trifoliate. Terminal leaflet apparently large, trinerved from above the decurring base; lateral nerves thick, branching on the lower side, lateral leaflets at a distance from the base of the terminal one, undulate and sparingly dentate on the borders, trinervate above the decurring base; secondaries thin with few branches; nervilles indistinct, oblique to the medial nerve.

Species related to *Negundo triloba*, Newby., Later Ext. Fl. p. 51, Illust., Plate XXIII. fig. 5, differing by the prolongation of the base of the lateral leaflets along the petiole, not cordate. Their nervation is however the same, and the borders also are marked by few sharp teeth. It may be a marked variety. 1 specimen.

Sapindaceæ.

96. *Sapindus caudatus*, Lx. 1 specimen.

Celastreæ.

97. *Celastrus Gaudini*, sp. nov. Leaves membranous, rugulose on the surface, large, oval-oblong or broadly oval, crenate or obtusely serrate, abruptly narrowed at base; secondaries alternate, about 6 pairs, much curved upward in passing to the borders and effaced; tertiary nerves and nervilles obsolete.

The leaves 5½ to 6 cm. long, 4½ to 5 broad, are apparently obtuse, the upper part is broken in all the specimens. The species is closely allied to *C. Heerii*, Sism. Contrib., p. 449, Plate XXIX. fig. 5. 2 specimens.

Iliceæ.

98. *Ilex sphenophylla*, Ung. Chlor. Protog., p. 149, Plate L. fig. 9. Leaves very small, short-petioled, obovate, cuneate or rounded at base, coriaceous, spinose-dentate, penninerved.

The specimens are very good and the species positively identified. 2 specimens.

Rhamneæ.

99. *Paliurus Zizyphoides*, Lx. 2 specimens.

100. *Paliurus tenuifolius*, Heer. Leaf small, membranous, ovate, acute, entire to near the apex, where it is marked with a few acute small teeth ; lateral nerves parallel to the borders up to near the apex, where they join the secondaries by anastomosing branches ; secondaries opposite, at a great distance from the primaries.

The leaf has the characters of the species as described and figured by Heer, Fl. Tert. Helv., III., Plate CXXII. fig. 31, and by Saporta, Ett., I. p. 122, Plate XII. fig. 5. Heer, however, says of the leaves that they are very entire ; but the upper part of the leaf figured by him, *loc. cit.*, is destroyed, while Saporta describes the leaves as subundulate-denticulate. The one which I refer to this species, considering it a mere variety, is preserved nearly entire. 1 specimen.

101. *Paliurus Coloradensis*, sp. nov. Leaf small, obovate, obtuse, denticulate above, triple nerved from above the base, with a single pair of opposite secondary veins above the middle of the leaf, parallel to the basilar ones, acrodrome and branching outside.

The top of the leaf is somewhat obliterated ; its nervation is much like that of *P. ovoideus*, Heer, Fl. Tert. Helv., Plate CXXI. figs. 58, 59, Plate CXXII. fig. 3. Its size is intermediate between that of figs. 58 and 59. But it greatly differs by its obovate form and the position of the intermediate pair of secondary nerves, as thick as the primaries and parallel to them. 1 specimen.

102. *Zizyphus fibrillosus*, Lx., U. S. Geol. Surv. of the Terr., VII. p. 276, Plate LII. figs. 1–6. The specimens of this species are fine, and the petiole of one of the leaves is preserved 2 cm. long. The base of the leaves is either round, subtruncate, or subcordiform. The largest leaf is nearly 10 cm. long, and 7 cm. broad in the middle. 7 specimens.

103. *Zizyphus hyperboreus*, Heer. The leaf is like that described in U. S. Geol. Surv. of the Terr., VII. p. 276, Plate LI. fig. 15, doubtfully referred to Heer's species described from Greenland specimens. The texture of the leaf is coarse, the nerves very prominent ; the nervilles uniting the lateral nerves to the borders are at right angles, thick, and the medial nerve has two pairs of branches in the upper part. 3 specimens.

104. *Zizyphus*, sp. undeterminable. 1 specimen.

105. *Rhamnus Goldianus*, Lx. 13 specimens.

106. *Rhamnus Cleburni*, Lx. 7 specimens.

107. *Rhamnus crenatus*, sp. nov. Leaf large, ovate-lanceolate, acuminate, rounded or subcordate at the base (broken), minutely crenate ; lower lateral nerves more open, the upper gradually more oblique, all much curved in passing toward the borders, and inclining to the midrib ; the two highest pairs acrodrome ; nervilles numerous, close, parallel.

This fine leaf is 12 cm. long (base and apex broken), 6 cm. broad a little above the base. It has the same form, size and nervation as *R. grosse-serratus*, Heer, Fl. Bornst., p. 20, Plate IV. fig. 10, differing by the borders being minutely crenate and the nervilles less distant. 1 specimen.

108. *Rhamnus rectinervis*, Heer. 1 specimen.

Juglandeæ.

109. *Juglans rhamnoides*, Lx. 3 specimens.

110. *Juglans*, species undetermined. 1 specimen.

111. *Carya antiquorum*, Newby. 1 specimen.

112. *Pterocarya retusa*, sp. nov. Terminal leaflet large, ovate-lanceolate; the lateral small, linear-oblong, blunt at apex, rounded-subtruncate at base; lateral nerves close, parallel at a broad angle of divergence, branching near their ends; surface rugose.

The leaflets are thick, denticulate or crenulate on the recurved borders, the lateral nerves, at an angle of 50°, are not more than 5 mm. distant in the small leaves; deeply marked. It is closely allied to *P. Americana*, Lx., U. S. Geol. Surv. of the Terr., p. 290, Plate LVIII. fig. 3, differing by the open proximate nerves. By its rugose surface and its nervation also, the species is related to *Juglans corrugata*, Ludw. Palæont., VIII., Plate LXX. figs. 11, 12, differing especially by the leaves being blunt or obtuse, not acuminate as in the European species. 6 specimens.

Pomaceæ.

113. *Cratægus betulæfolia*, sp. nov. Leaves subcoriaceous, variable in size, oblong lanceolate, or enlarged toward the base, pyramidal-lanceolate above, deeply acutely or obtusely dentate, trinervate from the base, pinnately nerved from the middle; primary and secondary nerves craspedodrome entering the teeth; lateral primaries with few branches.

The leaves vary in size from 3½ to 7 cm. long, and from 2½ to nearly 4 cm. broad below the middle. All the nerves are deeply marked, the teeth somewhat long, rather obtuse, either turned outside or upward. 21 specimens.

114. *Cratægus myricoides*, sp. nov. Leaves membranous, small, ovate-lanceolate, more or less deeply dentate, penninervate; lateral nerves simple or forking, oblique and straight to the borders, or curving inside before entering the teeth; teeth alternately larger, or large and bi-tridendate on the back.

The two leaves representing the species are only 2 to 3 cm. long, 1½ cm. broad, fragmentary. They resemble leaves of *Betula*; but the irregular nervation is that of *Myrica*, the two lower pairs of nerves being longer and entering the teeth, the upper shorter, curved, and effaced near the borders, all at unequal distance, not parallel. They have some likeness to the leaves of *Cratægus oxyacanthoides*, Goepp., Schoss. Fl., Plate XXXVI. fig. 1. 2 specimens.

115. *Cratægus Engelhardti*, sp. nov. Leaves of medium and small size, subtrilobate or simply ovate, enlarged above the base, rounded and abruptly deflexed to the petiole; trinerved at base or pinnately nerved, the lower lateral

nerves being opposite, from above the decurring base ; borders lobate, denticulate, the lobes short, denticulate around.

Species resembling much *C. tomentosa*, Linn., in the form of the leaves, the divisions of the borders, the decurring base, and the nervation, differing by the leaves being generally less deeply lobed, and the teeth shorter. The leaves vary from 7½ to 11 cm. long, 4 to 7½ cm. broad below the middle, the widest part. One of the leaves has the petiole or part of it preserved, 4 cm. long. 4 specimens.

116. *Cratægus antiqua*, Heer. As far as can be seen, the leaves are referable to this species, agreeing with it by the form, size, and nervation. The borders, however, are mostly destroyed, and the teeth, apparently obtuse, rather than acute as in Heer's species, Fl. Arct., I. p. 125, Plate L. figs. 1, 2. 5 specimens.

117. *Amalanchier typica*, Lx., var. A simple leaf a little smaller than the one figured in U. S. Geol. Surv. of the Terr., VIII., Plate XL. fig. 11, from the Green River Group, and with the teeth smaller and pointed. I refer it to the same species, but it may differ. The nervation is somewhat obscure. 1 specimen.

SUMMARY.

The collection of fossil plants from which the above data have been derived was made at Golden, Colorado, by Mr. A. Lakes, and contains 873 specimens. The number of fragments of vegetable examined for determination is 1,044. They represent 118 species, or vegetable forms considered as species, 28 of which are admitted as new species and described above, and 32 as new for the Flora of the Laramie Group, but known from other localities, making therefore for that Flora an addition of 60 species. Of those already known from localities outside of the Laramie Group, 11 are American (3 from Carbon, 3 from the Green River Group, 5 from Evanston), and 21 are European. All are of Tertiary age, mostly observed in the Lower Miocene; two of them are identified with Sezanne species or Eocene.

Of the species described above from Golden, as of those formerly known from the Laramie Group, either by the publications of Dr. Newberry or of my own, none is identified with any of those of the Middle Cretaceous (Cenomanian) or of the Dakota Group. In two only, a marked affinity has been recognized and mentioned ; *Populus elliptica*, Newby., Later Extinct Flora, Illust., Plate III. figs. 1, 2, which the author says has a striking resemblance in general form to that of *P. cuneata*, is closely related to *P. arctica*, Heer, of the Arctic Miocene ; and *Platanus primæva*, Lesqx., U. S. Geol. Surv. of the Terr., VI. p. 69, Plate VII. fig. 2, is not less closely allied to *Platanus Guillelmæ*, or

P. *aceroides*, Goepp., two species also abundantly distributed in the Tertiary, especially the Miocene of both continents. As from the Upper Cretaceous or Senonian measures no species of fossil plants have as yet been recognized as identical with or even related to any of those of the Laramie Group, the assertion that the flora of this last formation is Tertiary in its character remains positive and as yet unrefuted.

Indeed, as it can be seen in looking over the table of distribution, not only some of the more predominant species of the Flora of the Laramie Group are Miocene in characters; but some of them are identified with species of the present epoch, or at least closely allied to them. *Woodwardia latiloba*, for example, represented in the collection by 53 specimens, is a near relation of *Woodwardia Virginica*, Smith, not rare in the woody swamps of the Northern United States. *Betula fallax*, with 32 specimens, has the same degree of relation to *Betula nigra*, Linn., the Red Birch. *Populus Nebrascensis*, typically and closely allied to *P. arctica* and *P. Richardsoni*, two very common species of the Arctic Miocene, is represented with its varieties by more than 300 specimens. *Platanus Guillelmæ*, abundant in most of the localities where Miocene plants have been found, is represented by 70, and the allied species, *Platanus aceroides*, *P. Haydenii*, *P. Raynoldsii*, by 45. The authority of Professor Newberry is still more conclusive on the subject; for in describing the plants of the Fort Union Group in his Notes on the Later Extinct Flora of North America, he not only finds most of them related to Miocene species, but he identifies four of them with common plants of the present epoch: *Onoclea sensibilis*, *Corylus rostrata*, *Corylus Americana*, and *Amelanchier similis*, this last considered as a form of the very variable and common *Amelanchier Canadensis*, Tor. & Gr.

Formerly, or before the examination of the new specimens sent from Golden was made, I did not consider the Flora of the Union Group as of the same age as that of the Laramie, known as it was to me by the plant remains obtained at Golden, Black Buttes, and Point of Rocks. There were between the plants of these localities and those of Fort Union and the Yellowstone River, some points of affinity, marked in the profusion of Palm remains, especially *Sabal*, of which the most common species, *S. Campbellii*, Newby., first described from large specimens of the Yellowstone, was found equally abundant at Golden and the Raton Mountains. There were also a few identical species found at Golden and Fort Union: *Platanus Haydenii*, *P. Raynoldsii*, two species of *Juglans*, two of *Cissus*, and a *Carpolithes*. But the facies between the groups appeared different, that of the Union Group being strikingly conspicuous by the presence of some of the most common species of the Miocene, even of some species still living at the present epoch, as seen above, which had not been observed at any of the localities of the Eastern States where the specimens I had for my first examination had been found. These species, *Populus arctica*, *P. Nebrascensis*, *P. crenata*, *Platanus Guillelmæ*, *P. aceroides*, *Aralia notata* or *Platanus nobilis*, *Tilia antiqua*, *Negundo decurrens*, closely allied if not a mere variety of *Negundo triloba*, *Carya antiquorum*, *Amelanchier typica*, all Miocene species, now found in the collection made at Golden, show an intimate relation between the flora of Golden and that of Fort Union, which by new discoveries will probably become more apparent between the different localities of the Laramie Group, and complete the evidence of the unity of the characters of the flora.

The group of plants described here afford a remarkable evidence of the distribution of vegetable remains under peculiar circumstances. The specimens were obtained from a locality which has been visited many times by members of the U. S. Geological Surveys of the Territories, often by Mr. Lakes himself, and twice by myself. Nevertheless, not a single specimen of *Populus Nebrascensis*, nor of *Platanus Guillelmæ*, had been found there before: yet in a locality at the same horizon and at a very short distance, a few rods only, as far as I know, from the excavations formerly made, specimens of these two species and their varieties have been obtained in such abundance that they constitute nearly one half of the collection. This proves that the mode of distribution of the vegetable remains results in some cases from the deposition of the fragments at the place where the trees have grown, not from transportation by water. Though the specimens of Golden are very fragmentary, they are generally flat upon the surface of shale apparently composed of muddy deposits, seemingly progressing in their formation while the leaves were falling from trees grown either around woody swamps or on the borders of shallow lakes.

Recent explorations have brought on the discovery of a large number of localities rich in remains of fossil plants, over the whole extent of the Great Lignitic. The flora of the Laramie Group, which now counts only 250 species, will therefore probably soon become better known, and by the greatly increased number of its species will take an important place in the history of the ancient vegetation of the earth.

No. 4. — *The Faults in the Triassic Formation near Meriden, Connecticut: A week's work in the Harvard Summer School of Geology.* By WILLIAM MORRIS DAVIS.

IN previous articles on the Triassic formation of the Connecticut valley, I have expressed the opinion that faults occurred between the adjacent trap ridges. The opinion was based on the repetition of similar sequences of strata, the evidence of which will now be stated in greater fulness, so that it may be easily followed in the field by those who wish to examine this interesting region. During much of the work, which was undertaken for the United States Geological Survey, I have had the assistance of Mr. C. L. Whittle, who is now engaged in preparing an account of the results of his microscopic observations on the contact phenomena of trap and sandstone. After many visits to the region, a plan of exploration of the Meriden–New Britain district was laid out in 1887 for the students of the Harvard Summer School of Geology whom I accompanied as teacher, and as it has borne very well the practical test of two seasons of field study, it is adopted for presentation here. The localities were not discovered by any means in the order here described; indeed the district was traversed many times before the systematic repetition of its oblique block structure was clearly perceived; but when this is once made out, it may be best explained by presenting descriptions of its features as daily excursions in a selected order, in which they may be most readily appreciated by a new-comer.

Excursion 1. — Cross-Section of Lamentation Mountain.

Meriden serves as a convenient centre for excursions. Its position in central Connecticut and in the southern portion of the Triassic area of New England is indicated by the black square in Fig. 1. About a mile north of the city, (1) on Fig. 2,[1] the Meriden, Waterbury, and Connecticut River Railroad (Waterbury and Cromwell Railroad on the sketch maps) crosses over the Consolidated Road (New York, New Haven, and Hartford Railroad), and here one may begin the construction of a section

[1] The sketch maps that illustrate this paper are copied from town maps, published in county atlases. The roads are approximately correct, but the ledges have been located without instrumental measurement. In some cases, the structural lines as now drawn may have to be changed when accurate maps are prepared.

crossing the strike to the east, and thus mounting the monoclinal sequence of beds which descend eastward with much uniformity. Coarse sandstones and conglomerates outcrop in small ridges with abrupt slopes to the west, and control the local topography east of the railroad, where very little drift has been deposited. The attitude of the beds is tolerably constant; the strike averages N. 30° E., and dip, 12° or 15° to the east. Low ledges are plentiful over much of the distance, until the Meriden–Berlin road is reached, half a mile east of the railroad; then a short ascent up a wooded slope leads to the higher ridge of amygdaloidal trap (2), lying anterior to, *i. e.*, in front of the face of Lamentation Mountain. This ridge should be followed north about one third of a mile, to the fine exposure of its bed of ashes and volcanic bombs (3),[1] now locally well known through the efforts of the Meriden Scientific Association, at whose expense the base of the cliff has been opened by blasting, to secure fresh specimens of its remarkable rock. A fine shaly sandstone may be seen at a few points at the bottom of the cliff, underlying the ash bed. One of the bombs seems to have embedded itself in the sandy mud by the force of its fall, like the examples described by Scrope in the recent volcanic region of central France.

Climbing the cliff and crossing through the woods, an old quarry (4) is found at the edge of a pasture that slopes to the east with the dip of the beds. The sandstone is seen here, with strike N. 25° E., and dip 13° to the east. Two dark layers, consisting chiefly of small rounded and irregular fragments of trap, were found here by Mr. Whittle, and a few feet lower, the top of the lava sheet is seen in a little ledge in the woods. The lava is vesicular, and the sandstone immediately overlying it contains many of its fragments. A blast lately fired has disclosed this fairly well. Going eastward down the pasture, occasional outcrops of shaly sandstone (5) are found with normal strike and dip, forming little ridges in the valley between the anterior trap ridge and the main ridge of Lamentation Mountain. They also appear occasionally in benches (6), on the steep western slope of the latter. Percival speaks (Geology of Connecticut, p. 365) of a bed of impure limestone somewhere in this valley, but I have not been able to discover it; in former years the thin beds of Triassic limestone were burnt at a number of points, but with the improvement in transportation and the bringing of better lime from elsewhere, this has been given up, and the old limestone quarries are often covered over and lost to sight. After making

[1] This interesting locality was discovered on an excursion during the spring recess from college work, on April 9, 1887.

out the structure of the anterior valley, the observer should return to the anterior or amygdaloidal ridge and follow it northward about a third of a mile from the ash cliff; here a trap-conglomerate (7) replaces the ash and lava bed, and gives additional evidence of the contemporaneous extrusive origin of the volcanic rock. Thin beds of sandstone occur in the conglomerate, with strike and dip conforming to the general monocline. Half a mile farther north, the lava again appears and, in its northernmost outcrop (8), forms a bluff twenty to thirty feet high in a spindle-shaped space between two roads. From this point, one may renew the cross-section work by going eastward and climbing over the thick bed of lava that forms Lamentation Mountain (9); but the result is accomplished more easily by following the road, which lies chiefly on a drift plain, and passing over the low north end of the mountain on a level (10), until Spruce Brook is reached coming from the eastern slope of Lamentation and running north. Crossing a field a hundred yards to the south, the stream is found emerging from a little rocky channel (11), cut in the uppermost part of the Lamentation trap sheet, and running down over the sloping beds of sandstone that rest upon it. The strata dip and strike in accord with the general monocline. Close to the trap they contain numerous vesicular fragments derived from it; in some of these, the vesicles may be seen to contain little deposits of sandstone. It is an ideal "locality." A pool in the vesicular portion of the trap, shaded by overhanging trees, tempts one to a bath after a dusty walk. A little farther east, a ledge of brown shaly sandstone (12) crosses the road, with normal strike and dip; its outcrop persists for some distance north and south at frequent intervals. Half a mile yet more to the east, and at the further base of an immense drumlin, known as Stow Hill, another small trap ridge (13) is discovered; this may be called the posterior ridge, following Percival's nomenclature. The points thus far described furnish about as much work as one may care to do on foot in a summer day.

Returning along the eastern side of Lamentation, the posterior ridge may be followed southward with little interruption to its end, just beyond the Cromwell railroad. Where the railroad crosses it, a small but valuable contact of the lava is exposed with the overlying sandstone, which here contains an abundance of trap fragments for three or four feet over the back of the trap sheet, clearly indicating the extrusive origin of the sheet. The vesicles in some of these fragments are more or less completely filled with sand, and under the glass the bedding of these little deposits is seen to conform closely with the stratification of the surrounding sandstone, whose strike and dip still conform to the monocline of the region. Further extension of the cross-section to the east is not necessary for the present, and the return to Meriden may be made by the road that passes around the southern end of Lamentation Mountain, there known as Chauncy Peak.

A general section across the strike of the monocline is placed in its proper position on Fig. 2. A vertical section, constructed on the margin of Fig. 2 from the material gathered on this excursion, contains about fifteen hundred feet of sandstones and conglomerates at the base, then two hundred feet of amygdaloidal trap in the anterior ridge, followed by six hundred feet of thin bedded sandstones and shales in the anterior valley, four hundred feet of heavy trap in Lamentation Mountain, and fifteen hundred feet of sandy shales before coming to the posterior ridge, which may be one hundred and twenty feet thick. The total thickness of the aqueous and igneous beds traversed is some five thousand feet. It is at present still uncertain from all that I can learn how many feet of deposits are below the base of this section before reaching the crystalline foundation on which the Triassic formation rests; and the thickness of the beds that originally overlay the posterior trap is equally indefinite.

Excursion 2.—Cross-Section of Shuttle Meadow.

In order to measure the thickness of the underlying beds or to determine their sequence, a second excursion may be made to some point farther west,—as by rail from Meriden to New Britain, and then on foot or wheels to Shuttle Meadow reservoir, three miles to the southwest. From the valley south of the reservoir, the ground rising to the east leads over several outcrops of brown and red sandy shales (1, Fig. 3), with strike N. 30° E., and dip 10° eastward, before reaching the bold western face of the High Rock trap ridge (2). If one should climb over this rugged ridge and descend across the meadow at its eastern foot, a small trap ridge would be found (11), trending parallel to the main ridge, but much concealed by drift. No shale or sandstone is seen accompanying it, and so small an observation is hardly worth the time it will cost. Returning now westward to the valley south of the reservoir and ascending its western slope, the enclosing ridge is found to consist of amygdaloidal trap (3), with a bold cliff, trending N. 10° E., and facing westward over the Southington valley-plain. A mile to the south, a bed of impure limestone is exposed in a quarry on the back of the trap.

Below the cliff, a few outcrops of sandstone or conglomerate may be found. These data for a cross-section are less complete than those collected on the previous day, but they suffice for a rough diagram added in the margin of Fig. 3.

On the supposition that the whole valley consists of an unbroken monocline, the two sections now constructed can be placed in their proper relative positions by means of a map, which would result in showing that the second belongs about four and a half miles westward across the strike from the first, and therefore its beds stand about five thousand feet below those of Lamentation. But, if not already noticed, attention will soon be called to the similarity between the two sections; and the question then arises, how can this be best explained. It may be the result of similar processes repeated in a given order, whereby similar sequences of beds were deposited at different times; or it may be the result of one or more strike-faults, by which portions of a single sequence of beds are brought to the surface in different places. It remains to decide between these two alternatives.

A general consideration of the problem will make it evident that the explanation by repetition of similar processes becomes less likely, and that the explanation by faulting becomes more likely, with the increase in the number of beds in the repeated series; with the lack of genetic relation among the members of the repeated series; and with the increase in the number of times that such repetitions occur. It should also be noted that the two explanations are not mutually inconsistent; both might apply in a single field.

The drift covers so much of the surface that detailed sections cannot be constructed. The stratified beds are, on the whole, so much alike, that the precise identification of equivalent beds by agreement in composition is impossible. While it may yet be found that fossils will serve as a guide to the recurrence of repeated outcrops, this means of identification cannot at the present time be applied in the region we are examining. All that can be done is to make the best of imperfect evidence.

We may first examine the argument based on the number of members in the repeated series. The completed sequence of visible beds is: conglomerate and sandstone; trap of moderate thickness; thin limestone; shaly sandstone; heavy sheet of trap; more shaly sandstone; a thinner sheet of trap; and, finally, more sandstone. It may be conceivable that this sequence of beds was independently made at two different times; but it is not at all likely that so considerable an agreement should be the result of the accidental repetition of a sequence of deposits.

The second argument is based on the arbitrariness of succession or lack of relation between the different members of the series. Here the interpolation of contemporaneous lava flows at certain points in the series is significant; for as far as is known they bear no necessary relation in the time of extrusion to the deposit of conglomerate, sandstone, shale, or limestone. Professor Emerson has, it is true, regarded some of the limestones that occur associated with the trap sheets in Massachusetts as the product of thermal springs that were excited by the eruption of the trap. I cannot say anything as to the cause of the limestone deposit in Connecticut, but whether connected causally with the eruption or not, the association of limestone and trap is by no means invariable; the limestone occurs only, as far as known, on the back of the first trap sheet, and this in itself is enough to make one lean toward the explanation by faults. If all the beds were sedimentary, and their succession were of the normal kind described by Professor Newberry in his essay on "Circles of Deposition," the repetitions might perhaps be explained without faulting; but it has been seen that such is by no means the case. Before proceeding to the third argument, it may be noted that the explanation thus far given does not depend altogether on the contemporaneous extrusive origin of the trap; it is important to note this, for while extrusion has been well proved for the first or Lamentation section by observations on the previous day's excursion, it is not yet directly proved for the High Rock section, although as will appear in the sequel there can be little doubt that all the sheets of the district are extrusive. But if intrusive, it is difficult to conceive that intrusive sheets should have taken their places among the bedded rocks as systematically as these Meriden sheets have, unless they had been driven in between the beds before they were tilted, and then faulted afterwards. Therefore, whether the trap is intrusive or extrusive, the evidence thus far collected favors the hypothesis of faults, and of the eruption of the trap before faulting.

The third argument by which decision is to be made between repetition by faults and by recurrent processes, depends on the number of times the repetition occurs. If the two sections now described are the only ones in the valley thus repeated, they might possibly be regarded as the results of recurrent processes; but if similar sections occur frequently or habitually, with no more change in the corresponding members than should be expected in different parts of beds of lava, sandstone, conglomerate, and shale, then there can be no question that the repetition is due to faulting. It may be noted also that if faults are found in some number and in systematic relation and accord, they may be accepted as proved on less complete evidence than would be reasonably required to establish the existence of a single isolated fracture. In like manner, if the hypothesis of the occurrence of faults enables one to correlate a great number of otherwise apparently disconnected and arbitrary facts, it is therefore to be regarded favorably. Finally, if it lead to the detection of facts not before noticed, and thus gives the power of prophecy, it can be considered as fully established.

One who goes on the ground as far as this narrative has now led him, will, I think, find it already difficult not to lean too strongly towards closing the question in favor of one of the suggested explanations instead of maintaining an open mind in the question. As a working hypothesis, let the faults be admitted, and a simple terminology adopted in accordance with the explanation that they offer. Let the mass between two faults be called a block; or, if small, a chip. Let the thick sheet of trap be called the main sheet, and the others, the anterior and posterior respectively, in accordance with their position relative to the main sheet. Certain deductive considerations also need attention before going farther in the field; in our school excursions, these were briefly discussed on the ridge south of the reservoir, overlooking the Southington plain, during the noon rest of the second day.

First, if faults are suspected, what must be learned about them before they are completely known? The elements of a fault are: its outcrop line, its direction, position, and length; the hade of the fault plane; the throw of the fault; and the width and other characteristics of the fissure. Its depth, its date, and its cause are also subjects for more advanced inquiry. With all these elements in mind as subjects for search, one is more alert to discover them.

Second, if faults do occur, how can they be best recognized? Some easily identified bed is the first requirement, such as the main sheet of trap, which forms prominent ridges in the broad valley between slopes of crystalline rocks east and west, and can be easily seen from a distance. But, besides this, it is important to have also a number of thin hard beds whose lines of outcrops are more sharply defined than those of the broad main sheet, in order to determine the position of the fault with accuracy. The anterior and posterior trap sheets serve this purpose nicely.

Third, if the faults occur, what will be their effect on the topography of a well-denuded monoclinal mass, containing hard and soft beds? For the sake of simplicity, the case of a single hard bed reduced nearly to baselevel may be taken alone, and the dip of the monoclinal regarded as constant; the fault plane will for the time be considered vertical.

Variations from these simple conditions can be easily introduced afterwards. Several cases may be distinguished, depending on the relative directions of the fault and the strike of the beds.

A. If the fault (*f*, Fig. 4) run parallel to the strike of the monocline, and its outcrop lie behind a ridge, *a*, made by the hard bed, and the heave, *h*, is on the side of the dip, *d*, then the hard bed will be indefinitely repeated in a second ridge, *b*, parallel to the first. The distance between the two ridge lines may be called the offset, *t*; then $t = h$ cotan. *d*. The fault may lie anywhere between the two ridges. Such a fault economizes a formation in allowing a given thickness to cover a great width of country.

B. If the heave is on the side of the ascent of the monocline, some of the beds will fail to appear at the surface. This is, in contrast to the preceding, a wasteful arrangement.

C. If the fault, with heave of the same value and on the same side of the fracture as in A, run oblique to the strike with an angle *e* between the two lines, Fig. 5, the offset remains as before, but the two ridges are not indefinitely repeated; the north end of *b* overlaps the south end of *a*, and the overlap *p* equals *t* cotan. *e*, or *h* cotan. *d* cotan. *e*.

D. If the fault run square with the ridge, Fig. 6, there will be an offset as before, but no overlap.

E. If the heave be on the other side of the fault, *e* being less than 90°, Fig. 7, there will still be an offset as before but in the opposite direction, and instead of an overlap there will be a space in which there is no ridge.

All these are special cases, easily generalized. If the values of dip, heave, and angle between strike of beds and fault-line are represented as in C, the formula there given will apply to all cases; a negative heave meaning a change in the side of the uplift, and a negative offset meaning a loss of visible outcrop, as in case B.

To the student, at least, there is here seen good reason for the etymological connection of geometry and geology. In the geometrical conceptions, the angles are to be seen all sharp and precise; in the geological occurrence they are rounded off and obscured.

Thus prepared by a deductive review of principles that have been learned elsewhere and that may find application here, further exploration can be most profitably undertaken.

A little north of the point where the anterior ridge of High Rock was crossed in the morning, it falls off and ends in low ground at the southern point of the reservoir (4); but a little way to the west another and very similar trap ridge (5) begins, with offset of a little more than a quarter of a mile, and overlap of almost as much allowance, being made for the missing acute southern point of the western ridge, which is here rounded off. This suggests a fault of the pattern given in case C. Knowing the dip of the anterior trap sheet to be about 10°, the strike of the fault must be east-northeast; and its heave, 300 feet or more on the southeast. The surrounding topography is very suggestive of such a dislocation; a view of the oblique gap formed in the ridge as seen when looking southwest from a hill (6) on the west side of the reservoir is given in Fig. 8.

If the fault extend and maintain its displacement a mile or more to the northeast, it must intersect and dislocate the main trap sheet in the same manner as it has broken the anterior. Looking along the calculated trend of the fault from the north end of the anterior, we see the gap (7) by which we have come from New Britain, between the north end of High Rock and the high trap ridge (8) next northwest of it, to which no special name is attached. The outlet of the reservoir valley runs through this gap. Assuming that the fault is straight, we have now a better means of determining its direction by sighting the long line from one gap to the other; the bearing thus found is N. 60° E., which agrees satisfactorily with that determined by the offset and overlap of the anterior ridge. In further confirmation of the fault, an afternoon return trip may be made from the thrown portion of the anterior trap ridge, after following it northward half a mile (9), across the strike of the beds toward the thrown portion of the main sheet (8); and in so doing, the few shale outcrops that appear are in such close accord with those seen in the morning in corresponding position in the High Rock block that they may be regarded as equivalent beds. Standing on the high ground (10), west of the reservoir, and looking back across the fault valley, the correspondence between the two monoclinal blocks is very apparent, in topography as well as in structure. Rapid advance may now be made on the foundation thus laid.

Excursion 3. — The Great Fault West of Lamentation Mountain.

A third day may be spent looking for the fault that is supposed to separate Lamentation Mountain from High Rock. It must lie somewhere in the country between them. The search may best begin at the point where the cross-section was taken up on the first morning; but now exploration should be turned westward, descending in the monoclinal series. A little preparatory consideration of the areal topography of several blocks, Fig. 9, bounded by faults similar to the one in the reservoir valley, will be of service. Each block, consisting of a monoclinal sequence of harder and softer beds, such as has already been described as the result of the first day's walk, will possess its anterior, main, and posterior trap ridges, with several intermediate and associated ridges and valleys of sandstone and shale, in definite order. The ridges formed on the successive beds will end without apparent cause on the oblique fault lines that bound the blocks. If a block be narrow, a quarter to a half a mile wide, for example, the posterior trap ridge will have its south end to the north of the north end of the anterior ridge. At first sight, these two members of the block-sequence would not seem to belong together. Continuity in the monocline can therefore be found only by crossing the country within the limits of a single block, and advancing parallel to its enclosing faults. A cross-section made at right angles to the strike of the beds would soon traverse a fault line, and would only confuse the observer. This principle is all-important in deciphering the topography and structure of the region. Reference to Fig. 2 will show that the section there made was traced out obliquely for this reason, although no mention of it was made at the time.

The fact that there has been a long period (probably Jurassic and Cretaceous) of deep-reaching erosion after the faulting took place, facilitates our exploration by reducing the constructional form nearly to a baselevel plain, still perceptible in the hard crystalline plateau east and west of the Triassic area; but the task would be still easier if this great erosion had not been followed by a period of uplift and consequent denudation (post-cretaceous), in which the softer beds have wasted down well towards a lower baselevel surface where they are now generally drift covered, leaving only the crest lines of the thickest and hardest trap sheets to bear witness to the existence of the previous baselevel of the region. When a ridge formed by the main sheet is cut by a fault, the crest of the ridge gradually descends as it approaches the fault, and the two lines intersect on low ground. The crest line curves gently at the northern side of a block, and sharply at the southern, as in Fig. 9; hence the strong bluffs at the south end of the ridges in the neighborhood of Meriden. On first recognizing the existence of faults here, the observer may be disposed to postulate a horizontal motion along the fault line, in order to account for the offset of the corresponding ridges; but there is no necessity of this; a vertical uplift followed by a base levelling will serve as well, as has been indicated in the diagrams above.

Now returning to our excursion in search of the fault west of Lamentation and going west from the crossing of the Cromwell railroad over the Consolidated Road, Fig. 2, we pass two conglomerate ridges, and then find a strong bluff of trap (14), deeply quarried at its southern end. It is the easternmost and lowest of the bluffs that constitute the Hanging Hills. If it be a portion of the main sheet, then the fault may be in the little hollow occupied by the quarry branch track (15) of the Consolidated Road, and the trend of the fault would in this case be in the line from the south end of the quarry ridge to the north end of Lamentation Mountain, or N. 55° E., and all the conglomerate ridges and the anterior trap ridge of the first day's section must end as they run north to this line. I have seldom found a more pleasing confirmation of a theory in a predicted result than was afforded in tracing out this fault. Every little ridge, trending about N. 30° E., runs with well maintained continuity until it reaches the invisible fracture, and then, without apparent reason, it promptly ends (16). The farther east the ridge, the farther north it extends. The anterior trap ridge obediently follows the same rule (8), and so does the little outcrop of shale (5), in the valley between the anterior and the main sheets. Lamentation Mountain itself falls away for no apparent reason; its trap sheet seems to be as thick here as anywhere, but it cannot cross the invisible line of dislocation. Spruce brook, flowing north from locality (11) of the first day's walk, runs on shales for a quarter of a mile after crossing under the road, and then cuts down to the back of the trap for a little distance (17); the shales soon reappear, but with abnormal dip to the northwest, and finally end in a violently dislocated and crushed ledge (18). This is undoubtedly close to the fault line. A short quarter of a mile farther on, the course of the fault leads to a curious anticlinal, mentioned by Percival, which like the last finds explanation by the drag of the fault. Departures from the general eastward dip of the monocline are rare, and it is interesting to see that they are associated with one another and with other phenomena as the common results of a single controlling cause. Some isolated knolls of trap near by may possibly be blocks caught in the fault, but this is questionable.

The fault line from the quarry bluff northeastward is thus found to maintain a tolerably direct course as far as it has been traced, and it follows much the same course as the one discovered in Shuttle Meadow. We may therefore expect it to be prolonged to the southwest also. In walking in this direction from (15), Fig. 2, there is nothing decisive for a mile or so, unless a valley followed by the Cromwell railroad oblique to the strike of the sandstones be so considered; the valley broadens farther southward beyond Meriden, and is bounded on the western side by a strong ascent. On the face of this hill, not far north of the probably post-glacial trench that the Quinnipiac has cut through it from the west, there are numerous outcrops of reddish shaly sandstone with strike N. 70° E., and dip 15° northwestward into the hill, and thus accounting for its steep eastern slope; but the westward dip itself is very unusual in the Triassic area, and suggests some local disturbance. Standing on the hill and facing about N. 50° E., one may look in the direction of the quarry bluff by Meriden, and in the distance beyond it see the descending northern end of Lamentation, showing that the hillside is in line with the fault already traced. Just south of the Quinnipiac, there are plentiful outcrops; the beds are about level near the bridge, but farther east steepen to a dip of 25° northwestward, beyond which the outcrops suddenly end. This confirms the occurrence of the fault. As its heave is on the east and of a value of several thousand feet, it is natural enough to find the beds immediately west of it somewhat flexed upward from the attitude that prevails generally in the monocline. Their abnormal dip is satisfactorily explained by associating it with this fault, as in the stream bed northeast of Lamentation, already mentioned.[1] Still farther to the southwest, the hill is so broadly covered

[1] The upward drag on this great fault, by which the dip of the beds on its western side is here reversed from an eastward to a westward direction, is homologous with the drag that has flexed the posterior sheet (Percival's P 2, E 1) of Pond Mountain, the southernmost member of the main trap sheet, east of New Haven. This block is cut off by the heavy fault that limits the present area of the Triassic rocks on the southeast, and brings up the crystalline base of the formation against them; the drag has in one small locality even overturned some of the beds, so that the conglomerates that here belong beneath the posterior sheet seem to lie over it at a steep eastward angle. That they are really overturned and normally belong below the trap is shown, first, by the occurrence in the quarry near by to the north of much larger outcrops of similar conglomerate, dipping westward under the trap; second, by the dense texture of the trap that apparently underlies the overturned beds, this dense texture being elsewhere characteristic of the base of the trap sheet, and in strong contrast with the loose vesicular texture of the upper surface of the sheet; third, by the absence of all trap fragments in the overturned conglomerate, while they are plentiful in the shaly conglomerate with westward dip that overlies the trap in an exposure by a pond an eighth of a mile northeast; fourth, by the general abrupt eastern face and gentler western slope of the trap ridge, which shows that its prevalent dip must be westward, and that the eastern dip of the conglomerate is local and exceptional. Search has been made for cross-bedding in the conglomerate, by which its upper and lower surface could be so nicely detected; but it could not be found.

with drift that no further sign of the fault has been found there; there are, however, indications that it is extended a number of miles beyond, even to the intrusive sheet of West Rock and Gaylord's Mountain. Be this as it may, there can remain no more doubt as to the existence of a fracture between the Lamentation and the Hanging Hill blocks. This fracture we shall call the "Great Fault."

Excursion 4.—Faults south of Lamentation Mountain.

It was noted above that the occurrence of a number of faults systematically arranged might be taken as further evidence in favor of the fault theory as against the theory of repeated deposits. A fourth day may therefore be spent in searching for them. The first guide in the search will be, as has already been suggested, the gaps in the line of the main trap ridges. One of these gaps appears at the southern end of Lamentation, dividing it from Chauncy Peak. If a fault run between them, it must dislocate the anterior ridge also. Walk, therefore, to a point (1) Fig. 9, on the anterior ridge of Lamentation, a little south of the ash-bed that was visited on the first excursion. To the north, we know the ridge is continuous as far as the Great Fault. To the south, a short walk brings us to a little notch by which a small stream escapes from the anterior valley, and beyond which the ridge is continued in the same line as before; the notch must therefore be regarded as a simple transverse water-cut. But on following the ridge a little farther, it ends (2) on the northern side of an open meadow, and crossing here to the south nothing but conglomerate (3) is found, and with such strike as would if prolonged northward carry it directly to the trap. The fault between Lamentation and Chauncy may therefore probably pass by the southern end of the anterior thus determined. A bearing taken from the southernmost point of the anterior trap to the gap (8) at the south end of Lamentation reads N. 60° E., and this is within a few degrees the same as the bearing of the faults already described. As a further test of the occurrence of a fault here, the northern end of the anterior to the Chauncy Peak block should be found somewhat to the north of the southern point of the anterior to Lamentation. It is found (4), precisely as predicted, lying at appropriate distance in front of Chauncy Peak, containing an ash-bed with bombs of lava (5) like those already described in the anterior of the Lamentation block; and it ends directly under the southern bluff of the main sheet (6) in the northern block. A few shale outcrops are found on its back, and others appear on the bold western slope of Chauncy Peak. The fault has an offset of about 1500 feet and an overlap of similar value; its heave must be about 300 feet. Although of smaller displacement than the Great Fault, it manifestly belongs to the same system and contributes effectively to the rational explanation of the Triassic structure and topography. It probably determines the location of a ravine (7) southwest of the Berlin road towards Meriden, but I have not been able to follow it beyond the city, as outcrops are few and monotonous in that direction. On the other side of Lamentation Mountain, if there were time to go there, it probably causes a slight dislocation (9) in the posterior trap ridge; the displacement is so small that in speaking of this part of the posterior ridge when describing the last stretch of the first day's walk, the ridge was referred to as traceable with little interruption. If this identification is correct, it is probable that the throw of the fault decreases to the northeast, and that its line is somewhat curved, as indicated in the figure.

The wide valley between Chauncy Peak and the north end of Higby, or Middletown Mountain, through which the return to Meriden was made on the first day, suggests a fault with throw of value intermediate between that of the Great Fault and the one just described. Its examination may be conveniently begun by following the anterior of Chauncy Peak southward to its vague ending (10) near the Cromwell railroad. This termination must be near the southeast side of Chauncy Peak block. A wide swamp, in which the engineers of the Cromwell railroad found much difficulty in making a steady roadbed, conceals all outcrops for some distance, but by following the track for half a mile east from the end of the anterior, and then, at a point opposite the southern end of Chauncy Peak (11), crossing a little field to the south, several ridges of conglomerate (12) will be found in the woods; they strike N. 35° E. and their beds dip about 10°, and after crossing four or five such outcrops, a low trap ridge (13) is found; it is soon identified as yet another appearance of the anterior sheet, for it stands in proper position with regard to the main sheet, which rises in the high mountain to the east; it is very scoriaceous on the back, where it is followed by a road; and at a few places it shows the ash and bomb structure that has already in two other blocks been found to characterize the anterior trap. It must be followed north to its end (14), which is indistinctly located shortly before reaching the Meriden–Westfield road. Sighting back from here, we find a bearing of about S. 65° W. will carry the fault line back to the southern point of the Chauncy Peak anterior; the accordance with previous measures is satisfactory enough. But, in determining the course of a fault, care must be taken to select as guides at least three points, which lie alternately on opposite sides of the fracture. It is evident that an error may result from trusting too implicitly to the apparent termination of a ridge, for the real termination may be covered; but if three ridges, of which the first and third are on one side of the fault and the second is on the other, all terminate on the same straight line, the presumption is very strong that they indicate a straight fault and that the indication may be trusted. The case in hand therefore needs additional ridge-endings before the fault line can be established. The south end of Chauncy Peak (11) and of its posterior (15) and the high north end of Higby Mountain (16) serve abundantly for this purpose. The southern end (15) of the ridge posterior to Lamentation and Chauncy is found a little south of the railroad cut to the east of Highland station, mentioned on the first day's walk as affording a good exposure of the sandstone overlying the lava. The ridge ends in a little knoll back of a farm house and barn, north of the Meriden–Westfield road. In sighting backward from this knoll, the course of the fault is seen to be curved, and if the middle of the meadow between this point and the north end of Higby be taken as the location of the fault, its curvature is greater still; but this is hardly more than might be expected: a straight line fault is too rigid to be natural. On continuing the walk to the northeast, a reverse curvature of the fault line is required, in order to leave the long descending ridge (17) of Higby Mountain on its eastern side. The northernmost low end of Higby is found at High Falls (18), where the trap suddenly ends. The little gorge opened by Falls Brook discloses much breccia in fractures running northeasterly, and evidently associated with the strong fault close by. No other outcrops appear for some distance, but a cut on the Cromwell railroad, just west of Westfield station and about a mile and a half northeast of High Falls, reveals strong disturbance in the dip of the shales there exposed, as well as two faults of indeterminate throw. It is likely that these dislocations are associated with the fault that we have been tracing. It is interesting to notice that the course of the fault thus traced curves somewhat in the neighborhood of the north end of Higby Mountain, and that the curvature is closely conformable to that found between the Lamentation and Chauncy Peak blocks.

On returning to Meriden, a superb view of the valley may be gained by an easy walk up a path leading to the terminal bluff of Chauncy Peak from the road below it. The strong range known as Beseck Mountain, formed on the main sheet, may be traced many miles southward from Higby with little interruption. The broad back of the same sheet faulted down in the district of the Hanging Hills, all heavily wooded, rises on the farther side of the wide valley to the west. Descent from the cliff may be made by a little crevice, in which a narrow band of breccia is seen; its trend is northeasterly. A southward view of Lamentation with Chauncy at its farther end, and of the north end of Higby, from a point several miles to the north, is given in Fig. 10. Some distance up Falls Brook from High Falls, the sandstone lying on the back of Higby (19), Fig. 9, contains numerous fragments of vesicular trap; stones showing such inclusions are common in the stream bed.

Attention should here be called to the apparent double ridge at the north end of Higby Mountain; as if the main sheet were slightly dislocated by a strike fault, or as if it consisted of two lava beds, separated by a weaker stratum of some kind. The main sheet, which forms the bold west bluff of the mountain, ends south of Highland station (16); but a second ridge, a little lower than the first, comes into sight from behind the mountain, and extends a mile or more farther to the northeast (17, 18). This great extension of the second ridge, although so close to the first, suggests a change in the course of the fault, as already indicated. Another example of the double form of the ridge will be found on the excursion for the morrow.

Excursion 5.—Faults in the Hanging Hills.

The Hanging Hills, one of the most picturesque districts in the state, may be visited on the fifth day, beginning at the Quarry Ridge, along the margin of which ran the Great Fault discovered on the third day. Approaching the ridge by the lane east of the Fair Grounds, Fig. 11, it is significant that the ledge of conglomerate there followed strikes directly toward the trap bluff and ends on reaching the fault valley. When the quarry (1) is reached, attention will soon be taken by the variety in the structure of the trap, here so well exposed by quarrying. The greatest part is indeed rather uniformly dense and of medium texture, but in the upper platform along the west side of the opening and on the lower bench at the southwest end, much vesicular trap is found, and its relation to the dense trap brings up an interesting problem. Close examination will discover that the dense and vesicular masses are separated by a rather sharply marked surface of gently undulating form, inclined to the eastward at an angle of about twenty degrees, and hence about parallel to the prevailing dip of the monocline. Below this surface of separation, the vesicular trap may be seen to extend downward for a thickness of ten feet or more, becoming gradually denser below. The upper mass, on the contrary, maintains its dense texture to the top of the quarry, a height of sixty feet above the vesicular mass below it. The only way in which these facts can be explained seems to be to regard the two masses as separate lava flows; the lower one showing its upper vesicular surface, which, at the few points where it happens to be stripped bare, resembles the form of ropy lava, such as is called "pahoe-hoe" in the Sandwich Islands; the upper mass revealing only the dense under part of a later flow, from which the original vesicular upper surface has here been worn away. This is entirely in accord with what has been learned elsewhere in the Triassic formation; for if the lavas of this portion of the district are extrusive, it is the most natural thing in the world that the sheets should be composed of successive lava floods. The time between the outpouring of the two sheets here must have been short, for they are not separated by any deposit of sandstone or shale, nor does the upper surface of the lower flow manifest signs of wearing away, as it might if it had been long exposed to the weather above water level. It may be here mentioned that a sheet of trap exposed in the railroad cut between Springfield and Westfield in Massachusetts bears evidence of at least three successive flows, the thinnest being only a few feet thick.

Another feature of the trap quarry is found in the bands of fragmental material that traverse it from one end to the other, trending N. 57° to 68° E. One of the clearest of these runs along the margin of the upper platform and extends across the high face of the quarry. It is from two to four feet thick, stands nearly vertical, with a slight hade to the west, and consists of angular fragments of trap of all sizes contained in a matrix of what looks like sandstone, although it bears no distinct marks of stratification. The trap walls of the band are of the same medium texture as the rest of the upper flow, and are sharply defined; the trap fragments are of similar texture, without change from their margin into the centre. They vary in size from minute grains to great blocks, three or four feet across. Slickensided surfaces abound, generally parallel to the walls and sometimes extending into blocks of trap, which are slightly dislocated thereon. In short, these bands are fault breccias, the trap fragments coming from the adjoining rock, while the sandstone has been washed down the fracture from the beds that once overlay the trap, but which at this point are now worn off. As their bearing is the same as that of the faults already found from topographic evidence, it is manifest that they furnish us with dissections of small fractures similar to the greater ones that control the structure of the region. The quarry could not have been placed more advantageously for geological results.

The faults of the region have been found to have their heave on the east; if the dislocations revealed by the breccias belong to the same family as those that dominate the topography, we should expect them to present the same relative movements. The only opportunity to test this is found in the western part of the quarry, where the surface of contact between the upper and lower sheets affords a recognizable layer for identification on the two sides of the fracture. The displacement thus determined is of small measure, about eight or ten feet, but it is of the same order as the larger ones already determined, having its uplift on the eastern side.

Four fault breccias may be found in the quarry; their average bearing is N. 63° E., their hade averages 71° with much constancy. Near the eastern foot of the quarry a broad breccia is seen much weathered; it has probably been but little stripped of the cover that it had before the quarry was opened. The little hollow, along which the branch track is laid from the Consolidated Road, undoubtedly marks the site of the Great Fault, and if opened would be of much geological interest. Walking across the hollow to the sandstones with barytes veins on the eastern side, we have stepped down almost two thousand feet, for the Great Fault which sets Lamentation Mountain over a mile back from this portion of the main sheet can hardly have a less throw than that amount. A transverse section of the quarry would, if fully worked out, probably appear as in Fig. 12, and the occurrence of step faults as there indicated goes far to explain the reason for the easy opening of other fault lines into gaps such as characterize the region.

It may be noted that fault breccias have been found in several other localities, and that they accord in strike and dip with the system here described. Percival called them "clay dikes," and examples will be mentioned below.

An instructive view is opened by climbing to the top of the quarry bluff by its western slope. A northeast valley (2), Fig. 11, separates the quarry ridge from other similar but higher ridges (3), and indicates a fault. Isolated ledges in the valley suggest chips of trap broken from the adjoining blocks. The quarry ridge therefore belongs to a very narrow block, and its anterior trap can only be found by keeping carefully within the limits of its enclosing faults. Walking southwestward, a small trap outcrop (4) is found in the roadway west of the Fair

Grounds, and although not visibly traversing even the small measure of the narrow block, it may be fairly identified as the anterior sheet, by reason of its position. Its failure to make a continuous ridge may be attributed to weakness resulting from the numerous small faults that were seen in the quarry. Farther along in the block, ledges of conglomerate and sandstone (5, 5′) are found in appropriate position ; but their strike is seen to turn somewhat west of north, departing thirty or forty degrees from the strike prevalent in the Lamentation fault block, and thus helping to account for the abnormal trend of the southern face of the Hanging Hills. The fault bounding the quarry block on the northwest may be found by walking from the conglomerate ledges (5) towards a wooded ridge (6), which is soon discovered to consist of trap, and which must be regarded as the anterior sheet of another block by reason of its attitude betwen the strong bluffs of Cat Hole Peaks on the north and the conglomerate ledges (8) on the south. It is overlain with fine red shales (7), whose strike is N. 45° W. and dip 20° N.E. ; no contact with the trap has been found here, though it might be discovered by a little digging. The several breaks in the front of the anterior ridge probably indicate small faults, and may in part be associated with corresponding notches in the main sheet. This may be called Cat Hole block, taking the name from the deep pass in the main sheet on its western side. The view of the block from the round hill of conglomerate and sandstone (8) is especially valuable ; no point in the district illustrates more clearly the necessity of working out the structure of every block by walking parallel to its length, instead of as usual at right angles to the strike of the beds. The several members of the quarry block can be located : the main sheet in the quarry ridge (1), the anterior (4) alongside the Fair Grounds ; the conglomerate and sandstone ledges (5, 5′) below. Cat Hole block is equally distinct ; the main sheet in the castellated knobs at the end of the long ridges (3 — 3) ; the wooded ridge of the anterior trap with the red shales behind it ; and the conglomerate ledges below it, where we stand. Farther west, Notch Mountain block can be as well interpreted ; the main sheet in its superb cliffs surmounting a long talus ; the anterior (9), wooded again, west of us ; and the lower sandstones in the rolling ground farther south.

Oblique valleys, undoubtedly located on fault lines, enclose Cat Hole block on either side. Taking the anterior sheet as a guide to the dislocation on these faults, and regarding its position in Cat Hole block (6 — 6) as normal, we find it thrown to the northeast in the Quarry

Ridge block, and to the southwest in Notch Mountain block; and from this it is apparent that the faults are of the usual pattern, with heave on the southeastern side. The movement on each one may be one hundred or more feet.

A pleasant spot for lunch is found at the Cold Spring, in the ravine near the Poorhouse. This spring is fed in part by melting snow or ice hidden under the great trap blocks that have fallen from the cliff of Notch Mountain, and long ago attracted notice.[1] A water-cure sanitarium was built near it on the bench of the anterior sheet; but proving unsuccessful, it was bought by the city of Meriden for a Poorhouse; it is not likely that any other similar institution possesses so delightful a view as is here spread out to the eastward, even as far as Higby Mountain. Before following the wood road to the reservoir, the openings in the western end of Cat Hole anterior should be examined, as they show a peculiar structure, perhaps indicative of ropy lava flow. Sandstone is seen lying close over the anterior just south of the Poor House in Notch Mountain block, and a small piece of vesicular trap was found enclosed therein.

Broad views may be had by climbing the face of Notch Mountain instead of following the road through the wood below. A noteworthy feature is the furrowing of the top of the mountain by several ravines, parallel to the general direction of the neighboring faults. These and the crevice mentioned in the terminal bluff of Chauncy Peak are the topographic expression of small fractures similar to those dissected in the quarry bluff. The view from the southwestern bluff of Notch Mountain opens the West Peak block to easy inspection. The fine cliff of its main sheet rises from the farther side of the reservoir, and its anterior sheet forms a broad bench (11) to the south. On descending to the reservoir an exposure of red shales (10) is seen in the roadside, a little above the vesicular back of the anterior trap; its beds strike N. 30° W, and dip 6° N.E.

The reservoir valley has a little more northerly course — about N. 15° E. — than that followed by the faults hitherto met. For some time it appeared to be an exception to the general rule; but closer examination has led me to conclude that the valley is not coincident with the fault. This is certainly a hazardous conclusion, and not to be lightly accepted. The following facts lead to it. Toward the northern end of the reservoir, a hill of heavy trap (14) stands below the western face of Notch Mountain, and more in accord with the attitude of the

[1] Silliman, Amer. Journ. Science, 1st series, iv. 1822, 174.

West Peak sheet. The trend of the western face of Notch Mountain is N. 50° E., and it may be traced in a more or less distinct bluff or ledge (12) for a mile in this direction. On following up the intercepting canal cut in the trap to bring the streams from the back of West Peak into the north end of the reservoir, a band of breccia about a foot wide may be found traversing it, trending N. 60° E.; and the back of West Peak is furrowed with ravines (13) trending N. 55° or 60° E., showing that faults of the normal direction occur here as well as to the east of the reservoir. The general topography leading to the above conclusion may be perceived from a knoll (15) a good half-mile northward. The long northwestern face of Notch Mountain is from here clearly seen to be independent of the detached portion (14) of the West Peak block. A low trap ridge (16), a little to the west of the knoll, is probably to be identified as the posterior sheet of the same block.

The abnormal position of the reservoir valley finds no sufficient explanation. It may be located on a branch of the chief fault; but in such case the chief fault ought to be the site of the chief valley, and not merely of a little ravine. Perhaps a more likely explanation will some day be found by regarding the reservoir valley as the abandoned course of an old river, whose direction was taken during the pre-cretaceous base-levelling of the region, and maintained for a time after the post-cretaceous elevation, until some other stream, which encountered no heavy trap sheet and therefore deepened its channel quickly, captured and led away the head waters of the reservoir river; the reservoir notch would thus fall into the class of wind gaps derived from water gaps, not uncommon in the Appalachians. But different observers may well have different opinions here.

While on the knoll (15), the double form of Notch Mountain will be observed. A second trap sheet (17) seems to lie on the back of the first. (It is rather too distinctly drawn in Fig. 11.) The same thing might have been noticed from the back of the anterior sheet of Cat Hole block, where the roads form a little triangle. A rough walk through the woods around the base of the upper sheet (17) to Cat Hole shows the back of the lower sheet to be highly vesicular; a rocky talus hides the contact between the two. I have interpreted this as the topographic expression of the two lava sheets disclosed in the quarry bluff: the vesicular upper part of the lower sheet acts as a soft bed between the denser parts of the two flows, and the mountain crest is therefore doubled. The same double form may be seen in the mountains of Medina sandstone in central Pennsylvania, and for a similar reason.

The other trap mountains about Meriden do not show the double form so distinctly; the second ridge on Higby has already been mentioned; on the back of West Peak the upper sheet may perhaps be identified in certain ridges near the base of the wooded slope; and if the observer is ambitious of hard scrambling over rough trap ledges and waste branches of felled trees, he may attempt to work out the faults and the double sheet of Cat Hole ridges (3) to northeast of the Peaks; but this is not to be recommended as an easy return from the short walk of this busy day.

The eastward turn of the main sheet bluff from West Peak to the Quarry bluff deserves a word. It seems to depend on three causes. The strike of the beds changes from the general trend of N. 20° E. to N. 20° or 30° W. or more, and this alone accounts for much of the turn; the displacement on the faults accomplishes something in the same direction; and finally the accelerated recession of the cliff faces where the faults are numerous accomplishes the rest. The moderate altitude maintained by the main sheet in the Cat Hole and Quarry ridge blocks, where the fractures are numerous, bears witness to the effectiveness of the last cause.

Excursion 6.—North of West Peak.

A final excursion may be made along the range north of West Peak. For reasons that will appear later, the walk may be best begun at Cook's Gap, where the New York and New England Railroad crosses the trap range about three miles west of New Britain; thence southward we shall pass the Shuttle Meadow fault of the second day's excursion, and afterwards approach the northern side of the West Peak block. Taking early train from Meriden to New Britain, connection may be made with a local train on the New England Road, which on proper presentation of the case may probably be induced to stop at the western side of Cook's Gap, at a road crossing (1), Fig. 13.

Cook's Gap is unlike most of the others of the region in crossing the trap range almost at right angles, and thus indicating its independence of the fault system. It may be an abandoned river course, like the Reservoir Notch. Farmington River comes out from the crystalline uplands on the west about opposite to this gap.

The road at which we left the train follows the anterior ridge southward: sometimes it approaches the bluff, from which an extended view of the Southington plain is obtained; it is broadly drift-covered. No interruption in the ridge is discovered for a mile and a half; then near the outlet of Southington reservoir (2) two small notches are found, indicating dislocations with heave of seventy and eighty feet; these are probably connected with the indentations in the main ridge to the northeast, which bear about N. 50° E. from the notches. Another mile without interruption brings us to the Shuttle Meadow fault, Fig. 3 being repeated in Fig. 13; the bluff of the northern member of the anterior should be followed around its edge into the fault valley in order to appreciate the regularity of its curve. Three small dislocations appear in the North High Rock block, next beyond; and near the third one, fragments of vesicular trap are found in the shaly beds in the road (3). Advancing a little farther, an oblique valley (4) between North and South High Rocks is disclosed; if it is located on a fault, and if the fault belong to the prevailing system, a dislocation in the anterior ridge should be found when we have gone far enough southward to give the oblique valley a bearing of about N. 60° E., and the dislocation should be of the Shuttle Meadow pattern. At the expected point, the anterior bluff curves around and ends in a ravine (5), across which another bluff of the same form begins at a little higher level, indicating an uplift of say a hundred feet. The oblique valley between the High Rocks cannot be distinguished until the ravine is followed up towards the road; then its bearing is found to be closely parallel to that of the faults near by. The impure limestone that is found at a number of points in the region on the back of the anterior is exposed in an old quarry close by on the roadside.

If the vague conception of the Triassic structure with which Shuttle Meadow was entered on the second day's walk be now recalled and compared with the definite conception that has slowly grown up as the topography has been deciphered and the structure interpreted from it, the student will find that the alternative hypothesis of repeated sequences of deposition has no longer any claim on his attention. The hypothesis of repetition by faulting has found continued confirmation since it was first tested at Shuttle Meadow. Every method devised for testing the occurrence of faults has been applied, and no doubt whatever can remain of their occurrence. The members of the repeated sequence are sufficient in number to make a good case, and succeed one another too arbitrarily to be regarded as products of a single process; repetition is frequent, and when once perceived it becomes a prominent characteristic of the region; the faults by which the repetition is produced are strikingly systematic in direction, and all agree in having their uplift on the southeast; the complicated topography of the region is reduced to simplicity; and a limited power of prophecy is gained, as in the case of the notch in the anterior ridge, just described. The key to the structure of the region is discovered. When the walk southward along the back of the anterior ridge is resumed, and the terminal bluff of South High Rock is seen in its characteristic form, with Short Mountain rising beyond it, he must be indeed a sceptic who is not ready to predict that yet another notch in the anterior with normal offset and overlap will be found corresponding to this break in the main sheet. The notch (6) is soon reached, but on looking eastward as usual for the heaved continuation of the anterior, it is not to be found. The ground is low and open to the foot of the main sheet of Short Mountain, and it is only to the westward that there is any ridge (7) that may correspond to the anterior. Just as our generalization was to be established we meet a departure from it. The case is certainly of great educational value as well as of geologic interest; and one must approach it with an excellent geometric understanding of the several patterns of faults described on the second excursion, if he would not be puzzled by its departure from the topography of the faults thus far encountered.

Turning westward instead of eastward, a ridge (7) is found that corresponds in every way with the anterior, and a brief consideration of its position will show that it is an example of the case of Fig. 7, in which the heave is on the northwest of the fault and the downthrow on the southeast, the reverse of our usual style of dislocation. The offset is to the west, or negative, instead of to the east; and there is a lapse of bluff front instead of an overlap. After perceiving this there is no further difficulty. The main sheet of Short Mountain is seen to stand farther west than the same sheet in the next block to the north, thus confirming the conclusion derived from the anterior; and when looked at from the east, the backs of the two portions of the main sheet readily disclose their relative altitudes: the southern is depressed compared to the northern. The bearing of this reversed fault, determined by sighting from the notch in the anterior through the pass in the main sheet, is N. 65° E. It may be noted that if this course be turned a little to the left, as if the fault curved to the north, it would lead in about three miles to a peculiar fault breccia in the sandstones; one of Percival's "clay dikes," disclosed in a post-glacial stream channel, a mile south of New Britain, at the eastern base of a great drumlin. The peculiarity of this fault is that the deformation of the bedding on either side, shown in Fig. 14, indicates an uplift on the northwest; it is probably therefore an extension or a branch of the fault just described north of Short Mountain.

The southern boundary of the Short Mountain block presents nothing unusual, for both the anterior (8) and the main sheets (9) of the next block — West Peak — are offset normally to the eastward about a third of a mile. The course of the fault determined by sighting from the south end of the anterior of Short Mountain block to the north end of the West Peak main sheet is about N. 60° E. An old "paint mine" (10) lies on this line; the heap of refuse about it consists of a breccia of vesicular and dense trap cemented by barytes and other minerals. The same line, carried several miles northeastward, runs to a normal dislocation in a trap ridge (probably a second posterior) a little distance southwest of Berlin Junction station; shortly before reaching this dislocation, a "clay dike" (Geol. Conn., 378) is seen in the banks of the Mattabesick; its position places it on the fault line; its direction, about N. 40° E., accords fairly with that of the fault; its structure shows it to be a breccia; and the deformation in the bedding on either side, Fig. 15, shows that its heave and throw agree with the rule of the region. Midway on the same line, where the road from Cat Hole to New Britain crosses a stream by an old burnt mill between two ponds, the posterior trap is exposed in the stream channel, and close west of the road there is a four-foot breccia of trap and sandstone, bearing N. 50° E., with a hade of 15° northwest of the vertical, and slight uplift on the east as indicated by apparent repetition of the scoriaceous upper portion of the trap. This is probably a small fault, associated with the one that bounds Short Mountain on the southeast.

There are no other significant faults till the Reservoir Notch is reached; and the day's walk may be ended either by following the road (11), Fig. 11, that runs around the curve of West Peak, or by a shorter cut (12) leading through Cat Hole to Meriden.

Review.

All the chief faults from Cook's Gap to Higby Mountain — ten in number — have now been worked out. They accord fairly well in direction, as appears in the general map, Fig. 16, corresponding to the black square of Fig. 1. Here the several sketch maps, Figs. 2, 3, 10, 11, and 13, are outlined in their proper relative positions, and indicated by numbers 1 to 5; the main sheet is shaded, and the anterior and posterior are located on either side of it; the faults are drawn as broken lines. Finally, a section drawn at right angles to the prevalent trend of the faults is given in Fig. 17; it is not constructed closely to scale, but indicates the general structure of the region. The abnormal Short Mountain fault, with downthrow on the southeast, which when first found seemed to endanger our generalization, is seen to be only a single exception to a well marked rule. No other explanation of the structure of the region than that by faulting seems admissible.

It has been difficult and in most cases as yet impossible to trace the faults far to either side of the three trap ridges; elsewhere, the surface is so heavily drift-covered, and the sandstone or shale ridges are so monotonous, that dislocations cannot be demonstrated. But it is in the highest degree probable that the faults are not limited to the belt of trap ridges; the uniformity of direction and of throw over the considerable district where we have traced them indicate their extension over a much larger area, where more patient search may yet detect them.

The Triassic monocline must therefore be regarded as composed, in the Meriden–New Britain district, of a number of long and relatively narrow blocks, whose direction is oblique to the strike of their beds, but is in a most striking way accordant with the trend of the fundamental schists, where they are exposed to the southwest and northeast. I find it impossible to resist the conviction that this accordance is not due to chance, but that it points to physical dependence of the superficial on the deeper structure, as has been suggested in my earlier papers.

Cambridge, Mass., March 27, 1889.

EXPLANATION OF PLATES.

PLATE I.

Fig. 1. Outline map of southern New England, showing the Triassic area of the lower Connecticut Valley (dotted), and the area described in this paper (black square).

Fig. 2. Sketch map for first and third day's excursions around Lamentation Mountain.

PLATE II.

Fig. 3. Sketch map for second day's excursion around Shuttle Meadow Reservoir.

Figs. 4 to 7. Diagrams illustrating the topographic displacement produced by faults running at divers angles with the strike of the faulted beds.

Fig. 8. View of fault gap in the anterior trap ridge, southwest of Shuttle Meadow Reservoir.

Fig. 9. Diagram illustrating the general scheme of interpretation of the faulted Triassic monocline about Meriden.

PLATE III.

Fig. 10 a. Sketch map for fourth day's excursion from Lamentation to Higby Mountain.

Fig. 10 b. Distant view of Lamentation and Higby Mountains from the north.

PLATE IV.

Fig. 11. Sketch map for the fifth day's excursion in the Hanging Hills.

PLATE V.

Fig. 12. Generalized section of the Quarry ridge, near Meriden.

Fig. 13. Sketch map for the sixth day's excursion, from Cook's Gap to Short Mountain.

Fig. 14. Section of fault with heave on the northwest.

Fig. 15. Section of fault with heave, as usual, on the southeast.

Fig. 16. General map of trap ridges in the Meriden–New Britain district; the several sketch maps already referred to being located by rectangles numbered from 1 to 5.

Fig. 17. Generalized cross-section of the Meriden–New Britain district.

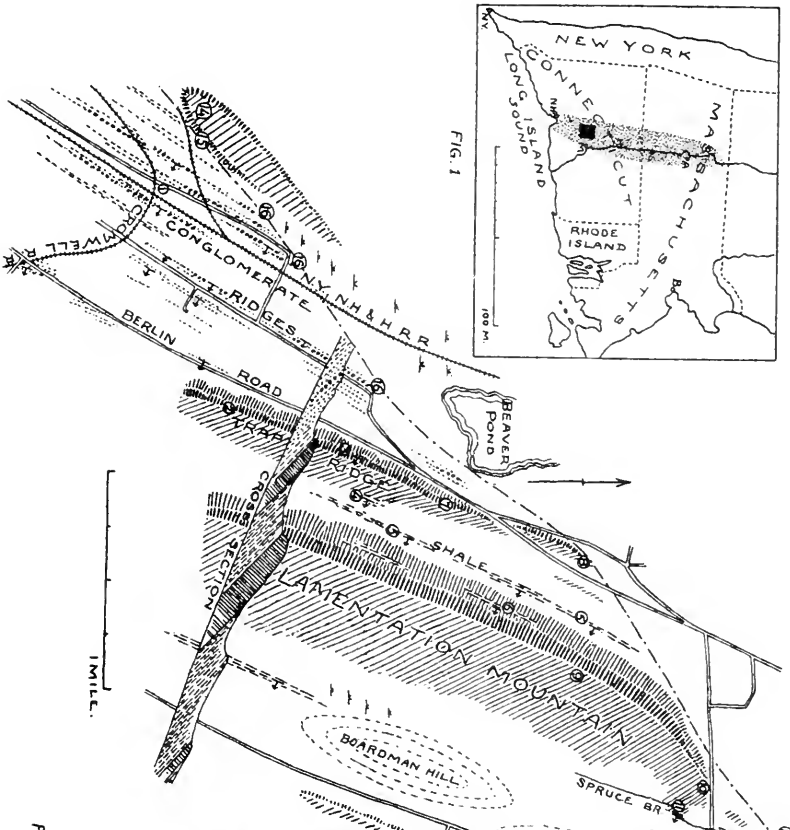

NEW YORK
CONNECTICUT
MASSACHUSETTS
RHODE ISLAND
LONG ISLAND SOUND
100 M.
CROMWELL R.R.
CONGLOMERATE RIDGES
N.Y.N.H.&H.R.R.
BERLIN ROAD
TRAP RIDGE
BEAVER POND
CROSS SECTION
SHALE
LAMENTATION MOUNTAIN
BOARDMAN HILL
SPRUCE BR.
SHALE
STOW HILL
TRAP
1 MILE
VERTICAL SECTION

FIG. 1

FIG. 2.

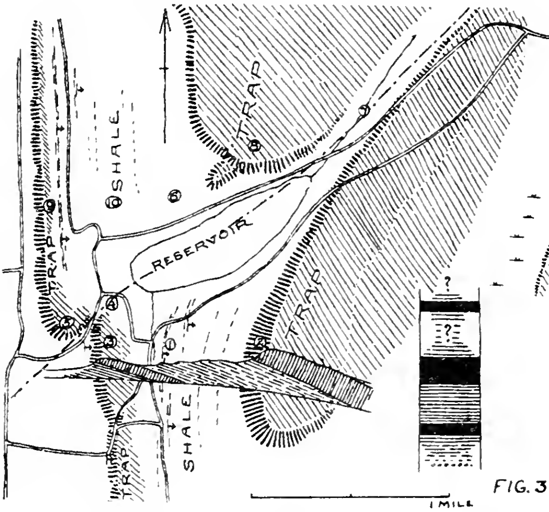


FIG. 3.

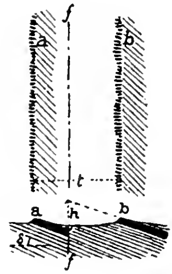


FIG. 4.

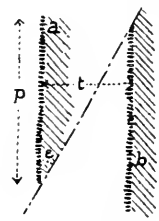


FIG. 5

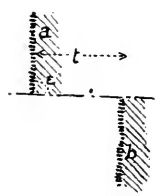


FIG. 6

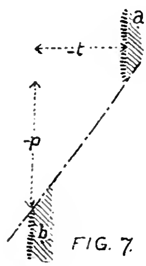


FIG. 7.

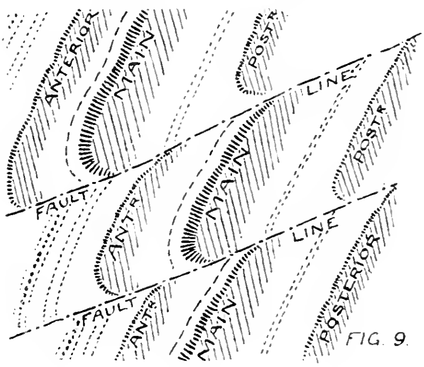


FIG. 9.

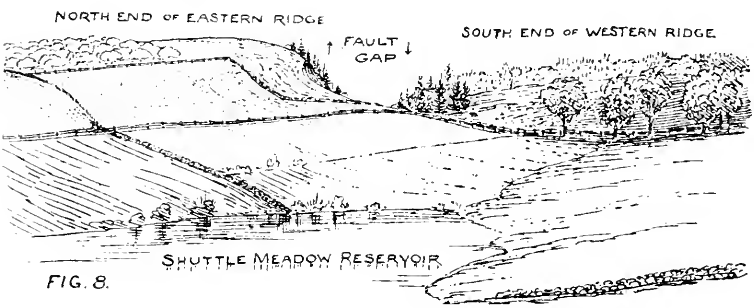


FIG. 8.

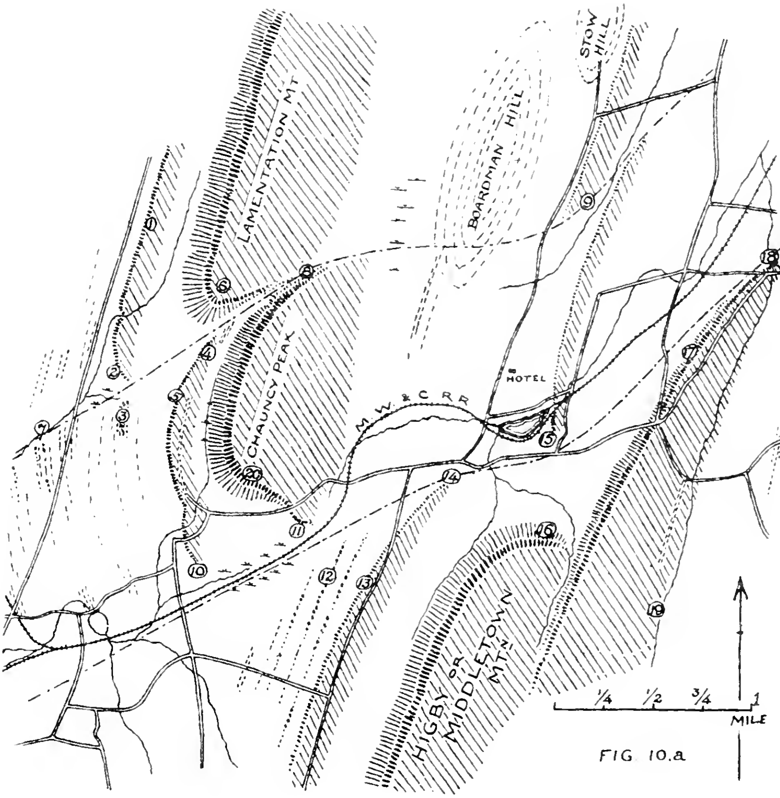


FIG. 10.a

FIG 10.b.

HIGBY AND LAMENTATION MOUNTAINS

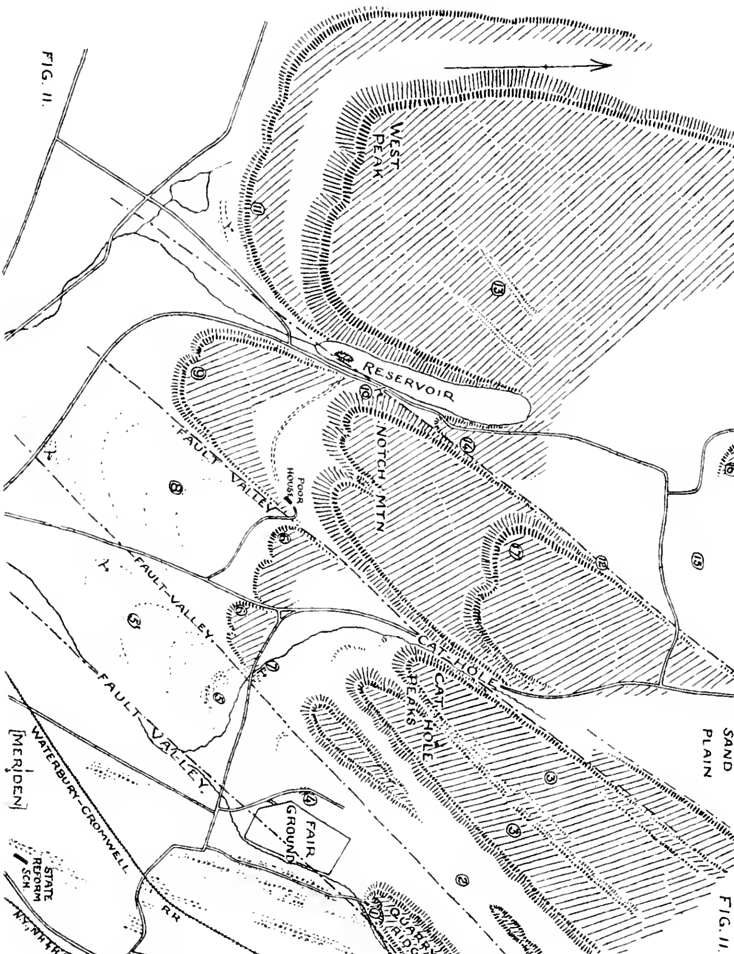
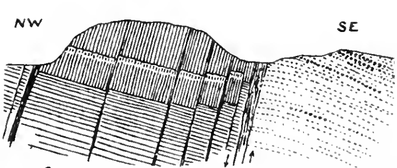

WEST PEAK
RESERVOIR
NOTCH MTN
POOR HOUSE
FAULT VALLEY
FAULT-VALLEY
FAULT-VALLEY.
CAT-HOLE
CAT-HOLE PEAKS
SAND PLAIN
FAIR GROUND
QUARRY RIDGE
WATERBURY-CROMWELL RR
STATE REFORM SCH.
N.Y.,N.H.&H.RR
MERIDEN

FIG. 11.



SECTION OF THE MERIDEN QUARRY FIG. 12.

FIG. 14

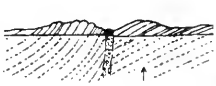


FIG. 15.

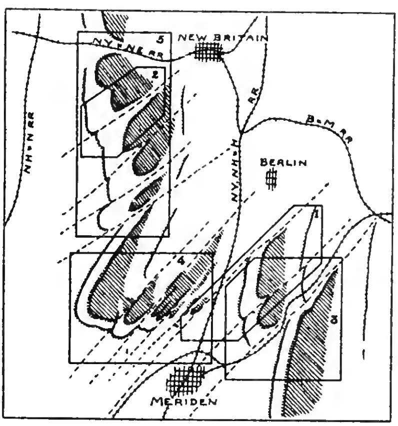
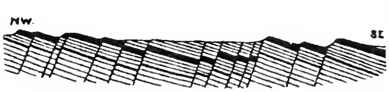


FIG. 16.



GENERAL CROSS SECTION. FIG. 17.

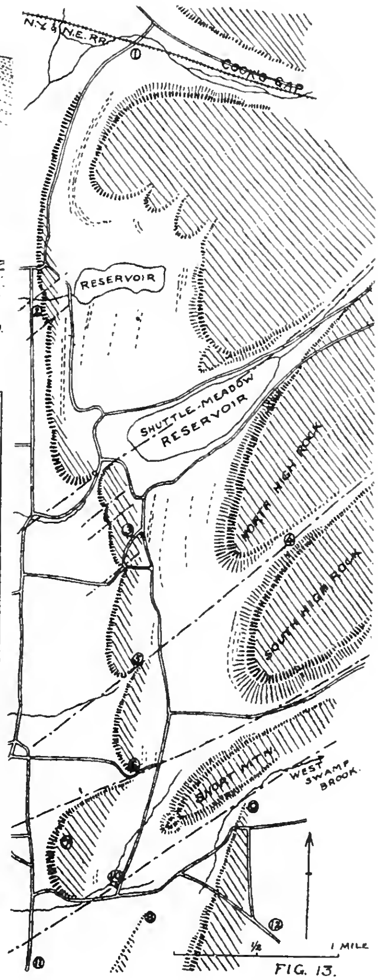


FIG. 13.

No. 5. — *On the Occurrence of Fossils of the Cretaceous Age on the Island of Martha's Vineyard, Mass.* By N. S. Shaler.

It has long been known that fossils apparently of Tertiary age occur in the peculiar rocks about Gay Head, on the western extremity of Martha's Vineyard. These strata of alternating clays, sands, and occasional lignites occupy the western half of Martha's Vineyard, in which region they rise above the sea level. They probably underlie the glacial deposits throughout much of the area of the island, and may have a yet wider extension. Even where the Tertiary beds lie above the sea level, they are generally covered by a thick coating of glacial débris. Where this débris has the character of true shoved moraine, the accumulations are often a hundred feet or more in depth. Where the detritus exists in the form of a sheet, it is less continuous, but nevertheless covers the greater part of the underlying rocks, which are only exhibited in a clear manner along the gulf-like shores.

In 1870, while engaged in some studies on the erosion of the coast lines of this island, I found several fragments of a coarse sandstone at various points in the drift material, which contained extremely obscure molluscan fossils. Among these were specimens of what appeared to me to be Exogyra, a genus which, as is well known, does not extend to the Tertiary period, and is practically limited to the lower portion of the Cretaceous. Although the evidence was extremely imperfect, it was enough to warrant a careful search of the island, with the hope of finding in place the beds whence the fragments were derived. I spent more than a month in this systematic inquiry before attaining to any results whatever. At length I discovered two localities where these sandstone fragments with imperfect molluscan remains were tolerably plenty. These positions are indicated in the descriptive sketch, Plate I. One of them lies on the western shore of what is called Lagoon Pond, immediately west of Cottage City. At this point a skilled collector may in the course of half a day discover half a dozen fragments scattered in the drift, which are clearly referable to Cretaceous rocks. A second and more important locality lies near the centre of the northern shore, at the distance of about three fourths of a mile from the coast line on the track of the last locality known as the "Woods Schoolhouse." The schoolhouse of the name has disappeared, for its foundations only remain; but the explorer can readily find his way to the spot by passing from the new schoolhouse on the Cedar Tree Neck road westwardly along the serpent kame, the only deposit of this nature on the island, until he passes a stone wall, a little to the west of which, in the roadway and on the bare ground thereabout, he may find an abundance of fragments of this peculiar sandstone. Circumstances prevented my undertaking any careful study of this place until seventeen years after its discovery. In 1887 I returned to the locality, and with the help of my assistant, Mr. Foerste, undertook a careful collection of the abundant fragments which I found at this point, as well as a systematic study of all the area of the island which gave promise of affording similar material. The search for other localities was fruitless, and as this is the only one on the island which has afforded fossils in condition for identification, I shall hereafter limit my account of the bed to what is exhibited at this point.

As is shown in the accompanying section, the Cretaceous fragments found at this locality occur only within a small area. They have been found over a surface having an east and west extension of about 300 feet, and a north and south length of about 200 feet. The position is immediately to the south of a shoved moraine, which extends up to and probably includes this part of the drift accumulations. In this area, from the surface to the depth of four or five feet, or as far as the excavation penetrated, by far the larger part of the fragments are composed of the deposit in question. The rock consists of a very coarse sandstone abounding in quartz pebbles, containing indeed little other material save quartz fragments from an inch in size downward. The largest of the fragments containing fossils are about three feet across and a foot thick; the greater part of them are extremely angular, showing by their form that they have been transported for a very short distance. Moreover the extreme softness of the material would make it impossible for it to endure any distant ice carriage. The sand in which the fragments containing fossils were embedded appears to be to a great extent derived from the destruction of the same rock. This fact is indicated not only in the physical aspect of the sands, but in the character of the vegetation which grows upon them. Generally, in this morainal district, the decomposition of the pebbles containing large amounts of feldspar and mica affords a moderately fertile soil, which maintains grass. In the area where these fragments abound, the sand is evidently far more siliceous than elsewhere in the area of the moraine, and is too lean to support plants. In part it is covered by a growth of lichens, and in part altogether bare of vegetation.

This assemblage of facts makes it seem clear that the locality whence this Cretaceous material is derived is not more than a few hundred feet to the north of the site where these fossils are found. Were it farther away, there could be no such concentration of the Cretaceous waste. The hypogene material would be more extensive than it is. I have therefore no hesitation in saying that we have in this immediate vicinity a deposit of Cretaceous age. It is probable that this deposit of small area is girdled about by strata of the same age as those about Gay Head. This is indicated by the fact, that, at various points in every compass direction from this locality, the drift contains large amounts of bright-colored clays such as give the name to Gay Head. These clays are not seen in their natural position, but are commingled with the glacial waste, the fact being that when the glacier overrode this area it ground up and commingled a good deal of bed-rock clays over which it moved with the morainal material brought from a distance. A careful study of all the exposures on Martha's Vineyard containing Tertiary clays has failed to show any distinct fragments of Cretaceous rock. This assemblage of facts has led me to the conjecture that some small remnant of the Cretaceous beds projecting through the enveloping clays of later age is the source whence these fragments containing fossils have been derived.

The foregoing conjecture is more probable, for the reason that it will explain in a satisfactory way the origin of much of the sedimentary matter contained in the beds of the Gay Head section. That section is remarkable for the very large amounts of siliceous matter contained in its sandy and pebbly beds. This material is substantially what would be obtained from the erosion of the Cretaceous strata such as are found at this point, and the reassortment of the materials.

The physical conditions of the fragments of Cretaceous rock appear to indicate that the beds were deposited near a shore line. The rock is of a very coarse texture, showing faint indications of cross bedding; the clay element is scanty, and the quantity of lime is very small. It is evident that the bed containing the fossils was accumulated with considerable rapidity, and that only in certain levels was the organic life developed in sufficient quantity to make the bed fossiliferous. All these conditions indicate that the deposit was formed near the coast line.

This opinion is borne out by the character of the fossils. The great prevalence of oysters, and the fact that the two valves are generally found separate from each other, in some cases appearing to have been worn by wave action before they were fixed in the strata, is almost conclusive proof that the deposits were made in shallow water. Although the Exogyras differ in a certain measure from our ordinary oysters, their distribution in this and other countries is always consistent with the hypothesis that, like their living kindred, they did not inhabit the deeper parts of the sea, but were dwellers in the shoal water.

The existing condition of the Cretaceous fragments affords us some light as to the condition of the rock before it was disrupted by glacial action. All the fragments containing fossils are extremely ferruginous, the lime of the shells having been replaced by limonite. This is the ordinary result of atmospheric action on superficial deposits of this nature. It appears to me quite evident that this replacement of the lime was effected while the material was in its original position, and this for the following reasons. The fragments of Cretaceous rock were in many instances found lying upon the surface of the soil, or only partly bedded within it. In these cases the limonation could not have occurred since the fragments came to their present position, for the reason that there would have been no source whence the iron could have been derived. There has evidently been no considerable degradation of the drift on this region since it was abandoned by the glacier. Owing to the position of the deposit it was not subjected to any water erosion. It is evident that the corrosive work since the disappearance of the glaciers has not taken away more than a few inches, if as much, from the surface. If the fragments had come to their present position without having experienced the processes of decay, the replacement of the lime could not have been effected. I therefore am forced to the conclusion, that this material had decayed in its original bed, before it was disrupted by the glacier, and that the iron was derived from superjacent beds in the original stratification. Although this conclusion is hypothical, it is of certain interest, for the reason that it combines with the other known facts to indicate that the glacial erosion which has taken place in this region has been of slight amount. If it had been great in quantity, if several hundred feet of the section had gone away, we should not only have had this detrital material of Cretaceous age distributed over a larger field, but the fragments would probably have come to this point in an unoxidized condition.

A very severe rain-storm which occurred in the month of September, 1888, disclosed a portion of the sections in the neighborhood of the point where Cretaceous fossils are found. Although the sections are obscurely exhibited, a tolerable notion can be formed as to the character of the materials along a line having a length of about 2,000 feet. The position of the beds is in general indicated in the accompanying diagram, which gives a somewhat generalized section from the north shore of the island, a little west of Cedar Tree Neck, across to the small brook on the Cedar Tree Neck road. On the north shore the beds occasionally exposed after severe storms consist of grayish green sands, with occasional iron concretions resembling those found in the "Wood Schoolhouse" locality. Some of the fragments closely resemble the material containing fossils at the last mentioned locality, and in one fragment an unrecognizable species of oyster was observed. At the highest point delineated in the section, the shoved frontal moraine is partly interrupted, so that the underlying rocks are exposed. Here we find a section having a length of about 300 feet, showing a deposit of grayish green sands alternating with red and white clayey sand, the dip of the beds being to the northwest, the angle varying from 45° to 60° of declivity. Proceeding south, we find 300 feet of section in which the beds are concealed from view; then a small exposure of red clayey sand with an obscure dip, not more than 60 feet in thickness of beds being exposed to view; then 140 feet of measures hidden by the covering of drift; following that, 70 feet of red and white clayey sand, very micaceous, dip obscure, but apparently in the same northwest direction. Again, southward, a covered section of about 100 feet in length, in which the drift is more or less churned up with grayish sands presumably derived from the underlying beds. This is the point where the fragments containing species of fossils described in this report were obtained. Farther on, 600 feet of the section is unexposed; then, for 180 feet, we have mainly greenish gray sands, having a total thickness of about 80 feet, with traces of yellow and white sands above and below them. At this point the dip is clearly shown. It is to the northwest, at an angle of from 35° to 50°. Following to the southward, 150 feet of the section is concealed; then for the distance of about 125 feet, to near the margin of a small brook, the reddish clays appear at the surface, but the dip is not clear. It appears to be in the same northwest direction. At several points in the greenish measures, some compact ferruginous layers resembling those containing fossils are found; but in none of these beds have I as yet been able to obtain organic remains. They serve, however, to indicate that the material containing fossils is really derived from this section.

Until fossils are actually found in a bedded condition in the deposit, it will not be possible to assert in a positive manner that this section is of Cretaceous age. It still seems possible that the fragments containing fossils may be in their nature exotic, as are the fossiliferous materials in the beds at Gay Head. It is to be noted, however, that the greenish gray sand in the section containing the fossils differs considerably in its general aspect from the beds at Gay Head. Moreover, there appears to be an absence of lignites in this portion of the Vineyard series.

The prevailing northwest dips of this section are in contrast to the attitude of the Gay Head series. I have carefully examined the bedding with reference to the theory that the dislocation is due to glacial thrust. I find it impossible to accept this view, for the following reasons. In the first place, the dips are everywhere tolerably uniform, except within a foot or so of the glaciated surface. In this uppermost part of the section the thrusting and dragging action of the ice is distinctly exhibited in the somewhat sharp flexure of the beds, as well as the considerable contortion which they present. It seems to me impossible to believe that a steadfast dip such as is shown by these beds could have been produced by the thrust of a glacial sheet. If the dislocation were due to the direct forward movement of the ice, we should have to explain these dips by the supposition either that the beds originally horizontal were thrown into an arched form, and that we have here the northwest side of the anticlinal, or that the beds were completely overturned in order to produce the existing dips. There is no trace of such an arch exhibited in the section. Indeed, the presence of such a fold is contra-indicated by the fact that the dips increase to the southward, and the hypothesis of a complete overturn finds no support whatever in the facts. Last of all, we observe that the surface of this district apparently retains its pre-glacial topography. A system of stream valleys is traceable over all the section where the Vineyard series of deposits rise above the sea level. The persistence of a pre-glacial topography, manifest even in the details of the surface, — a topography on which the drift materials are simply imposed, — is overwhelmingly against the supposition that the dislocations are in any measure due to the action of the ice-sheet.

In a memoir on the Geology of Martha's Vineyard, prepared for the Annual Report of the Director of the U. S. Geological Survey for 1885–86, I have endeavored to show that the deposits at Gay Head, probably of Miocene or early Pliocene age, were formed in a delta at a time when the level of the shore was perhaps not more than 200 feet below its present position. If the evidence from the fossils and the physical condition of these Cretaceous deposits is to be trusted, it indicates that in a much earlier time the shore on this part of the

North American coast was also not far from its present altitude. These fragments lie at the height of about 150 feet above tide-water; the most elevated point at which I have traced the Tertiary deposits of the Gay Head series is about the same height. Taken together, these two sections afford interesting evidence of the existence of the shore line close to the present coast in two remote stages of the earth's history.

The occurrence of Cretaceous deposits in this part of New England is particularly interesting, for the reason that it indicates the former extension of the deposits of this age to points much farther north than they have hitherto recognized on the eastern versant of the continent. Hitherto, no beds of Cretaceous age have been known on the Atlantic coast north or east of New Jersey. This new locality establishes the existence of such beds about 100 miles farther north, and about 200 farther east than those which occur in the New Jersey area.

The fact that the Martha's Vineyard Cretaceous material was apparently deposited near a shore line, appears to indicate that the Cretaceous section, at least that part which belongs in this particular horizon, never covered the general surface of New England. Therefore we cannot fairly attribute to erosion the absence of this portion of the Mesozoic deposits in the New England area and the region to the northward. It seems to me more likely that these beds were never deposited on that portion of the continental surface.

Palæontology of the Martha's Vineyard Cretaceous.

Although there can be hardly any question as to the general geological position of the beds whence these fossils were derived, their precise place in the section is not readily determinable with the material at hand. As will be seen from the appended figures of fossils, the remains are very imperfectly preserved, revealing the existence of four species which are characteristically Cretaceous in their aspect. The species, however, differs so far from that which has been found in more southern portions of the continent that no sufficient identification of the particular horizon is possible.

The most abundant fossil is the Exogyra, shown in Figs. 19 and 20 of Plate II. The specific differences between the several species of Exogyra are rarely if ever sharply defined. The Martha's Vineyard form appears to be sufficiently distinct from any others which have been described to warrant the application of a new specific name. So far, no distinct Exogyras have been found above the horizon of the Cretaceous period. Indeed, it seems likely that this genus does not range up to the very summit of that series, but passes out of existence shortly after the Middle Cretaceous section. Therefore the occurrence of this fossil of itself affords fair ground for concluding that the deposit does not belong to a higher level than the Middle Cretaceous. The species of Camptonectes has never been found above the middle of the Cretaceous series. Indeed, it appears to be characteristic of the lower portion of that section. It may be taken as evidence, that the beds in question do not extend below the horizon of the Cretaceous. The other fossils which are described and figured are less determinative in their value. They are, however, so far as it has been possible to identify them, not inconsistent with the hypothesis that these beds are of Cretaceous age, and that they probably belong in the lower portion of that period.

In the present state of our knowledge concerning the field from which these Cretaceous fossils are derived, it does not appear worth while to undertake any description of the species. Although the material is in fair condition for such work, it seems to me likely that further study of the field will develop much better specimens. I have therefore sought to do no more than refer these species to their genera, with suggestions as to the apparent affinities of certain forms. In preparing this list, I have been so fortunate as to be able to confirm my general determinations by the advice of Dr. C. A. White, Palæontologist of the U. S. Geological Survey. My thanks are due to him, and also to my assistant, Mr. Aug. F. Foerste, for a careful search of the island of Martha's Vineyard, in order to determine whether localities other than those I had found existed on the island. Although the result of this was purely negative, it has been of value to the investigation. I am also indebted to Mr. Foerste for the preparation of the drawings figured on Plate II. of this report.

The foregoing report is intended as a preliminary statement concerning the Cretaceous rocks of this interesting locality. I hope to explore the field by systematic excavations, and thus secure more complete and accurate information than has here been presented.

EXPLANATION OF PLATES.

PLATE I.

This plate gives a sketch map of the island of Martha's Vineyard, intended to afford in mere outline sufficient indications as to the position of the Cretaceous localities which have so far been determined. The principal locality where these fossils are found is shown by the line indicating the position of the section given at the bottom of the plate. From this point the fossils were obtained which are mentioned in the text and figured in Plate II. The locality on Lagoon Pond lies on the eastern face of that sheet of water from one third to one half a mile south of the entrance to the pond. The fossils from this locality are extremely imperfect, and are found in occasional fragments of Cretaceous rock involved in a thick section of drift. A third locality, where a single fragment of a fossil oyster was observed, is on the southern part of the island of Chappaquiddick, which lies to the east of Edgartown.

At various points to the eastward of a line drawn from Great Tisbury Pond to Lumbard's Cove the drift is frequently stained with ferruginous sandstone waste, which is probably derived from Cretaceous deposits. It is possible that a portion of the stratified rock deposits lying to the westward of the above mentioned line may also be of Cretaceous age.

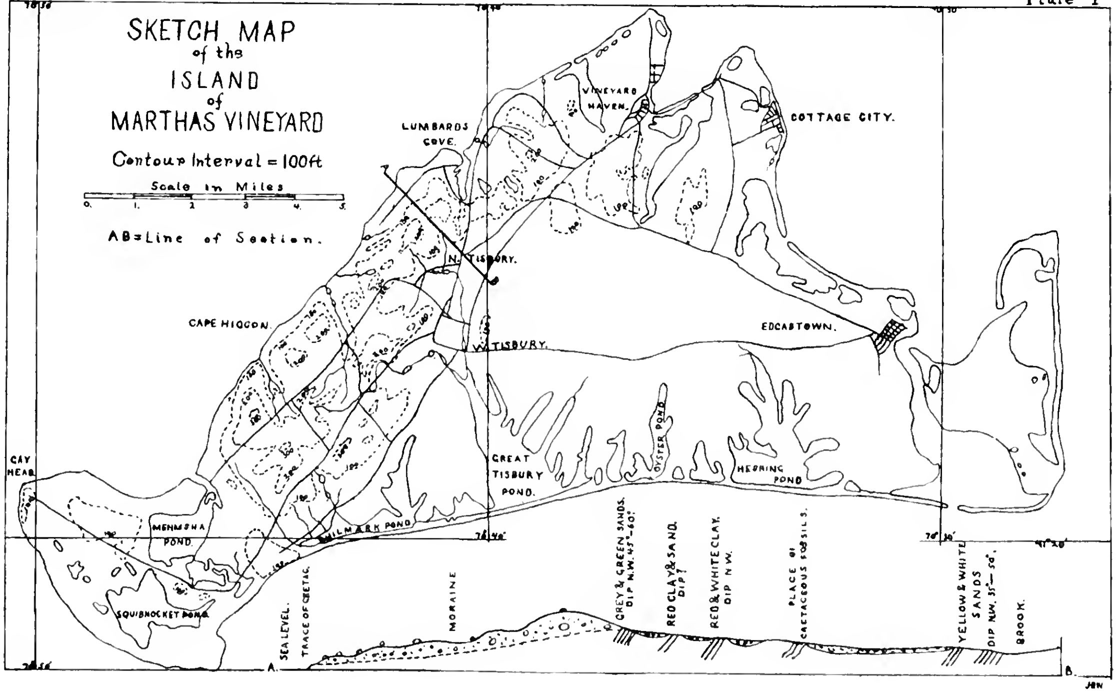
For a further account of the geology and topography of this district, see my Memoir on the Geology of the Island of Martha's Vineyard, in the Seventh Annual Report of the Director of the U. S. Geological Survey.

PLATE II.

Fig. 1, 1 *a*, 1 *b*. New genus? Compare *Myoconcha*.
Fig. 2. *Plicatula* or *Ostrea*. Compare *Pl. instabile*, Stol., and O. *lugubris*, Conrad.
Fig. 3. *Tellina (linearia)*?
Fig. 4. *Cardium*?
Fig. 5. *Pteria*.
Fig. 6. *Lucina*?
Fig. 7. *Turritella* (*nerina*?).
Fig. 8. *Camptonectes Burlingtonensis*, Gabb.
Fig. 9. *Camptonectes parvus* (?), Whitfield.
Fig. 10. *Chemnitzia*.
Fig. 11. *Lucina*.
Fig. 12. *Cerithium*.
Fig. 13. *Anomya*?
Fig. 14. *Turritella*.
Fig. 15. *Nuculana*.
Fig. 16. *Ostrea* or *Exogyra*?
Fig. 17. *Modiola*.
Fig. 18. *Modiola*?
Fig. 19, 20. *Exogyra*. Compare *E. ostracina*, Lam.

Shaler
Cretaceous Fossils

Plate 1



Shaler
Cretaceous Fossils

Plate 2.

Boston Photogravure Co.

No. 6. — *The Intrusive and Extrusive Triassic Trap Sheets of the Connecticut Valley.* By William Morris Davis and Charles Livy Whittle.

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Contents.

1. — Introductory.

The outcrops of conglomerate, sandstone, and shale in the Triassic formation of the lower Connecticut Valley are generally inconspicuous, and alone would hardly afford means of deciphering the structure of the region; but they are accompanied by ridges of strong relief, marking the resistant edges of trap sheets whose close conformity to the adjacent sedimentary beds has long been recognized. It was noticed by the elder Hitchcock that some of these sheets were extrusive. Manifestly these are of great stratigraphic value, for after taking their places in the stratified series, they constitute truly conformable members of the mass, and may be used as guides to the deformations that the whole has suffered.[1] Attention was called to their value in this respect by the senior author of this essay in 1883,[2] and since then something of the structure of the region has been worked out[3] for the United States Geological Survey by means of the dislocations of the sheets that are regarded as extrusive. The field about Meriden has also been found an

[1] Chamberlin and Irving. Bull. 23, U. S. G. S., 1885, pp. 100, 101.

[2] Amer. Journ. Science, XXIV., 1882, p. 347. Bull. Museum Comp. Zoöl., Geol. Ser., I., 1883, p 249.

[3] Amer. Journ. Science, XXXII., 1886, p. 342. Amer. Assoc. Proc., XXXV., 1886, pp. 224–227. Seventh Ann. Rep. U. S. G. S., 1888. Bull. Museum Comp. Zoöl., Geol. Ser., II., 1889, pp. 61–87. Amer. Journ. Science, XXXVII., 1889, pp. 423–434. Meriden Scient. Assoc. Proc., 1889.

excellent training ground for the Harvard Summer School of Geology. There is, however, still difference of opinion as to which of the trap sheets are of extrusive origin, and it has therefore seemed advisable to examine all the evidence thus far collected which bears on this question.

2.—Means of Distinguishing Intrusions and Extrusions.

Our belief is that the eastern traps are extrusive sheets, which were poured over the floor of the Triassic estuary from various and undiscovered vents at several times during the deposition of the bedded members of the formation: that three of the sheets attained areas of many square miles, — perhaps of several hundred square miles, — the second of the three being the sheet now seen in the main line of ridges from Branford northward to Meriden and beyond to the Massachusetts line, while the first and third constitute the anterior and posterior ridges respectively. It is probable, also, that certain other eruptions occurred later, although the outcrops of their flows are not yet well correlated. If such be the facts, we should expect from our knowledge of existing lavas to find many indications of the contemporaneous origin of these sheets. Deposits of ashes and bombs may reveal the locus of eruption. More or less disturbance may have been created in the unconsolidated sediments as the lava flood advanced over them at the bottom of the estuary. Successive flows or intermittent advances of a single flow may have quickly followed one another, forming a composite sheet of lava. While the middle part of a flow would be relatively dense, the upper part would be vesicular, after the fashion of modern flows, and the surface might exhibit the ropy or clinkery character of lava streams. After the eruption, the igneous sheet would be gradually buried by the continued deposit of sediments that settled slowly down in all the cavities and inequalities of the surface, thereby acquiring a stratification in minute accord with all its irregularities. Where the waves and currents of the ancient estuary were strong enough, clinkery fragments may have been moved about on the surface of the sheet from the more exposed situations, and carried to the deeper, quieter water, there settling down with finer detritus from a more distant source.

On the other hand, if the lava sheets that we have pictured as extrusive were in reality intrusive, nearly every feature would be changed. The contrasted features of the two kinds of sheets must surely be distinct enough for preservation and detection. We have therefore searched the region carefully for all the outcrops and openings that might give opportunity of testing these deductive possibilities, and we now present the result of this search.

During the progress of our field and laboratory studies, the latter having been carried on by the junior author, we have looked for the results of similar studies in other regions. It appears from this that the question as to the intrusive or extrusive origin of lava sheets is seldom discussed in detail; as a rule, it has been settled by the citation of a few facts, without going through the greater labor of making complete diagnoses. We cannot therefore always determine whether all the criteria of intrusion or extrusion are present in the examples referred to. Opportunity for observation is often limited; search for outcrops is frequently hasty; but the criteria that are cited are as a rule distinctive. Putting all these together, we find that the facts indicative of an intrusion are as follows: —

An intrusive sheet is not confined to a single horizon, but may break across the adjacent strata.

The lower and upper portions of an intrusion are nearly identical. Offshoots may traverse the superincumbent beds for some distance from the main sheet.

The texture of the mass is, with small exception, dense throughout, being uniformly and coarsely holocrystalline in the middle, but becoming very close-grained and glassy close to the upper and lower surfaces, with the development of marked porphyritic structure and of minerals not observable in the middle, and non-polarizing action immediately at the contact.

A cellular or amygdaloidal texture is rarely developed, and when occurring seems to be confined to the upper portion of the sheet. The microscope generally does not discover a definite boundary or a tangential arrangement of feldspar crystals around the walls of these pseud-amygdules, and their cavities are therefore ascribed to replacement.

The porphyritic crystals of the upper surface are arranged tangentially to the inequalities of the enclosing rock, showing the former to be secondary to the latter.

Enclosed fragments of the country rock may be found near the upper, as well as near the lower, surface of the sheet.

The overlying rocks, as well as the underlying, are fractured and disturbed, and friction breccias are sometimes formed along the contact surfaces, the fragments from the intruded and the enclosing rocks being mutually and mechanically commingled.

The beds above the sheet, as well as below, may be altered by heat. The alteration is commonly seen in change of color, induration, production of new minerals, or the development of a local prismatic habit.

Strongly contrasted with all these are the features characteristic of extrusions: —

An extrusive sheet lies conformably on the surface over which it was poured.

The lower and upper portions are strongly unlike.

The upper surface sometimes manifests a ropy flow structure, and sometimes consists of a mass of clinkers.

Vesicular or amygdaloidal texture is very common, especially near the upper surface, and sometimes within the mass.

A composite structure, as of two or more flows, is not uncommon.

Vesicles are often drawn out in a common direction, parallel to the adjacent surface, and indicative of motion; but greatly elongated "spike" amygdules stand at right angles to the neighboring surfaces. These amygdules are commonly characterized by a definite boundary, and by a tendency to an arrangement of the adjacent feldspar crystals parallel to their walls, and are therefore regarded as the product of expanding gases. Pseud-amygdaloidal cavities are also common.

There is a marked tendency to the development of a porphyritic structure throughout the whole mass.

The overlying beds show no evidence of alteration by heat.

The overlying sediments are arranged conformably with the upper surface of the sheet; open vesicles and the spaces between clinkers are more or less completely filled with sediments, deposited conformably with the surface on which they rest.

A stratified mixture of clastic materials and trap fragments, the latter more or less water-worn, overlies the sheet.

Extrusive sheets may be associated with ash beds and volcanic bombs, and with beds of volcanic conglomerate, more or less water-worn, in a horizon nearly continuous with the lava sheet.

It may be added, that the effects of heat and of mechanical disturbance in the underlying beds are features common to sheets of either intrusive or extrusive origin; and that absence of induration and apparently complete conformability with adjacent beds cannot be taken as proving extrusion.

Induration is one of the most commonly quoted effects of the action of igneous masses on adjacent sedimentaries. Percival makes frequent reference to it in his Report on the Geology of Connecticut. Yet, of all the above mentioned signs of intrusive sheets, it is perhaps the most difficult one to recognize. Simple induration is easily enough determined with a hammer; but it is another thing to decide whether it results from well advanced cementation by minute deposits of calcite or quartz brought by infiltrating waters, or from baking by heat. The sandstone overlying Saltonstall or Pond Mountain at its northern end is excessively hard; but its hardness is due to secondary deposits of calcite, and not in the least to fusion or baking. Moreover, it frequently happens that the beds overlying undoubted intrusions or adjoining dikes are not hardened: this is commonly the case with sandstones, as, for example, on the back of Gaylord's Mountain. Shales are more affected by a dehydration of their clayey constituents, new minerals being formed when the temperature is higher and water abundant. Sections cut from ordinary biscuit-ware show under the microscope no essential difference from the hydrous kaolinite from which the ware was made, excepting a greater compactness. The argillites of Somerville, Mass., manifest little local alteration near their abundant dikes; as if the general metamorphic process which changed the original clay-beds into argillite had been so complete that the comparatively slight local influence of the dikes was not sufficient to carry the change any further. The argillites of Quincy, Mass., contain small garnets close to the large intrusions of the Blue Hills. The shales overlying the Palisade Range have been changed in color and texture so as to resemble hornstone; biotite, hornblende, and epidote have been locally developed.

The induration of the sedimentary rocks immediately overlying the trap sheets has not been neglected in the study of the ridges; but while simple induration is associated in some cases with unquestionable signs of intrusion, it is found in other cases with equally decisive indications of extrusion, and we have therefore been driven to the belief that mere induration is by no means of constant occurrence or definite association, and that it must be regarded as of little determinative value, at least for the Connecticut eruptives.

Our search for evidence of the origin of the trap sheets has been carried from the coast of the Sound, by New Haven and Branford, along the greater part of the various trap ridges, to Cook's Gap, west of New Britain. Attention has been given chiefly to the back of the sheets, for the upper contacts are much more significant than the lower; but, although the upper contact lines must altogether amount to one or two hundred miles in length, the number of exposures upon them is very small. Upper contacts are generally found in streams that descend the back of the ridges, and these have therefore been examined most carefully. The list below embraces all that we have yet discovered. The localities are numbered to correspond with the figures on the map of Plate I., and are arranged according to the sheet to which we suppose them to belong, beginning with the trap range near the western border of the formation, and proceeding with the anterior, main, and posterior sheets farther east; these being interpreted as has been explained in earlier articles.[1] Some specimens from the Palisade Range of New Jersey, collected in 1883, are described with those from the western range of the Connecticut Triassic. The several smaller ridges, not correlated with any of the sheets above named, have not been closely examined, and are not here referred to, except in locality 26. The pages in Percival's Report on the Geology of the State, where he describes the localities here mentioned, are added to our list, for the sake of convenient reference. Our descriptions are made as concise as possible, in order to shorten the necessary repetitions; several of the more interesting and instructive localities are given more space in special accounts further on. Mention is made in certain cases of peculiarities of structure that do not bear directly on the question under investigation, partly in order that observations might not be lost, and also in the hope that the details thus collected might in time lead to new generalizations. Certain microscopical variations in the trap naturally resulting from differences in the conditions of solidification are added to those which have a direct bearing on the question of origin; not that they are criteria in themselves, but that they have become recognized as commonly accompanying the two kinds of eruption. For example, the occurrence of porphyritic crystals in an eruptive rock does not establish its extrusive origin, but extrusive sheets are notably more porphyritic than those solidifying beneath the surface. So, too, a holocrystalline structure does not warrant us in saying that a rock is undoubtedly intrusive; but intrusives are more frequently holocrystalline and extrusives more frequently glassy.[2] But we have not attempted to give a complete petrographic account of the specimens that have been examined. It seems advisable to postpone this until samples from all the Triassic basins of the Atlantic slope can be studied together.

1 Seventh Ann. Report U. S. G. S., 1888.

2 See, on the other hand, the account of recent lavas from Kilauea, in which glass is rare or wholly absent. E. S. Dana, Amer. Journ. Science, XXXVII., 1889, p. 461.

3. — General Features of Intrusive and Extrusive Sheets in Connecticut.

GROUP I. WESTERN RIDGES.

Locality 1. *Section numbers,* 85–89. *Local name,* East Rock. *Percival's Report,* pp. 395–398. *Percival's notation,* W. S. I. (1).

General Account. — The southwestern face of this fine mass is well exposed in a strong palisaded cliff on the border of New Haven, below which the underlying sandstones can be seen at several points. The overlying sandstone close to its contact with the trap was found on the northeastern slope, in the woods, about a third way down from the summit. This rock is regarded as a part of the West Rock sheet, from which it is thought to have been separated by a fault; similar faults of smaller throw are supposed to account for the notches in the southeastern extension of East Rock itself.

Sections cut from specimens taken from the upper contact and from four feet below it cannot be distinguished from sections similarly selected from the base of the sheet.

The trap is wanting in vesicles of expansion throughout its mass, and is holocrystalline except at contact with other rocks. Extremely close-grained and glassy at the upper contact, where it shows microscopic flowage parallel to surface of junction with the overlying sandstone. Sandstone directly above does not contain fragments of trap; hand specimens appear much more dense than from beds distant from the trap sheet.

Locality 2. West Rock. *Percival's Report,* pp. 394–396. *Percival's notation,* W. S. I. (4).

The general features of this ridge are like those of East Rock; but no exposure of the upper contact has been found on its back. As far as seen, it is of dense texture, even in the uppermost parts exposed. The southern end of the ridge, where the underlying sandstone is quarried and exposed in contact with the trap, may be reached by the West Haven horse cars from New Haven; the remainder of the ridge is wooded and less easily examined.

Locality 3. *Section numbers,* 194–199. Gaylord's Mountain, Roaring Brook. *Percival's Report,* pp. 402–404. *Percival's notation,* W. S. II.

Gaylord's Mountain is a slightly dislocated continuation of the West Rock range; on its back, Roaring Brook has cut a picturesque ravine, well known in the neighborhood and easily reached by a walk of two miles and a half from Cheshire station of the New Haven and Northampton Railroad, or by a less distance from the station of the same name on the Meriden, Waterbury, and Connecticut River Railroad. It gives the only good exposure of the overlying strata known to us on the back of the western trap sheet, and deserves careful examination.

The trap here is without vesicles throughout its mass; holocrystalline except at contact with other rocks; at its upper contact it is extremely fine-grained and glassy; flowage action is seen in the microscopic arrangement of the feldspar prisms parallel to upper line of junction. Upper surface of sheet obliquely traverses the beds of the overlying sandstones and shales; several small offshoots of fine texture extend into the overlying rock (Fig. 12). Pebbly sandstone directly above the sheet does not contain fragments of trap, and is not perceptibly affected by the igneous mass even close to the junction; the shales that elsewhere approach the sheet are apparently indurated. See special account.

Section numbers, 45–55. Palisade Range, New Jersey.

The easternmost or lowest trap sheet of the New Jersey Triassic area seems to correspond with the lowest or westernmost sheet of the Connecticut area, and is therefore referred to here in order to extend the number of examples quoted. Its base is finely exposed in contact with the underlying sandstones at the Hamilton-Burr duel ground in Weehawken, on the bank of the Hudson, opposite New York City; this outcrop is well figured in Plate IV. of the Annual Report of the New Jersey Geological Survey for 1882. Other exposures of the underlying sandstone are common up the west bank of the Hudson, but contacts are relatively rare. The only upper contact known is one pointed out some years ago by Professor Cook (Geology of New Jersey, 1868, p. 201), in Englewood, about a mile south of the station of that name on the Northern New Jersey Railroad, in a brook channel a few hundred feet west of a road.

The trap of this sheet is dense throughout, as far as examined at numerous outcrops. Its texture is rather coarse in the middle of the sheet, but becomes very fine at lower and upper contacts. The adjacent bedded rocks are distinctly altered from their original condition, with the development of new minerals. No fragments of trap are found in the overlying beds.

Under the microscope the trap is seen to be almost identical with that from Gaylord's Mountain, but more olivine is present in the holocrystalline portions. Approaching the upper and lower contacts, there is a gradual disappearance of the augite and a decrease in the coarseness of texture; the augite disappears at the contacts, porphyritic crystals of olivine become abundant, and the rock is extremely fine-grained and glassy. Occasional pseud-amygdaloidal areas occur in the trap; but no vesicles due to the expansion of occluded gases have been observed.

GROUP II. EASTERN TRAP RIDGES.

Division I. Anterior Ridges.

Locality 4. *Section numbers*, 26–28. Anterior at northern end of Totoket Mountain. *Percival's Report*, pp. 344, 345. *Percival's notation*, A. 1. N. of E. II.

The ridge anterior to Totoket has few strong outcrops; the one here referred to is at the north end of the main sheet in a stream bank, east of S. W. Loper's, South Durham (Fig. 3). Best reached by stage from New Haven to North Guilford. Base of sheet for a thickness of eight feet consists of a breccia of scoriaceous trap and clastic material, cemented together by quartz and calcite; upper part extremely vesicular; no upper contact found. Lower portion glassy and porphyritic.

Locality 5. ½ mile S. E. of East Meriden. *Percival's Report*, pp. 302–305. *Percival's notation*, A. 1. of E. III. (3).

The anterior to the long Durham range is traceable for many miles, but is often heavily covered with drift. The bluffs of the ridge are of the ordinary dense trap, and its back is as usual vesicular. About a quarter of a mile south of Black Pond, near East Meriden, there is a faint depression in its back, and here the ground is covered with numerous fragments of sandstone containing pieces of vesicular and angular trap (Fig. 13). A shallow opening would secure excellent specimens. It seems as if there was here a depression in the surface of the sheet, into which local fragments of trap were washed with sand from a more distant source.

Locality 6. West of northern end of Higby Mountain. *Percival's Report*, pp. 362–365. *Percival's notation*, A. 1. of E. III. (4).

The gap between Higby Mountain and Chauncy Peak is followed by the Meriden, Waterbury, and Connecticut River Railroad, and by the highway from Meriden to Westfield (Fig. 4). A road branches from the latter in the gap, and runs south on the amygdaloidal back of the anterior ridge. Following it about a third of a mile, and then turning west into the woods, a few ledges are found consisting of ashes and bombs, such as are more fully described under locality 8. Half a mile farther south, the sandstone lying on the back of the highly vesicular trap is exposed in the roadside. Numerous vesicular fragments of trap are included in the sandstone. Clastic deposits are seen in many of the vesicles in these fragments.

Locality 7. Southwest and west of Chauncy Peak. *Percival's Report*, p. 364. *Percival's notation*, A. E. III. (5).

The road from Meriden to Westfield crosses this anterior ridge about half a mile southwest of Chauncy Peak, and the above-mentioned ash and bomb structure is visible in roadside cuts (Fig. 5, locality 7′). A farm road follows the vesicular back of the ridge to the northwest, and the ledges to the west of it show the same structure again, locality 7.

Locality 8. *Section numbers*, 83, 84 *a*, 209–212. Anterior of Lamentation Mountain. *Percival's Report*, pp. 265, 266. *Percival's notation*, A. of E. III. (5).

The road from Meriden to Berlin follows the base of the ridge anterior to Lamentation Mountain for some distance (Fig. 5). About two miles north of Meriden, a curious bluff of volcanic ashes and bombs is seen in the face of the ridge, locality 8. The underlying sandstone is first seen at the foot of the bluff; the overlying sandstone is found by crossing the ridge to its eastern slope, locality 8′, passing several trap ledges in the woods on the way.

The trap is underlain by a bed of fine lapilli, about thirty feet thick, containing numerous rounded blocks or bombs of dense trap, from six inches to three feet in diameter; one of these blocks is half imbedded in the underlying sandstone. This basal ash bed is undoubtedly the same as the one mentioned in the two preceding localities, but it is not seen much farther north; half a mile in that direction there is a local trap conglomerate in the same horizon with the anterior sheet; vesicular and water-worn pebbles are here interbedded with sand, as if this point were not far distant from a wave-beaten margin of the anterior lava sheet. The trap of the ridge is frequently cavernous and amygdaloidal, and remarkably so near the upper surface. No local closeness of grain at upper contact; overlying sandstone deposited parallel to inequalities of trap surface; fissures and vesicles near surface filled with sand, connecting upwards with overlying sandstone. Fragments of vesicular trap and abundant grains of water-worn glassy trap in sandstone at contact; two thin tufa beds a few feet above trap sheet. See special account.

Locality 9. Anterior to Cat Hole Peaks. *Percival's Report*, pp. 375, 376.

Two small openings in the anterior ridge east of the Meriden poorhouse, a mile and a half northwest of the city (Fig. 6), expose the lower part of the sheet. It is generally of dense structure, but presents extremely irregular forms, as if consisting of ropy masses of flowing lava; the spaces between these masses are filled with a much weathered loose material that may perhaps be lapilli; there are numerous "spike" amygdules (see special account of locality 13) near and at right angles to the convex surfaces of the lava masses. The upper portion of the same sheet, where seen on roads on the back of the ridge, locality 9′, is highly vesicular.

Locality 10. Anterior of Notch Mountain. *Percival's Report*, pp. 375, 376. *Percival's notation*, Ant. to E. IV. 1 (3).

A hundred feet southwest of the Meriden poorhouse, the sandstone appears a little above the trap of the anterior sheet to Notch Mountain (Fig. 6); a small piece of vesicular trap was found in it. The same anterior sheet, where exposed in the Reservoir Notch, a third of a mile to the west, is extremely vesicular in its upper part.

Locality 11. Anterior to Shuttle Meadow Mountain.[1] *Percival's Report*, pp. 375, 376. *Percival's notation*, Ant. to E. IV. 1 (4).

A few poor exposures in the road on the back of this anterior, half a mile south of Shuttle Meadow Reservoir, reveal weathered fragments of vesicular trap in the sandstone overlying the sheet. Some of the vesicles in these fragments contain clastic deposits.

Locality 12. Anterior to Farmington Mountain. *Percival's Report*, pp. 375. *Percival's notation*, Ant. to E. IV. 1 (9).

An excellent exposure of this anterior is found about a mile east of Farmington, directly north of Stetson's house (Fig. 7). Middle of sheet dense; bottom sparingly cavernous; upper portion generally sub-amygdaloidal to cavernous; very vesicular at upper surface, where numerous vesicles are filled with indurated bitumen;[2] surface of sheet very uneven, with sandstone conformably filling hollows and open vesicles; intimate mixture of trap fragments and sand grains on upper surface.

[1] Called "North High Rock" in Bull. Mus. Comp. Zoöl., 1889, No. 4, Fig. 13.

[2] Percival, Geol. Conn., 1842, p. 375.

Locality 13. *Section numbers,* 175–182 *b.* Farmington River Gap, Tariffville. *Percival's Report,* pp. 391, 393. *Percival's notation,* A. to E. IV. 2 (2).

The main and anterior ridges are traversed by the Farmington River at Tariffville (Fig. 8); the Connecticut Western Railroad passes through the gap and exposes the complex structure and the upper surface of the anterior ridge in a long cut a quarter of a mile east of the village. The upper surface is seen again on the east bank of the river, just above the road bridge.[1]

A double sheet, as if of two flows. Lower sheet generally dense; sub-amygdaloidal, very porphyritic and glassy toward upper surface; upper portion very vesicular, and near surface contains "spike" amygdules. No local close grain in trap at top of sheet; sand grains conformably stratified in vesicles and small irregularities of surface; mixture of large and small fragments of trap with sand over surface, this mixture passing laterally into a tufa bed; trap fragments often rounded as if water-worn.

Upper sheet compact at the base; sub-amygdaloidal and vesicular in upper portion; generally very porphyritic and originally possessing a glassy base; overlying sandstone not seen in railroad cut, but well shown on opposite river bank below, locality 13′, where it carries numerous trap fragments. See special account.

Division II. — Main Ridges.

Locality 14. *Section numbers,* 1–4, 73, 76. Saltonstall Mountain. *Percival's Report,* pp. 323, 324. *Percival's notation,* E. I.

Saltonstall or Pond Mountain is the southernmost member of the eastern main trap range; it forms a well marked crescentic curve, with Saltonstall Lake lying along the inner side. An under contact, locality 14′, is found in the cut of the Shore Line Railroad, a quarter of a mile east of Fair Haven station, and an upper contact is almost revealed at the eastern end of the same cut. The back of the sheet is very scoriaceous all along the shore of the lake, but no upper contact is found until the northeastern end of the ridge is nearly reached, when it is exposed in a little gully in the woods on the back of the sheet over a pasture, locality 14 (Fig. 2).

The trap is porphyritic and was originally glassy; at lower contact with sandstone, the trap is brecciated, fine-grained, and glassy; slightly vesicular; vesicles elongated, indicating flowage action. Very vesicular

[1] W. North Rice, Amer. Journ. Science, XXXII, 1886, pp. 430–433.

and irregular texture near its upper surface; stratification of sandstone conformable to irregularities in the upper surface. Intimate mixture of sand grains and trap fragments along and above line of junction; surface fissures and vesicles filled from above with sand grains, distinctly stratified parallel with the sandstone bed above. The hardness of the overlying sandstone is due to induration by infiltrated calcite, etc., and presents no evidence of being derived from baking by heat. See special account.

Localities 15, 16. *Section numbers*, 5–17, 77. Totoket Mountain, inside south and north hooks. *Percival's Report*, pp. 336–338. *Percival's notation*, E. II.

Totoket Mountain is a well formed crescent, next north of Saltonstall Mountain. Exposures of the upper contact with the sandstone were found in a stream, locality 15 (Fig. 2), half a mile northwest of North Branford, in the southern hook of the crescent; and again in a stream-bed inside of the northern hook, locality 16 (Fig. 3). Another stream, a mile southwest of the last, locality 16′, cuts a channel in what seems to be a bed of clinkers.

The trap is porphyritic, and originally possessed a glassy base; upper surface very vesicular and irregular; sandstone lamination conformable to uneven contours of surface; intimate mixture of rounded (water-worn) trap grains and sands at contact; occasional trap fragments in sandstone for a few feet above; clastic grains of trap, quartz, etc., fill vesicles, with lines of deposition parallel to the stratification of the sandstone above; sand in vesicles is connected with the sandstone above by narrow necks. The overlying sandstone, locality 16, is indurated by cementation, and shows no signs of baking.

Locality 17. *Section numbers*, 204–207. Higby Mountain. *Percival's Report*, p. 351. *Percival's notation*, E. III. (4).

The eastern base of Higby Mountain, south of the road from Meriden to Middlefield, is followod by the upper course of Fall Brook, which at a point about a quarter of a mile south of the road lays bare a valuable exposure of sandstone lying on the trap, locality 17 (Fig. 4). A second exposure is found a little farther south, locality 17′. Numerous fragments of vesicular trap enclosed in sandstone are found in the stream for some distance northward.

The trap is porphyritic, and originally glassy; upper surface very vesicular, much decomposed, and uneven; not excessively fine-grained at upper contact. Sand grains fill vesicles and irregularities of surface, conforming closely to their shape; intermixture of sand and numerous large and small trap fragments along line of junction; occasional rounded (water-worn) fragments of amygdaloidal trap even five feet above trap sheet.

Locality 18. *Section numbers*, 132–134. Lamentation Mountain. *Percival's Report*, pp. 351, 352. *Percival's notation*, E. III. (5).

A road passes the north end of Lamentation Mountain and bridges Spruce Creek, that flows northward from the back of the mountain. Exposures of sandstone on the trap are found up and down stream from the bridge; the best locality is about an eighth of a mile up stream, south (Fig. 10), where the exposure is of much interest.

Trap porphyritic and glassy, particularly at upper surface; upper contact not locally of close texture; upper portion of irregular texture, highly vesicular, with uneven, rolling surface; sand grains fill fissures and vesicles near surface of trap; narrow necks filled with the same clastic material connect these vesicles with the sandstone above; intimate and complicated mixture of sand and trap over the upper surface (Fig. 15); stratification of sand in vesicles and above sheet conformable to surface, and generally parallel.

Water-worn fragments of vesicular trap occur in sandstone for two or three feet above surface of sheet. The vesicles in these fragments often contain small particles of trap mixed with quartz and muscovite grains.

Locality 19. *Section numbers*, 136–150. Meriden City Quarry. *Percival's Report*, pp. 370, 371. *Percival's notation*, E. IV. 1 (1).

The small easternmost ridge of the Hanging Hills group (Fig. 5 or 6) has been deeply quarried for railroad ballast and road metal at its southern end, and now presents an excellent dissection of a complex trap sheet, — the most instructive quarry in the region. It is about a mile north from the centre of Meriden. The trap of the quarry consists of a lower and an upper portion, separated by a well defined surface, inclined to the eastward with the general dip of the Triassic monocline. The lower sheet is exposed for about ten feet below the surface of separation; the upper, for sixty or eighty feet above it. Lower sheet extremely porphyritic, vesicular, and glassy; upper part scoriaceous, of rolling, ropy surface, showing evidence of normal weathering previous to quarrying. A small amount of foreign clastic material occurs mixed with scoriæ at contact with upper sheet. No local close-grained texture at upper contact.

Upper sheet dense as far as exposed in quarry; becomes somewhat fine-textured at contact with lower sheet; its original upper surface not seen in the quarry, but half a mile northeastward on the east side of the ridge, locality 19′ (Fig. 6), the trap becomes vesicular. Several lines of fault breccia traverse the quarry, consisting of large and small angular fragments of trap contained in apparently unstratified sandstone; often slickensided; the trend of these breccias agrees with that of the neighboring faults, as determined by stratigraphic evidence. See special account.

No other significant exposures of the main sheet have yet been found in its further northward extension in Connecticut.

Division III. Posterior Ridges.

Locality 20. *Section numbers*, 34–37, 74, 75. First ridge posterior to Saltonstall Mountain. *Percival's Report*, p. 324. *Percival's notation*, P. 1, E. I.

The upper surface of this posterior ridge is exposed only near its northeastern end, at a road crossing, about a mile northeast of Salstonstall Pond (Fig. 11). Elsewhere the outcrops are generally dense, but sometimes vesicular on the back of the ridge.

Upper portion of sheet very vesicular and glassy; not locally close-grained at junction with overlying sandstone; sand grains and trap fragments occur together at upper contact; sand fills vesicles in trap; occasional water-worn fragments of trap in the sandstone a foot or more above the sheet; base of sheet sub-amygdaloidal.

Ridges of very coarse trap conglomerate occur in the neighborhood, but their relation to this sheet is not yet clearly made out.

Locality 21. *Section number*, 18–23, 187–193. Second ridge posterior to Saltonstall Mountain. *Percival's Report*, p. 325. *Percival's notation*, P. 2, E. I.

According to our interpretation of the stratigraphy, this ridge is a second outcrop of the sheet already seen in the first posterior, here showing a western dip, as if on the eastern side of a synclinal; its base is open in several small abandoned quarries near a road crossing, half a mile northwest of Branford station, Shore Line Railroad, locality 21 (Fig. 11); and its upper surface, with something of the overlying sandstone, is seen an eighth of a mile north of these quarries, on the eastern side of a small pond, locality 21'. The great fault that uplifts the crystallines on the eastern border of the Triassic formation passes close to the southeast of this ridge, and is probably the cause of the reversed dip of its sheet and of the local fracture and overturning that it exhibits.[1] Trap generally porphyritic and glassy; dense at the lower contact; several exposures of fault breccia with the sandstone (Fig. 17); trap sends minute tongues of pure glass into lower sandstone, and occasionally encloses grains of quartz and feldspar. Highly cellular at upper surface on northwestern slope; its junction with sandstone above is not marked by local close texture; sandstone immediately above contains numerous fragments of vesicular trap; intercalated beds of shale and trappy conglomerate occur near base of sheet.

Locality 22. *Section numbers*, 31–33, 40, 73, 78. Ridge near Middlefield Station, Air Line Railroad. *Percival's Report*, pp. 355, 356. *Percival's notation*, P. 2 (S), E. III. (3).

This posterior is traceable for several miles on the east of Durham Mountain, but the only satisfactory exposure is in a railroad cut, a little way west from Middlefield station, Air Line Railroad. Base of sheet sub-amygdaloidal as a whole, and locally very vesicular and uneven; subordinate intercalated layers of trappy shale and irregular masses of abundantly vesicular trap near base; some vesicles filled with clastic grains of quartz, feldspar, muscovite, and fragments of glassy trap. Upper surface very vesicular. Trap generally glassy and porphyritic.

Locality 23. *Section numbers*, 24, 25, 72. Falls of the Aramamit River. *Percival's Report*, pp. 354, 355. *Percival's notation*, P. 2 (X), E. III. (4).

This is probably on the same posterior ridge as the preceding, although its direct connection has not been traced. Rock Falls Station of the Air Line Railroad is close by (Fig. 9). Trap generally glassy and porphyritic, and not locally close-grained at junction with overlying rock. Upper surface extremely vesicular, with many vesicles filled with clastic material connecting with the main mass of sandstone above by narrow necks. Trap grains mixed with trap fragments at contact and for several inches above. A beautifully water-worn pebble of trap was found imbedded in the sandstone several feet above the sheet. Drift boulders in railroad cut near by show contacts and mixture of trap and sandstone.

[1] Amer. Journ. Science, XXXII., 1886, p. 347; Bull. Museum Comp. Zoöl., Geol. Series, II., 1889, p. 72.

Locality 24. *Section numbers*, 120–123. Highland Lake. *Percival's Report*, pp. 336–338. *Percival's notation*, P. 4, E. III. (5).

The ridge posterior to Chauncy Peak is cut near its southern end by the Meriden, Waterbury, and Connecticut River Railroad, a quarter of a mile east of Highland station (Fig. 4). An excellent exposure. Under contact not shown. Trap generally dense; originally glassy and porphyritic; not locally close-grained at upper contact; upper portion extremely vesicular; sand grains filling vesicles and fissures, their lines of deposit conforming to the irregularities of the trap surface (Fig. 14); these deposits connected with the sandstone above by necks; inequalities in upper surface of trap covered by conformably stratified sandstone. Numerous angular, vesicular, large and small fragments of trap lying above the sheet; spaces between these filled with irregularly but conformably stratified sandstone; vesicles in fragments filled with sand; some of the vesicles only partly filled, and in such cases the upper surface of the filling is parallel to the dip of the Triassic monocline.

Locality 25. *Section numbers*, 124–131. Hartford Ave. and N. Stanley St., New Britain. *Percival's Report*, pp. 381, 384. *Percival's notation*, P. (ε), E. IV. I. (7).

The overlapping ends of the small trap ridges on the northeastern border of New Britain are regarded as faulted portions of a single posterior sheet; a small stream flows between them. The eastern ridge is quarried, and discloses the base of the sheet; the upper contact is found where the stream runs on the back of the western ridge.

Trap generally dense, but containing local amygdaloidal areas, surrounded by dense trap, as if produced by intermittent flowing; very vesicular at upper surface, and originally possessing a glassy base; sandstone immediately above contains water-worn grains and fragments of much decomposed trap.

Locality 26. *Section numbers*, 132–136. Near Trinity College, Hartford. *Percival's Report*, pp. 385, 386. *Percival's notation*, P. (ζ), E. IV. I. (9).

This ridge is of doubtful relationship: it may be a second posterior sheet, and therefore not directly comparable with the previous examples. Its middle portion and base are well exposed in large quarries. The trap is generally dense; triangular areas between the feldspars contain a little glass; the lower portion is brecciated and extremely scoriaceous; obsidian-like grains of trap in shale immediately under trap; upper portion vesicular, but overlying sandstones not seen. See special account.

4.—Special Accounts of the more important Localities.

The following more extended descriptions of certain selected localities are added, to give a better understanding of the fulness of evidence on the question in discussion than could be obtained from the foregoing summary. We thus present examples of what we interpret as an intrusive sheet at Roaring Brook, on Gaylord's Mountain; a bed of volcanic ashes and bombs, presumably near the locus of eruption of one of the extrusive sheets, in the anterior ridge of Lamentation Mountain; the base of an extrusive sheet, at Hartford; the top of an extrusive sheet in Saltonstall Mountain; and extrusions of complex structure at Meriden and Tariffville.

Roaring Brook, Gaylord's Mountain. Locality 3.—On entering the ravine of Roaring Brook from the drift plain at the eastern foot of Gaylord's Mountain, outcrops of sandstone are soon encountered with dip of 40° to the eastward. These are followed for several hundred feet up stream until the rock in the stream bed is found to consist of fine-grained trap, the line of contact having been passed unnoticed. A little search is needed to discover it, but when once made out it can be followed with some distinctness. In a general way, the trap sheet thus disclosed lies parallel with the beds above it, but on tracing its surface up the ravine, it is seen to depart significantly from perfect parallelism and comes in contact successively with different beds. Moreover, it gives forth very distinct branches or leaders (Fig. 12), one of which extends for twenty feet into the overlying strata. The margins of these offshoots, as well as the edge of the sheet itself, are tolerably even, in marked contrast with the excessive irregularity of the upper surface of the trap sheets of the eastern ranges. The overlying beds give not the least sign of trap fragments which so generally characterize the beds lying on the back of the eastern sheets. Taking all these features together, and placing them in contrast with those of the sheets on the eastern side of the valley, there can be no question that their consistent differences are due to some fundamental difference in the manner of eruption of the lava. We are forced to the conclusion, that the western sheet has been driven in between the previously deposited beds of sandstone and shale, while the others have been poured out on the surface of certain beds, and afterwards buried under others of later date. Study with the microscope confirms this conclusion. The trap of West Rock, a continuation of Gaylord's Mountain to the south, has been described petrographically by Hawes, and classed by him as a dolerite.[1] Sections from near the middle part of the trap sheet forming Gaylord's Mountain do not appear to differ materially in their microscopic characters from those of West Rock. The trap is holocrystalline far from its upper and lower junction with the sandstone or shales, and, as has been pointed out by Hawes, is much less altered, and contains fewer hydrated minerals, the products of decomposition of the augite, feldspar, etc., than the eruptive masses forming Saltonstall Mountain, or the Durham range, to the east. Hawes believed this difference to be connected with geographical location, and thought it had nothing to do with geological age.[2] According to J. D. Dana,[3] the great alteration of the trap in the eastern range took place at the time of ejection, and depended on the encountering of subterranean waters which the molten rock took up in its passage through the sandstone strata. Hawes followed this view, and thought the eruptive magma might in such a way assume the diabase type, while under less humid conditions the same magma on consolidating would form a dolerite.

It appears, however, that the difference in the hydration of the eastern and western traps can be better accounted for by original structural and mineralogical differences incident to the very different conditions under which the several trap sheets solidified. This will be referred to again in the special account of Saltonstall Mountain.

In the trap from Gaylord's Mountain, on approaching the overlying sandstone, there is a gradual fining of the texture and an increased tendency towards a porphyritic structure, the porphyritic crystals there being set in an undifferentiated, non-polarizing base. The augite occurs more rarely in well-outlined individuals, and constantly tends towards a granular structure. Olivine, which has been detected in minute grains in the same rock to the south, has once been abundant at the Roaring Brook contact, in well-outlined porphyritic crystals, but is now mostly altered to a fibrous grass-green to yellowish-green serpentine, or entirely replaced by pseudomorphous calcite or dolomite. The augite occurs less and less plentifully upwards, and at two inches from the junction with the sandstone it cannot be found even in grains. Accompanying the loss of augite and the increase of olivine, there is, especially at the contact, a development of a non-polarizing base in which are scattered innumerable acicular ledges of feldspar, some porphyritic, showing an

[1] Amer. Journ. Science, IX., 1875, p. 186. [2] Ibid., p. 190.
[3] Ibid., VI., 1873, p. 107

arrangement parallel to the adjacent surface of the sandstone. The glassy base with its accompanying dots of ferrite is best shown in sections from the narrow leaders running into the overlying sandstone (Fig. 12). These leaders penetrate the sandstone for a distance of several feet; the largest, which is three inches wide at its beginning and over twenty feet long, is seen under the microscope to be nearly pure glass, in which minute double refracting areas are abundant; the smallest leaders are mere threads, and in composition are essentially glass.

Although as a whole the western trap is little changed, marked alteration and hydration are shown in the upper surface of the trap of Gaylord's Mountain, and in the leaders; and it is to be noticed in connection with the much greater hydration of the Saltonstall range, that this zone of glassy trap corresponds to the general glassy base of the extrusive sheets. By the association of the intrusive trap at Roaring Brook with the coarse sandstone immediately above, it has probably been brought into contact with water to a greater or less extent, and part of its alteration may be attributable to this cause. No amygdules occur in the trap, except rarely one of a pseud-amygdaloidal character; there is no tendency towards a mixture of the two rocks along the line of junction, either of the kind seen above the extrusions or like the breccias known with certain intrusions.

The microscope affords no evidence that the conglomeratic sandstone has been indurated by heat. The sandstone is much decomposed, owing to alteration of its feldspathic constituents, and its grains are somewhat incoherent. This failure to show induration does not, however, militate against the intrusive origin of the trap. Similar sandstone at the base of Saltonstall Mountain exhibits no greater evidence of heat induration, although it was surely subjected to a high temperature.

As far as both microscopical and field evidence go, there can be no doubt that in the case of Gaylord's Mountain we have a well marked example of an intrusive sheet. No observers have given it a different interpretation.

The Ash-bed in the Lamentation Anterior. Locality 8 (Fig. 5). — Two miles north of Meriden, near the road leading to New Britain, the following section is exposed in the ridge anterior to Lamentation Mountain. The base of the bluff on the upper slope of the ridge shows a small outcrop of fine-grained, brownish red sandstone; immediately above this there are twenty or more feet of tufa-like material, containing oval and discoidal areas of close-grained trap that we have interpreted as volcanic bombs. Above the tufaceous deposit is a sheet of very amygdaloidal trap, overlain by a dark pinkish gray sandstone, carrying two thin subordinate layers of trappy material a few feet over the contact. In the hand specimen and under the microscope, this sandstone appears identical with the fine matrix of a trap conglomerate noted by Percival as occurring half a mile to the north, and presumably forming the stratigraphical equivalent of the tufaceous deposit at this point. The sequence of outcrops here disclosed is one of the most valuable that it has been our fortune to discover, and has attracted much local attention since it was found in the spring of 1887. It will well repay attentive examination. The following account refers in greater part to its microscopic structures.

Under the microscope the material of the bluff enclosing the volcanic bombs is found to be made up of small fragments of trap, generally very fine-grained and much altered. Small greenish brown areas dotted thickly with ferrite are non-polarizing as a whole; these appear to be volcanic glass. A few porphyritic ledges of plagioclase occur in them. Most of the eruptive grains have been altered to chlorite and quartz, and are intimately mixed with granular calcite. The microscope fails to discover any grains of water-worn quartz or other clastic material, although it is probable that more or less normally deposited sediment occurs thinly scattered through the mass. No stratified arrangement of the trap grains is noticeable in the microscopic sections, except an orientation of chlorite plates parallel to the stratification of the sandstone on the back of the ridge, and to a rude lamination brought to sight in the face of the tufaceous bed by weathering. Following Geikie, this bed would be called a tufa, consisting of a shower of lapilli. It appears to have been deposited rather rapidly in a body of water, and probably at no great distance from a point of eruption, as it soon disappears to the north and west. It is traceable a mile and a half to the southeast, in localities 6 and 7.

The volcanic bombs occurring with the lapilli give the face of the bluff a curious mottled appearance. They show no definite arrangement, but are more numerous near the bottom of the bed, where one of them seems to have imbedded itself in the underlying sandstone; they are remarkable for their non-vesicular character and their compact uniform texture from the centre to the surface. The microscope detects no variation in texture in any part except that due to a partial alteration of the surface. It shows them to be extremely close-grained, with porphyritic crystals of augite set in a ground mass of minute plagioclase needles and brownish glass. As regards their origin the microscopic study yields no solution, but the field evidence leaves little doubt in the observer's mind. The thin trap sheet overlying the lapilli is, wherever observed at this locality, more or less vesicular, and in many places cavernous. The greatest vesicularity is at its upper surface, and in the hand specimens from the contact with the sandstone above the sand is seen to have minutely penetrated the cavities and fissures of the scoriaceous amygdaloid. The sand grains not only occupy surface vesicles, but they have percolated along cracks and irregularities in the trap to a depth of two feet below the surface; in some cases, they apparently lie between or surround large areas of amygdaloid. Irving speaks of similar phenomena in connection with the upper surfaces of extrusions in the Lake Superior region, and refers to them as sandstone "veins."[1] The lamination of the overlying sandstone is parallel to the surface of the trap, conforming closely to its minor irregularities. Flowage action is seen in the trap in the elongation of its vesicles.

An interesting point is the occurrence of two thin layers of tufa in the sandstone just above the trap, each about an inch in thickness and about a foot apart. These layers appear in the hand specimen of a rusty brown color, composed of water-worn fragments of trap mixed with clastic quartz, and have a much weathered appearance. Under the microscope their tufaceous character is well shown; vesicular porphyritic trap grains abound, and others of non-polarizing character are derived from yellowish glass, now partially or wholly devitrified. Mixed with the trap fragments, there are abundant grains of quartz, muscovite, and orthoclase, probably derived from the crystalline rocks which surround the Triassic formation. The tufas as well as the sandstone effervesce readily with dilute hydrochloric acid, owing to the presence of secondary calcite. The sandstone owes its dark color in a large part to the presence of comminuted dust-like particles of extremely weathered trap, scattered through it and now altered to earthy chlorite and fine dots of ferrite.

The several well-marked features of this interesting locality leave no doubt that the trap sheet here is of extrusive origin.

Hartford City Quarry. Locality 26.—One of the posterior sheets, as yet not safely correlated with other outcrops, forms a ridge of moderate height, with strong western bluff, in the southern part of Hartford, where it is extensively quarried for road material. Trinity College stands on its eastern slope.

[1] Copper-Bearing Rocks of Lake Superior, Monogr. V., U. S. G. S., 1883, p. 292.

The upper portion of the sheet is vesicular, but its upper contact is not seen. The under contact is well revealed in the quarry, and affords the best exposure for the study of the base of a sheet that we have yet found. It is of interest also as being the locality described many years ago by the elder Silliman.[1] Yet this particular contact is not altogether characteristic of the under contact of most of the extrusive sheets, for as a rule the junction of the trap with the shale is without complication of any kind : one lies smoothly on the undisturbed surface of the other.

The underlying shale of the quarry will be first considered. Four inches below the trap, the shale locally consists of tufaceous material. Round and linear fragments of yellowish brown glass are seen under the microscope, thickly sprinkled with minute particles of some decomposition product of iron. These partially devitrified glassy areas are undoubtedly the remains of obsidian-like fragments deposited as the normal result of erosion from some volcanic flow, or as ejected matter from a volcanic vent. In either case, volcanic vents sent forth showers of ashes or flows of lava, presumably at no great distance from this point, and at the time of the deposition of the sandstone.

The contact line between the bottom of the trap and the underlying shale is as a rule irregular and indistinct. The lower portion of the trap for a distance of four feet presents a very vesicular and scoriaceous appearance, not unlike the upper surface of the lower flow exposed in the Meriden Quarry. The microscope shows portions of this scoriaceous material thickly sprinkled with well marked gas cavities, many of them having a linear arrangement, roughly parallel to the upper surface of the shale, due to the flowing action of the trap while in a viscous condition. The same parallelism is also well shown at the upper surface of the first flow in the Meriden Quarry, locality 19.

The trap for a thickness of several feet is not only abnormally scoriaceous, but is extremely broken. Irregular and rounded areas of vesicular trap are apparently cemented together by brown calcareous sandstone possessing a lamination generally parallel to the stratification of the shale below. The microscope shows these brown areas to be mixtures of secondary quartz, calcite, and a little chlorite, arranged in layers ; they must have been deposited by infiltrating waters. The texture of the trap gradually increases in coarseness as we approach the central part of the sheet, and then grows porphyritic and finer-grained near the upper surface. Careful search has failed to discover its upper surface in

[1] Amer. Journ. Science, XVII., 1829, pp. 121–132.

contact with shale or sandstone on the eastern slope of the ridge, but it is generally very vesicular, and resembles in all particulars the upper surfaces of all the well determined extrusions in the valley.

If the abnormal scoriaceousness and broken character of the under surface of the trap be rightly interpreted as a result of the flowing beneath water, then its anomalous character, as compared with the lower contacts of numerous other extrusives in the valleys, remains to be explained. We have little direct evidence on this point, but conclude, as sufficient heat and moisture to form a scoriaceous texture at the bottom of the flows were present in all cases, that some other factor must determine the variation between the considerable disturbance manifested here and the lack of disturbance at the contact of sand beds and the base of flows in other localities. The most available additional factor is a variation of pressure, and this would be a minimum at the base of a thin flow in shallow water. The Hartford sheet is probably not over forty feet in thickness. Emerson has described a similar disturbance and brecciation at the base of a rather thin flow in Massachusetts. It may therefore be the case that thin lava flows in shallow waters develop an unusually scoriaceous structure at their base as they advance.

Saltonstall Mountain. Localities 14 (Fig. 2) *and* 14′. — The curved outline of this ridge seems to be the result of a gentle folding after the sheet had taken its place in the bedded series, rather than a consequence of conditions attending the time of eruption; the same may be said of the larger and somewhat more irregular curve of Totoket Mountain, next to the north. There is an almost intuitive hesitation before the suggestion that anything so massive as a lava sheet could be folded, but this must disappear on recalling the strong folds of the heavy sandstones of Pennsylvania, or the stupendous contortions of the gneissic rocks on which the Triassic formation rests. If the sheet were intrusive, it might, to be sure, have wedged its way in between the sedimentary beds after they had been tilted and gently folded, thus accepting their guidance as to the form its outcrop should present; and this has been currently believed, both here and in the case of the similar but larger curves of the trap ridges in New Jersey. It is therefore of more than local importance to determine whether the Saltonstall sheet is an intrusion or an extrusion; for if the latter, it surely cannot have originally taken its present form, but must have passively suffered deformation from an initial horizontal attitude.

The small opportunity for observation of the contacts of this sheet with the adjacent beds has already been mentioned. The base is seen in the Shore Line Railroad cut, locality 14′. The back of the sheet has been carefully searched from one end to the other with no success except in the little gully in its northern hook, locality 14 (Fig. 2), but the general uneven and scoriaceous texture of its upper portion is continuously visible for two miles or more as it dips under Saltonstall Lake; this is seen to best advantage by rowing along the shore in a boat, which may be obtained at the southern end of the lake.

The base of the trap sheet for a distance of several feet is decidedly amygdaloidal and close-grained; and, owing to its broken character and the subsequent infiltration of secondary quartz and calcite, it locally resembles a breccia. Under the microscope, the trap is seen to be very amygdaloidal, and the vesicles are elongated by the flowing of the trap conformably to the line of junction with the sandstone below. Specimens of this breccia-like mass appear identical to the eye and under the microscope with those from the base of the anterior at the north end of Totoket Mountain, locality 4.

Round areas of a brownish material resembling water-worn fragments of sandstone are apparently enclosed by the trap near its junction with the sandstone, but the microscope shows these to be secondary deposits in vesicles, and to consist of quartz and granular calcite, products of alteration, stained brown by iron. Similar areas are found at the base of a trap ridge on the northeastern limits of New Britain, locality 25, where Percival erroneously refers to them as consisting of dark red jasper, the product of the indurating action of the trap;[1] also at the base of the tufaceous bed of the anterior to Lamentation Mountain, locality 8, and at the Hartford City quarries, locality 19. A section of sandstone three inches below the trap sheet of Saltonstall shows water-worn fragments of trap, and denotes that at the time of the deposition of the sandstone layers there were bodies of trap undergoing erosion in the neighboring region: they may have been derived from the front of this very sheet before it had advanced so far as the locality in question.

The upper surface of the trap forming Saltonstall Mountain is extremely vesicular and irregular; the vesicles are sometimes well defined, sometimes vague, indicating both gas expansion and replacement as their cause. The texture shows a distinct decrease in coarseness as we approach the upper contact, although the upper portion, as a general rule, is more coarsely crystalline than the lower portion in contact with the sandstone. Pumpelly speaks of this fining of the texture on ap-

[1] Geol. Conn., 1842, p. 383.

proaching the upper surface as common to all amygdaloids studied by him in connection with the copper-bearing rocks of Lake Superior; and these sheets are well known to be extrusive.[1] It is to be noted here that coarseness of texture, even at the base of lava flows, presumably depends, other factors being the same, on whether extrusion takes place on land surfaces or under water; so that we should expect the trap to be much finer in grain when extrusion takes place under water, since texture is a function of rate of cooling.

When a section across the upper contact is examined under the microscope, the lamination of the sandstone, which occupies the inequalities in the upper surface of the trap, is seen to conform to the general contour of the hollows. This conformity is usually visible in the thin section, even when not noticeable in the hand specimen; it is of common occurrence in other localities along the eastern ranges, and is highly significant of the deposit of the sandstone subsequent to the eruption of the trap. Sections of the trap at the upper surface of the sheet also exhibit vesicles, more or less open upwards, which are partly or wholly filled with stratified clastic deposits, connected with the overlying sediments by narrow necks. In some cases the sand-filled cavities are apparently isolated in the trap, but this appearance is owing to the fact that the thin section is transverse to the opening along which the sand grains filtered into the cavities. The clastic grains occupying the vesicles are usually of the most enduring minerals derived from the ancient crystalline rocks, on the side of the Triassic estuary: these are quartz, various feldspars including microcline, hornblende, and muscovite, cemented together by granular calcite stained red by ferric oxide. Small fragments of vesicular trap occur here also, not the least interesting of the constituents. The grains first deposited are generally arranged with their longer axes roughly parallel to the contour of the lower portion of the vesicle; grains later deposited appear approximately parallel not only to one another, but to the general stratification of the main mass of overlying sandstone, and also to the stratification in a number of similar vesicles in the upper portion of the trap sheet at this point. So highly specialized an occurrence of clastic material in vesicles at the surface of a trap sheet can have but one interpretation: the trap sheet is extrusive. Like the conformity of the sandstone or shale to the upper surface of the trap, the clastic filling of the surface vesicles is very characteristic of the eastern ranges, and is

[1] Metasomatic Development of the Copper-Bearing Rocks of Lake Superior, Proc. Amer. Acad., XIII., 1877–78, pp. 282, 283.

particularly interesting in the way it recalls the details of the slow process by which these trap sheets were buried. Irving mentions the occurrence of filled vesicles at the upper surface of the diabases and diabase-porphyrites of the Keweenawan series of Lake Superior, and cites it as one of the strongest proofs of the extensive origin of these rocks.[1]

Fragments of vesicular trap are not uncommon in the sandstone immediately overlying the surface of the sheet ; their edges appear somewhat water-worn. It is of course possible that such fragments as these might have been derived with the sand from some distant source, and that they therefore do not in any way bear on the contemporaneous extrusion of the subjacent sheet. In such a case we should expect to find fragments of trap at various horizons in the Triassic series, showing no definite association with the intercalated trap sheets, but this is not the fact. The sandstones and shales throughout the valley here and there contain abundant fragments of trap, but, except in a few cases that will be specified, the fragments occur only in the bed immediately overlying some one of the sheets of the eastern trap ranges ; the fragments are commonly vesicular, and as such cannot have survived long transportation ; they are moreover but imperfectly water-worn, if at all, and are sometimes angular, and can therefore be referred only to a source close at hand. It seems reasonable to conclude, on these several grounds, that the trap fragments in the sandstones that rest on the trap sheet of Saltonstall Mountain may be accepted as giving indication that the sheet had been formed before the deposition of the sandstone above it. The action of waves and tidal currents on the scoriaceous, irregular, and fragmental surface of a lava flow would be entirely competent to detach and transport relatively coarse pieces of the lava from more to less exposed situations, and mingle them with fine sands derived from more distant sources; and this process might continue with decreasing activity until the last remaining knobs of lava were buried under the growing sandstone cover. This interpretation is the only one that appears consistent with the facts here noted. The sandstone lying on the back of this trap sheet is distinctly harder than is common in the region, and our first impression was that its hardness was due to baking, and that the trap sheet was intrusive ; but this is not in the least borne out by more careful study. The hardness of the sandstone is due to cementation by infiltrating calcite in chief part, and not at all to change from the ordinary structure of sandstone. The sandstone on

[1] The Copper-Bearing Rocks of Lake Superior, Monogr V., U. S. G. S., 1883, pp. 79, 139, 140.

the back of the Totoket sheet, locality 16, is similarly indurated, and shows as little indication of baking.

In review, it may be said that the absence of any tendency towards a finer crystalline texture in the trap immediately at the contact with the larger sandstone areas, the highly vesicular texture of the upper portion of the mass, the parallelism of the axes of the sand grains and of the lamination of the deposits that they form, the connection of the sand filled vesicles by narrow necks with the sandstone above, and the occurrence of trap fragments in the overlying sandstone beds, all point to the extrusive origin of the trap sheet, and to the subsequent deposition of the sandstone upon it. After reaching the conclusion that the Saltonstall sheet is extrusive, it may be profitably compared with the West Rock and Gaylord Mountain sheet. The first contrast to be mentioned, and the one most conspicuous in the field, is the presence of numerous vesicles in the upper portion of the eastern sheet, and their absence in the western: this we would refer to the small pressure upon the surface of the extrusion at the time of its cooling. The few vesicles near the base of the sheet may have been produced at the front of the advancing flow, when its thickness was not so great as afterwards. Next may be mentioned the general holocrystalline, non-porphyritic, and relatively coarse texture and the small degree of alteration of the western sheet, while the eastern is more or less glassy and porphyritic throughout, and greatly altered. The eruption into water and the highly scoriaceous texture of the upper portion must have favored quick cooling and subsequent alteration in the eastern sheet, without normal subaerial weathering; the effect of the presence of much glassy base must also be considered, for this is peculiarly prone to alteration; it is now as a rule wholly devitrified to chloritic substances, microliths, ferrite, etc. But none of these factors could affect the intrusive sheets; their imprisonment between the beds deep below the surface would allow them to cool slowly, and thus acquire a coarse texture, and would decrease the rate of hydration and alteration; for these reasons we find them preserving in a great degree their original characteristics. It should be noted, however, that inasmuch as a thin extrusive sheet is vesicular through a greater proportion of its mass than a thick sheet, thick lava flows may be much less altered than thin ones. Thus the heavy sheet of Mount Tom in Massachusetts is practically anhydrous, while the thinner sheet of Saltonstall Mountain contains 3.9% of water.[1] Finally, there is a most marked and per-

[1] Hawes, *loc. cit.*

sistent contrast between the features of the upper contact in the western and eastern sheets. These need not be again stated; suffice it to say that the features of the western sheet demonstrate the trap to be secondary to the sandstone, while those of the eastern sheet are equally conclusive in showing the sandstone to be secondary to the trap. It does not seem too much to say that all the many peculiar features of these two sheets find reasonable explanation as consequences of the strongly different conditions of their origin.

The localities referred to above as yielding trap fragments, but not lying on the back of a trap sheet, are the trap conglomerate of the anterior to Lamentation Mountain, which is certainly the stratigraphic equivalent of the adjacent trap sheet; the heavy trap conglomerates northeast of the first posterior ridge to Saltonstall Mountain, which are perhaps to be associated with the posterior, although probably dislocated from it by faults; and a single case south of Durham, where one fragment of vesicular trap was found in a conglomerate, distant from any trap sheet, but near the eastern crystalline boundary of the formation.

Meriden Quarry. Locality 19 (Figs. 5, 18). — The Meriden City quarry, in the easternmost ridge of the Hanging Hills group, has been attentively studied, and with much profit. Suites of specimens were carefully collected from above and below the surface of separation between the upper and lower masses of trap which appear here, with a view to examining the evidence of double flow presented. Numerous specimens were also taken from the linear breccias of sandstone and trap fragments which traverse the quarry, in order to compare them with fragments of sandstone included in trap, such as occur in a dike at Mount Carmel, locality 27, several miles to the southwest, and to discover if they should in any way bear on the intrusive or extrusive origin of the Meriden sheet.

The lower mass of trap, *a, a*, Fig. 18, is seen beneath the upper, *b, b, b*, on the west side of the quarry, where abundant evidence may be found to show that the two were produced by separate eruptions. They are divided by a somewhat irregular surface, like that of rolling ropy lava, and usually marked by a seam, more or less open to the weather. The lower trap is changed to a reddish brown color for a depth of three feet or more below its upper surface, and contains numerous amygdular areas of chlorite, giving it a mottled appearance, simulating an altered sandstone to the eye. The reddish brown color gradually disappears downward, and at four feet below the junction it is replaced by an earthy blue-green trap having abundant amygdules of chlorite and calcite, and to the eye appearing much fresher than the reddish trap.

Numerous sections were cut from the red superficial portion of the lower sheet, and from its contact with the dense trap of the upper sheet. in order to detect any clastic material that might occur there. Very little was found, but immediately upon the upper surface of the lower sheet a thin layer was discovered consisting of rudely stratified grains of clastic quartz and orthoclase, mixed with angular fragments of trap, like that of the red seam. Some of the trap grains are glassy, non-polarizing, and of a light green color, thickly sprinkled with minute dots of ferrite. They are probably fragments of the pumice-like surface of the lower sheet; other grains are amygdaloidal, and contain small ledges of some triclinic feldspar. The whole is cemented together by quartz and calcite. There is no marked tendency towards a stratified arrangement of the grains, such as characterizes deposition in water. The trap grains appear to have been the result of the comminution of scoriæ on the surface of the lower sheet during the ordinary progress of subaerial erosion, while the occasional grains of orthoclase or quartz may have been deposited by wind or stream action; and from this we have supposed that the thickness of the lower sheet was somewhat greater than the depth of the water into which it flowed. Hitchcock long ago noted that the reptilian tracks in the sandstones in Massachusetts occurred chiefly in the beds closely overlying the trap sheets, as if the depth of the Triassic estuary had been decreased for a time by the lava that had flowed into it.

The lower trap of the quarry at ten feet below the red seam, where it is the least altered as far as the quarry exposes it, is fine-grained, of a dark greenish blue color, and of a uniform texture, containing abundant amygdaloidal cavities. Mineralogically it is composed of extremely altered porphyritic crystals of plagioclase in a ground mass of minute crystals of the same, which are in turn set in a matrix of the unindividualized base. The base in places is a yellowish green glass, and in others is wholly devitrified. The augite that it undoubtedly contained originally has been entirely removed by alteration. Calcite and secondary quartz are abundant, the former so plentiful that the rock effervesces readily, even with very dilute hydrochloric acid. Under the microscope, the rock appears profoundly decomposed; its numerous amygdules being due to replacement, with the occasional exception of a well-outlined cavity, the result of gas expansion. Admitting the original presence of augite, the lower sheet would be classed as a glassy form of augite-porphyrite.

The texture of the rock steadily grows finer, and the cavities due to gas expansion more numerous, as we approach the surface of junction with the upper sheet; and there is at the same time a marked increase in the amount of glass forming the base. At five feet below the contact the vesicles occupy nearly one fourth of the space, and in slide 140 of our collection they are seen to be elongated parallel to the surface of contact, as if indicating flowing action. The origin of the vesicles by gas expansion is beautifully shown in this slide by the well marked tangential arrangement of the feldspar crystals about the elongated and tortuous amygdaloidal cavities, conforming even to their minor irregularities. Sections from the red seam, just under the junction, show this portion of the trap to have been blown almost to shreds by the escaping gases. The scoriaceous character here cannot be doubted; fully two thirds of the rock is made up of secondarily deposited calcite and quartz, filling the irregular cavities and vesicles of the porous mass. The inter-vesicular areas consist of a greenish glass, thickly sprinkled with hair-like microliths of feldspar and an occasional porphyritic crystal of the same. The red color of the seam is due to the formation of iron sesquioxide. Hawes noted that the oxidation of iron-bearing minerals exposed to surface weathering is from the protoxide to the sesquioxide state, while the change is from one protoxide to another when not thus exposed, as is true of the eastern ranges.[1] It therefore seems likely that in this instance the red color of the surface of the lower sheet indicates surface weathering before the upper sheet was erupted, thus confirming the suggestion already made, that the thickness of the flow was great enough to raise its surface above water. It is rare that this red color is seen in the traps of the Triassic area.

The scoriaceous character of the sheet at its upper surface is much more strongly marked than in others thus far examined in the Connecticut valley; this is also thought to be connected with the appearance of the surface of the sheet above the surface of the body of water into which it flowed. Cooling under the air must have taken place much less rapidly, and under much less pressure, than when below the water surface, thus permitting a more complete expansion of the occluded gases and the production of a highly pumiceous surface layer.

The trap of the upper sheet just above the red seam appears in the hand specimen much less altered than that from below. Even at the

[1] Amer. Journ. Science, IX., 1875, p. 190.

contact with the scoriaceous upper surface of the lower trap, the rock is sufficiently coarse to detect porphyritic plagioclase crystals; but amygdules are entirely wanting. Under the microscope a few pseud-amygdaloidal areas are seen. The rock shows evidence of an original glassy base, seen in the triangular areas between ledges of feldspar; it is made up of triclinic feldspar, magnetite, and occasionally a minute grain of olivine. There is a slight local tendency toward a porphyritic structure; but this is lost ten feet above the lower trap. Calcite and chlorite, the usual decomposition products, occur at the base, the latter being sufficiently abundant to give the rock a greenish color next above the red seam; this is lost ten feet above the contact, and the great mass of the upper sheet is of a very dark bluish color and holocrystalline. The mineralogical composition given above is that of a normal diabase, the amount of olivine being so small that it can hardly be classed as an olivine-diabase. While the upper surface of the lower trap is abnormally scoriaceous, the base of the upper sheet is abnormally coarse and free from vesicles, as compared with other trap sheets resting on sandstones or shales. This can be explained by the well known poor conductivity of volcanic scoriaceous substances, whose presence here permitted the upper trap to cool and solidify slowly, and produce a more complete crystallization. A practical illustration of the low conductivity of such material is found in the use of scum or slag from iron furnaces as a packing for steam pipes.

The lower sheet may be confidently called an extrusion, but as far as this quarry goes, there is nothing to determine the origin of the upper sheet. This, however, is fully settled by the general field evidence of the region, which correlates this whole mass with the heavy sheet of Lamentation Mountain, and that sheet has been clearly shown to be extrusive.

The field evidence here referred to concerns the occurrence of faults, which, as is so generally the case, are at nearly all points buried under surface waste. It is therefore of particular interest to examine the bands of breccia (*c, c, c*, Fig. 18) by which the quarry is characterized, as they are best interpreted as small examples of the great dislocations by which the structure and topography of the formation are deciphered. The breccias therefore deserve attentive study. The apparently unbedded sandstone, of which they in good part consist, is best interpreted as a fine clastic filling of the fault fractures, derived from above, where the walls were of sandstone or shale, and gradually filtered down among the large and small angular blocks of trap that were broken from the quarry sheets ; but, on the other hand, the sandstone might also, until its continuity in bands across the quarry was noticed, be regarded as fragments of sandstone picked up and included in the trap at the time of its eruption : not that such inclusions would necessarily indicate intrusion, for extrusive sheets are well known to contain fragments oft he adjacent country rock.

The general attitude of the several bands of breccia negatives the second interpretation. The bands all maintain a straight course through the quarry; a single band may cut the lower, as well as the upper sheet ; the bands stand at right angles to the general extension of the sheets ; they are parallel to one another and to the course of the large faults by which the region is broken. The dividing surface between the lower and upper sheet in the southern end of the quarry is seen to be dislocated by one of the bands, with small heave on the east, this being the relative displacement of the large faults in the region. Neglecting this sufficient series of indications of their origin, we examine their structure more closely, and discover that they are frequently slickensided, and that the trap fragments that they contain are sometimes broken since taking their places in the bands. Moreover, these trap fragments are themselves included in the sandstone matrix of the bands ; the fragments are angular, and show no variation of texture from centre to surface ; the sandy matrix contains small broken grains of sandstone, as well as of sand. Again, if the sandstone which accompanies the trap fragments had been picked up and included in the main mass of trap at the time of eruption, it should present evidence of the action of heat, as in induration, or more likely in some alteration, for the relatively small areas of sandstone in so large a mass of trap must have long been subjected to intense heat. With this idea in mind, a comparison was made of sandstone from the breccia bands with a block of sandstone in a large dike a little north of Mount Carmel station, New Haven and Northampton Railroad, locality 27, to which Professor Dana had called our attention. The blocks of sandstone in this dike are five or six feet long and two or more wide. When struck with a hammer they give a ringing sound, characteristic of induration. Sections of the sandstone show it to be principally composed of quartz grains mixed with fragments of feldspar, and closely cemented by a clayey material. While it exhibits no significant alteration in composition from ordinary sandstone, it cannot be doubted that its exceptional density was the result of the dehydrating action of heat from the molten dike on the kaolinite that formed the clayey cement. The contact of the dike and sandstone is sometimes blurred, as if they had been locally melted together; and the texture of the dike becomes finer on approaching close to the included sandstone fragments, just as it does on approaching its sandstone walls.

Returning to the quarry, we find that the sandstone from the breccia bands has no indication of induration, except that resulting from the moderate cementation of its clastic material by secondary quartz and calcite deposited around the grains. Sections of the sandstone in contact with the included trap fragments and with the main mass of the trap sheet show a well marked laminated arrangement of the sand grains nearly parallel to the walls of trap and to the faces of the trap fragments; this points decisively to the deposition of the sandstone posterior to the eruption and fissuring of the trap. There is also a laminated arrangement of the sand grains on all sides of the trap fragments, as far as examined, which we do not fully understand, but which may be perhaps interpreted as indicating continued motion of the faulted masses while the breccia was still moist and soft, every trap fragment moving as a whole and thus calling for an adjustment of the sand grains around it. There is no change in the texture of the enclosing mass of trap on approaching the breccia bands, such as would certainly appear if the sandstones were inclusions. A change of texture is so characteristic of rapid marginal cooling that it is often shown immediately at the border of large amygdaloidal cavities, as has been mentioned by Pumpelly,[1] and as is well marked in our slide 141, from near the upper surface of the lower trap in the Meriden quarry, and again still better in slide 218 from the Middlefield Railroad cut, locality 22, in which a nearly spheroidal vesicle is surrounded by a layer of trichitic glass having an area as large as the vesicle itself.

In order to apply this test carefully to the case in hand, several sections were cut from the trap in the quarry, on either side of the best exposed breccia, at the contact, and one and four feet away. These show no tendency towards a finer grain, or towards a development of porphyritic crystals or glassy character on nearing the breccia; the character of the trap remains constant to the contact. Moreover, the angular fragments of trap in the breccia are of uniform texture, and are identical with the trap on either side, except for a little greater weathering in the former. These fragments may therefore have been derived by fracture directly from the enclosing walls; but certain minute grains of very fine-grained decomposed trap, also occurring in the breccia, appear to

[1] Metasomatic Development of the Copper-Bearing Rocks, *loc. cit.*, p. 283.

have been derived from the upper surface of the surrounding trap, or from another trap mass above.

We therefore conclude, in reviewing the examination of the breccias, that sand and sandstone grains and a moderate share of rounded grains of close-textured normally eroded trap were all filtered together down the fissures that traversed the sandstones and trap sheets, and that on reaching the points exposed in the quarry they found a confused mass of large and small angular fragments of trap, broken from the walls at the time the fissures were made, the whole forming a highly characteristic breccia. Such breccias are not uncommon in the valley, as at Branford, locality 21 (Fig. 17), where they are associated with the great fracture by which the formation is bounded on the east; and in the Tariffville Railroad cut, locality 13, of minor importance. Percival knew a few of them, and called them "clay dikes."[1] While our conclusion may therefore be considered well supported, it must be remembered that the breccias do not afford any evidence as to the intrusive or extrusive origin of the trap sheets, and are therefore to be regarded as of secondary importance in this essay, however valuable they may be structurally.

Tariffville. Locality 13. — One fourth of a mile east of Tariffville station on the Connecticut Western Railroad (Fig. 8), a cut exposes a valuable section of the anterior ridge.[2] The greater part of the cut is in massive trap; a narrow band of breccia occurs near its middle. At the eastern end of the cut, the upper portion of the sheet shows a thin bed of tufaceous material, which locally passes into a bed of trappy sandstone along the strike; and above this there is a second sheet of compact trap of moderate thickness, with its upper surface lost in drift. The two sheets together constitute the anterior ridge at this place. There appears to be little if any lithological distinction between them; they are both glassy varieties of augite-porphyrite. The upper surface of the lower trap, although generally amygdaloidal, is not so much so as is usually the case. Immediately beneath the sandstone layer, the amygdaloidal cavities have an aberrant character, being several inches in length and generally about one fourth of an in inch in diameter, with their longer dimension normal to the surface of the sheet. Amygdules in such cavities have been described from one of the extrusive copper-

[1] The relation of these breccias to the faults of the region is more fully discussed in a previous Bulletin of this volume, No. 4, p. 77.

[2] See an account of this locality by W. North Rice, in the Amer. Journ. Science, XXXII., 1886, pp. 430–433, where it was first brought to public notice.

bearing traps in the Lake Superior region, where many of them were composed of native copper; hence the name "spike amygdules," as given by Pumpelly.[1] Irving also mentions them from the same locality, and Hawes refers to similar ones occuring in the trap of Connecticut as "pipe-stem" amygdules.[2] Nason notes their occurrence in the trap of the Watchung Mountains in New Jersey,[3] which Darton thinks is of extrusive origin,[4] and Winchell reports them in greenstone from Thessalon Point, Ontario.[5] Their occurrence in the lower trap of the Tariffville cut is restricted to a zone of little depth near the surface of the sheet, where it may be supposed that escaping gases found the easiest direction of expansion to be toward the surface; hence their peculiar position. A fortunate breaking of the trap may liberate one of these rod-like amygdules; they are composed of concentrically deposited calcite with a chlorite centre, or more rarely the chlorite centre is wanting and the amygdule is now hollow. An occasional amygdule of ordinary form associated with the spike amygdules is beautifully banded, with its lamination parallel to the stratification of the sandstone above, and hence dipping with it at the same angle, about twenty-five degrees southeastward. Under the microscope, the bands are seen to be composed of granular calcite and secondary quartz, the banding being due to fluctuations in the supply of ferric iron during the process of filling the vesicles. The lower part of the amygdules is extremely granular and ferruginous; the upper part usually consists of composite calcite individuals, and is free from iron. Some amygdules near the surface contain grains of clastic quartz or orthoclase lying in the calcite filling, as is so common in the eastern sheets, and arranged with the major axes of the particles parallel to thebedding of the sandstone and lamination of the amygdule. Cavernous amygdules with banded structure were also found in the Farmington anterior ridge, locality 12. Their only other occurrence in this country as far as known, is in the amygdaloidal melaphyse at Brighton, near Boston, Mass., where the great number and essential parallelism of the bands to one another, and to the bedding of the overlying slates, has been taken to indicate deposition of some kind guided by gravity.[6] In all these cases it may be fairly argued that

1 Proc. Amer. Acad., XIII., 1877–78, p. 296.
2 Amer. Journ. Science, IX., 1875, p. 191.
3 Geol. Survey of N. J., Report for 1888, p. 37.
4 Amer. Journ. Science, XXXVIII., 1889, p. 134.
5 Geol. and N. H. Survey of Minn., XVII., p. 15, Plate I.
6 Proc. Boston Soc. Nat. Hist., XX., 1878–80, p. 426

the accordance of the bands in the various amygdules with the bedding of the adjacent sedimentary layers demonstrates the eruption of the igneous sheet before the deformation of the whole mass; but manifestly it does not bear on the manner of its eruption.

The microscope reveals a marked decrease in the coarseness of the texture of the trap upwards as the overlying sandstone layer is approached at the eastern end of the railroad cut, and a corresponding decrease in the freshness of the rock; but the texture nowhere becomes so fine as that on the back of Gaylord's Mountain. The intermediate sandstone at the south end of the cut contains fragments of amygdaloidal trap in abundance, often water-worn; but a little distance to one side, this mixture is replaced by a strongly marked tufa bed in the same horizon, resembling in color and appearance the lapilli from the ash and bomb deposit in the Lamentation anterior, locality 8; under the microscope it shows decomposed fragments of glassy trap in a cement of calcite and chlorite with occasional fragmental grains of quartz and muscovite.

The upper trap sheet does not present significant features in the railroad cut, but descending to the river and crossing by the road bridge, where its upper surface is apparently found, several exposures occur a little way up stream, in which there is the usual mixture of trap fragments with the sands of the sandstone that overlies the sheet. This is thought to be the upper surface of the upper anterior sheet, because no other trap outcrop is to be seen until the base of the heavy main sheet is reached.

The breccia in the middle of the cut resembles the breccias of the Meriden quarry, but is much narrower, being only four to six inches wide. It is a fissure in the trap, on which some slight faulting has taken place, as is shown by slickensides; it is filled with a mixture of sand and angular trap fragments, and was undoubtedly formed posterior to the production of the trap.

5. — Conclusions.

It is difficult for those who have become convinced of the correctness of a certain conclusion to state in an impartial manner the evidence on which the conclusion rests. We shall therefore not attempt to review all the evidence presented above, but will briefly call attention to the uniform association in the eastern trap ranges of the numerous characteristics of extrusive sheets, while the western trap range as consistently manifests the several characteristics of an intrusive sheet. It must be remembered, too, that of the numerous localities instanced on the eastern ranges, all (with one exception, Hartford) belong to only three extrusive sheets; and hence the evidence that is found at one point supplements or confirms that found at another in a most satisfactory manner. All this seems to us to be beyond explanation either by accidental coincidence or mistaken identification. While judgment might well be suspended if our argument rested on single examples, or on numerous examples confusedly arranged, it is difficult, even if necessary, to maintain an open mind in the face of evidence at once so full, so varied, and so accordant. If all the trap sheets of the region were of one kind, the argument would be weakened; for in the absence of either kind of sheet, the peculiarities of the other would not be illumined by the light of contrast. The presence in the single region under consideration of sheets with the features of intrusions and extrusions therefore greatly increases the confidence that one may feel in the case, and warrants the acceptance of those sheets that we have called extrusive as conformable and contemporaneous members of the Triassic series, by means of which the dislocations of the formation can be detected.

The fullest statement of the method by which the extrusive trap sheets can be thus employed is given in the article above referred to,[1] by the senior author, in which the process of investigation followed by the advanced section of the Harvard Summer School of Geology during a week's work about Meriden is presented in detail. It is now our design to continue the investigation in the district northwest of Hartford, where a preliminary excursion has indicated a change in the course of the faults from the uniform northeast trend that they possess in the Meriden district. When the faults are mapped out over a considerable area, comparison can be made between their course and the strike of the schists on either side of the Triassic valley, on which the course of the dislocations is thought to depend.

[1] The Faults in the Triassic Formation near Meriden, Conn., Bull. Museum Comp Zoöl., Geol. Series, I., 1889, pp. 61–87.

NOVEMBER 16, 1889.

EXPLANATION OF PLATES.

PLATE I.

Fig. 1. Map of Triassic area in Connecticut from Long Island Sound to the north bend of the Farmington River, based on Percival's map in his Geology of Connecticut. The numbers in circles refer to localities on the several trap ridges described in the text, and in most cases figured on a larger scale in later plates. See page 104.

Plates II. and III. contain outline maps traced from town maps in county atlases, the trap ridges being sketched in black; they cannot claim much accuracy, but will probably serve as guides to the localities that furnish exposures of critical contacts.

PLATE II.

Fig. 2. Adjacent ends of Saltonstall and Totoket Mountains. For locality 14, see p. 110; locality 15, see p. 111.

Fig. 3. North end of Totoket Mountain. Locality 4, see p. 107; locality 16, see p. 111.

Fig. 4. North end of Higby Mountain. Locality 6, see p. 107; locality 17 and 17′, see p. 111; locality 24, see p. 115.

Fig. 5. Chauncy Peak, south end of Lamentation Mountain, and Quarry Ridge, Meriden. Locality 7 and 7′, see p. 108; locality 8 and 8′, see p. 108; locality 19 and 19′, see pp. 112, 113.

Fig. 6. Notch Mountain and eastern ridges of the Hanging Hills. Locality 9 and 9′, see p. 109; locality 10, see p. 109; locality 19 and 19′, see pp. 112, 113.

PLATE III.

Fig. 7. Farmington Mountain and its anterior ridge. Locality 12, see p. 109.

Fig. 8. Farmington River Gap, at Tariffville. Locality 13 and 13′, see p. 110.

Fig. 9. Rock Falls of Aramamit River. Locality 23, see p. 114.

Fig. 10. North end of Lamentation Mountain. Locality 18, see p. 112.

Fig. 11. Posterior ridges to Saltonstall Mountain. Locality 20, see p. 113; locality 21 and 21′, see pp. 113, 114.

PLATE IV.

Fig. 12. Overlying sandstone traversed by a small leader from the trap sheet of Gaylord's Mountain at Roaring Brook, locality 3. See pp. 115 and 116.

Fig. 13. Angular fragments of trap imbedded in sandstone on the back of the anterior ridge of Higby Mountain, half a mile southeast of East Meriden, locality 5. See p. 107.

Fig. 14. Drawing from a microphotograph of a section of vesicular trap from the ridge posterior to Chauncy Peak at Highland Lake, locality 24. The trap is black, with white areas representing minute pseud-amygdules and an occasional prism of plagioclase; the large central space within the trap is an amygdule, containing clastic material (dotted) at the bottom, with the once horizontal lines of deposition now tilted parallel to the general monocline of the region; the upper part of the amygdule is filled with calcite, of which part is stained with some ferruginous material (fine lines), and the rest is composite crystalline calcite (blank). See p. 115.

Fig. 15. Drawing from photograph of sandstone in contact with vesicular upper surface of trap, forming Lamentation Mountain, locality 18. The black areas are the thin walls separating vesicles; white spaces are amygdules of calcite. See p. 112.

Fig. 16. Drawing from photograph of hand specimen of sand grains filling open vesicles in trap, Falls of the Aramamit River. Two vesicles have lower bands of calcite, and the remaining space filled with clastic material. Locality 23, see p. 114.

Fig. 17. Breccia from fault in a road-cut in the second posterior ridge to Saltonstall Mountain, near Branford, locality 21. This fault is probably a branch of the great fault by which the Triassic formation is limited on the east. See p. 114.

PLATE V.

Fig. 18. The City Quarry at Meriden, looking northwest; locality 19. *a*, *a*, the lower flow in the southern part and the western alcove of the quarry; *b*, *b*, *b*, the upper flow, forming most of the mass here exposed; *c*, *c*, *c*, breccias of angular trap fragments and sandstone, traversing the quarry. See pp. 112, 127. The northern extension of Cat-hole Ridge is seen in the distance.

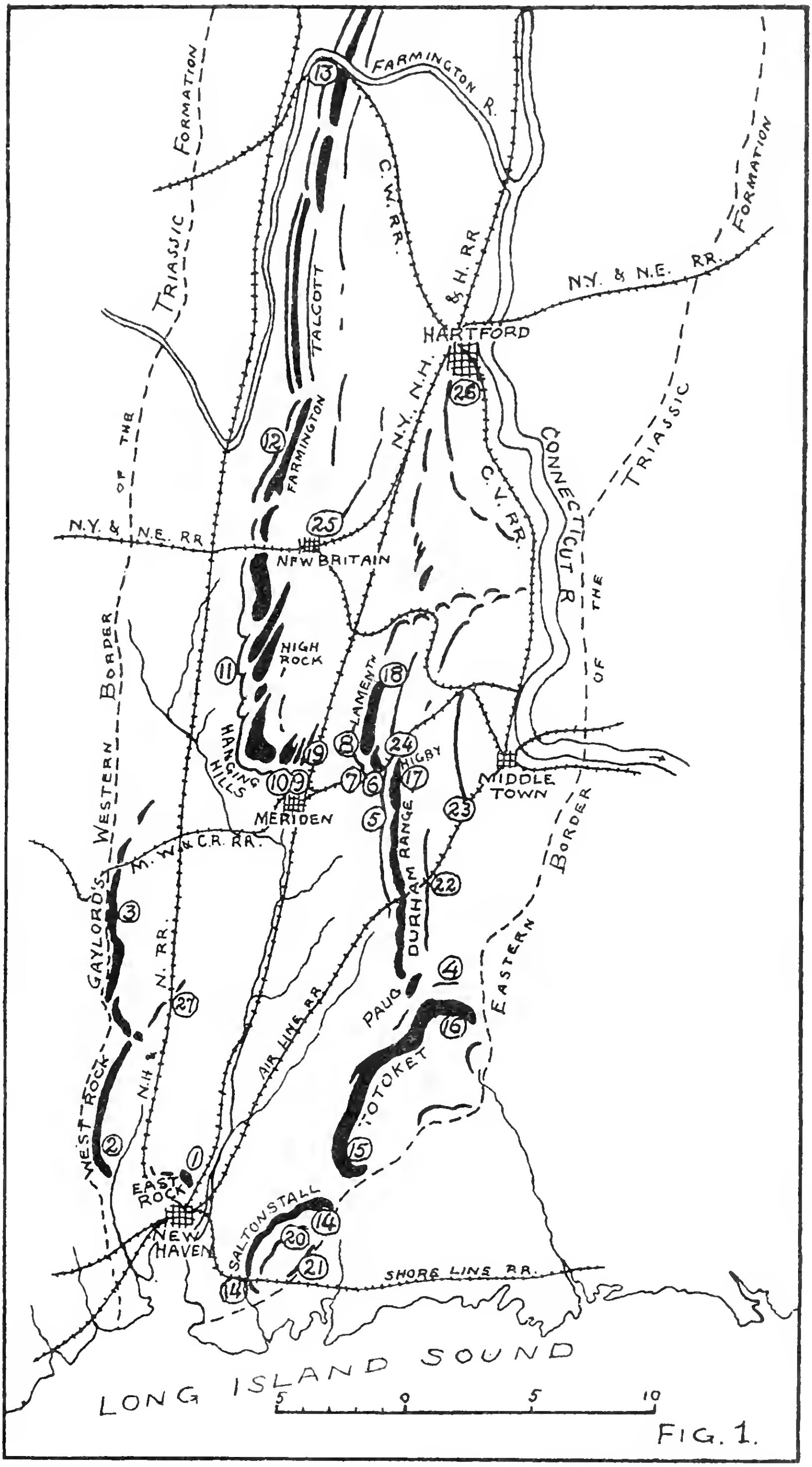

FIG. 1.

Photo Lith by L S Punderson & Son, New Haven Conn

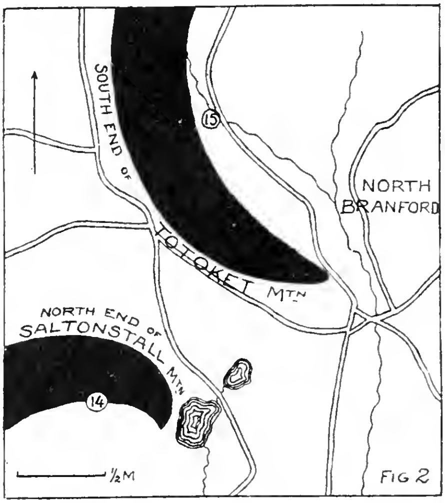

FIG 2

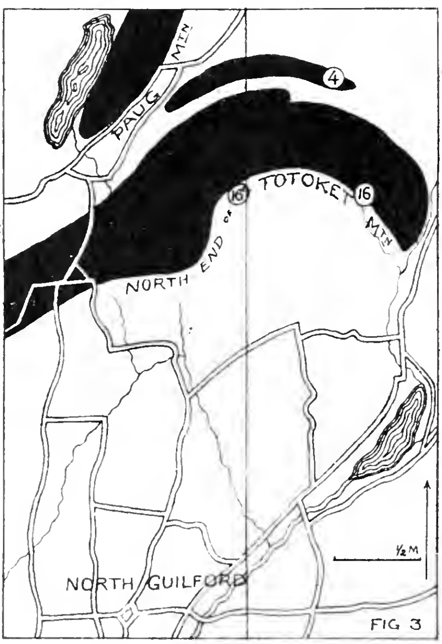

FIG 3

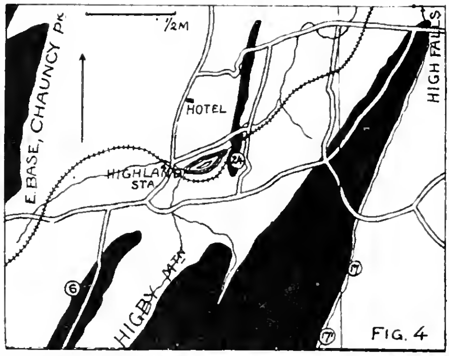

FIG. 4

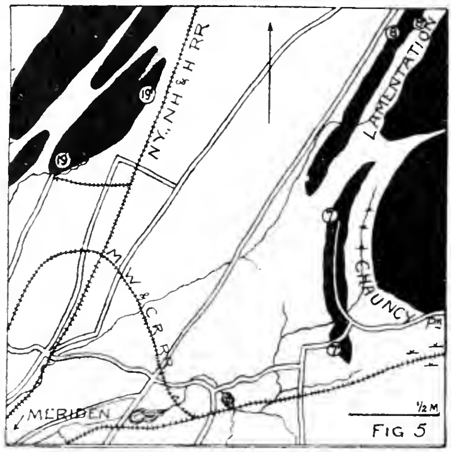

FIG 5

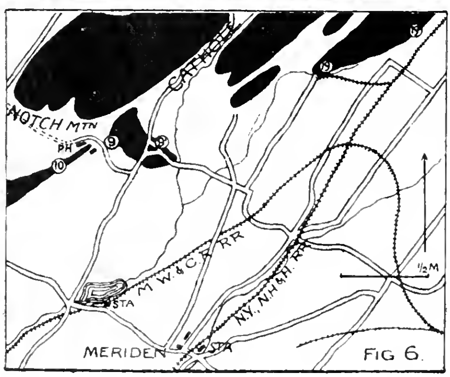

FIG 6.

Photo Lith by L. S. Punderson & Son, New Haven Conn

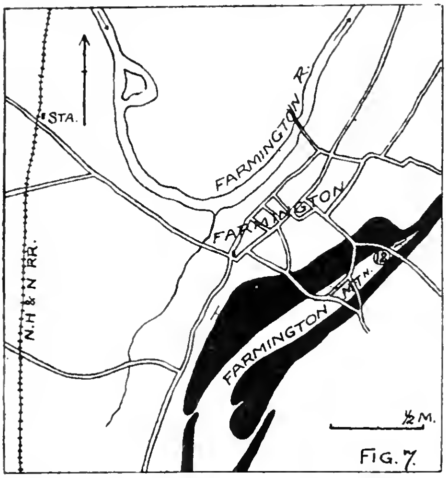

FIG. 7.

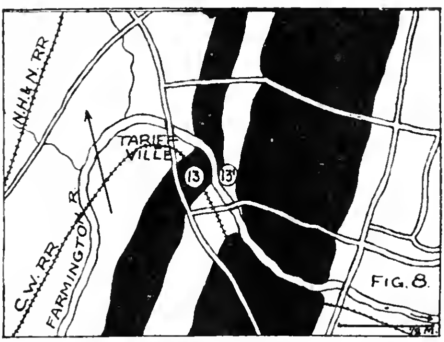

FIG. 8.

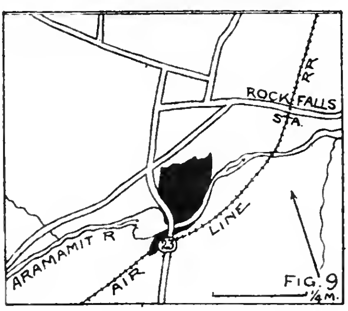

FIG. 9

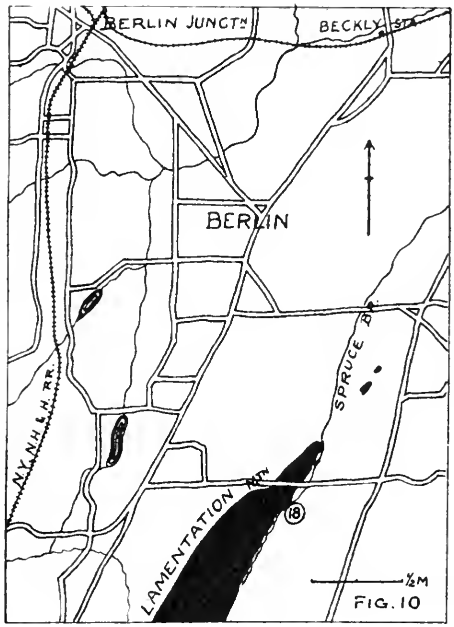

FIG. 10

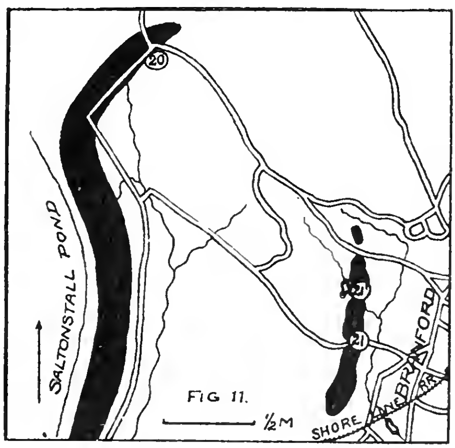

FIG 11.

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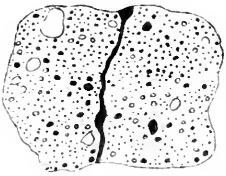

FIG. 12. × 2/3

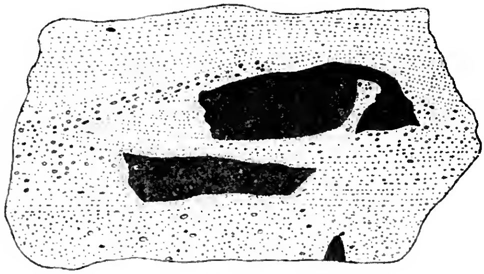

FIG. 13 × 1/3

FIG 14 × 37

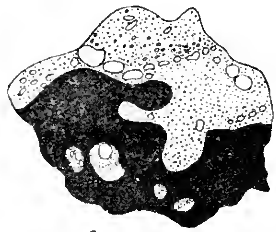

FIG. 16. × 2/3

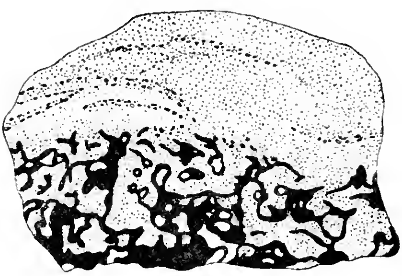

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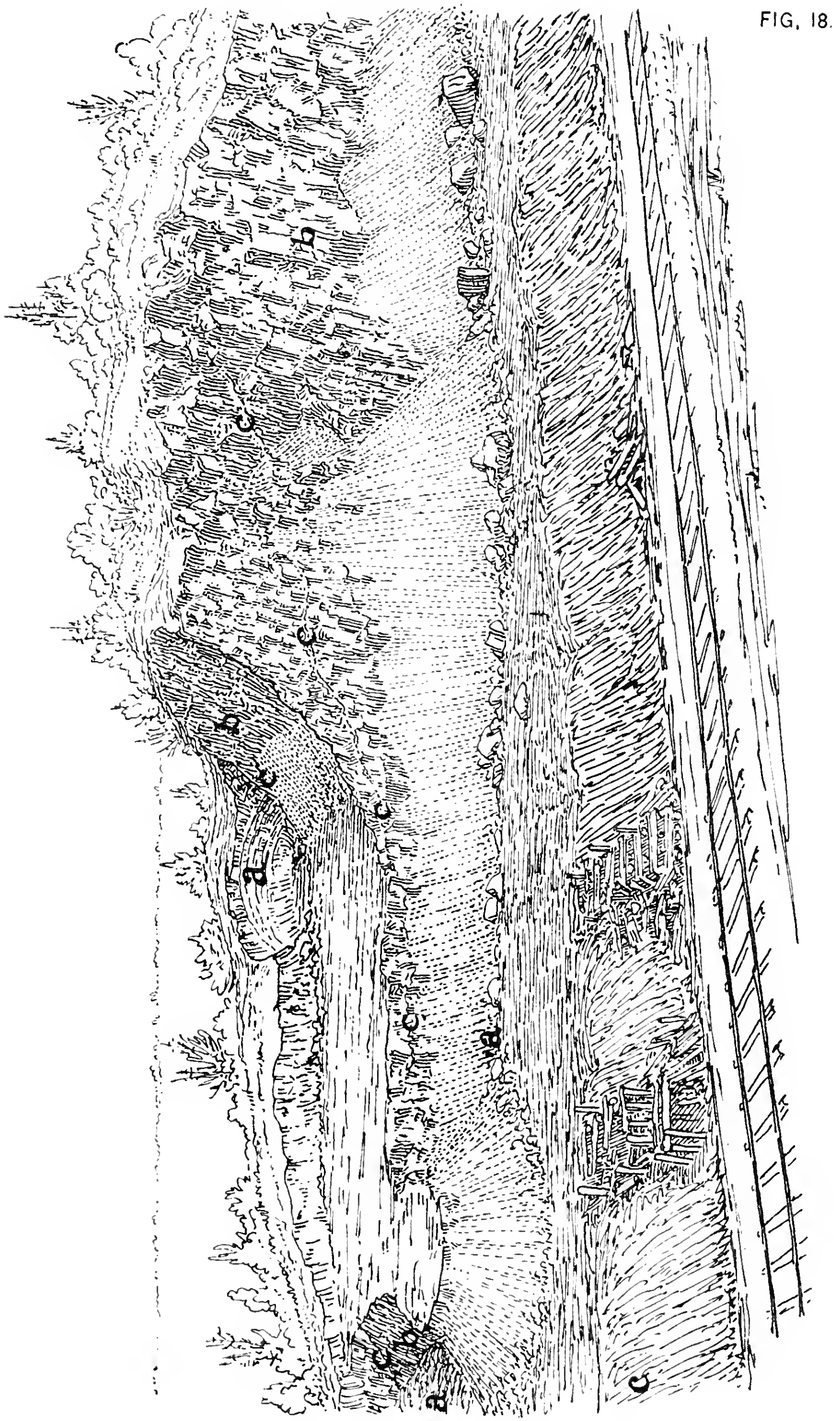
PLATE V.

FIG. 18.



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No. 7. — *The Topography of Florida, by* N. S. Shaler. *With a Note by* Alexander Agassiz.

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Both in its general form and in the detail of its surface, Florida presents many interesting features. I propose in the following pages to pass in general review the more important topographic elements of this peninsula, and to consider the information which they give us as to the general history of the continent.

The peninsula of Florida, as is readily seen by glancing at an ordinary map, forms a salient on the coast line which departs widely in its general character from all the other great capes of the continent. The prevailing trends of the eastern coast are from northeast to southwest. This projection extends in a general northwest and southeast direction. All the other greater peninsulas of the continent are distinctly mountainous in their character. This of Florida is formed of low lands, rising as a broad fold from the deep water on either side to a vast ridge, the top of which is relatively very flat, there being no indications of true mountain folding in any part of the area. All the other great peninsulas of the continent, except that of Yucatan, which in certain ways resembles Florida and may be causatively connected with it, are composed of old rocks. The last named salient is made up altogether of very recent strata.

The detailed topography of Florida is almost as anomalous as its general configuration. The region of the Everglades in the southern part of the peninsula, and that known as the "Lake District" in the northern, are both eminently peculiar in their configuration, having, so far as I am informed, no likeness in any other part of this country.

The first question before us concerns the origin of the Florida uplift. It will be observed that we have on the peninsula of Florida a very remarkable ridge, which has grown up from the sea-floor to the altitude of about five thousand feet; and a somewhat similar elevation in the archipelago of the Bahama Islands. Neither of these ridges has a mountainous character. Indeed, it is at first sight difficult to find the analogues of these great anticlinal-like folds in the existing structures of the land. They can hardly be classed with any of our known table lands, for the reason that such elevations are in all cases more or less associated with definite mountain folding. The only similar structure which is known to me is that exhibited in the "Cincinnati anticlinal," that well known ridge extending from near Columbus, Ohio, to Northern Alabama. This elevation in length and breadth may be compared to that of Florida, though it never had more than one half the height of the Floridian peninsula.

In endeavoring to account for the Florida ridge, we must bear in mind the processes of deposition which have evidently occurred in this region. The geological history of the sedimentation is about as follows. To the west of Florida, in the Gulf of Mexico, we have a region which from a remote time has been the seat of extensive accumulation of sediments. The Mexican Gulf in a more or less perfectly definite form is one of the oldest topographic features of this continent. It is, as is easily seen, the remainder of the continental trough which from an early time has received a great share of detritus from the Appalachian and Cordilleran fields. It has therefore been a region tending to subsidence, through the well known influence of the weight produced by sedimentary deposits on the surface of the earth. This subsidence has naturally been attended by phenomena of counter-thrust elevation, the characters of which I think are found in the curious uplifts of Yucatan and Florida, which serve in part to bound this region of downward movement. Besides the sediment contributed to the region of the Mexican Gulf from the continental portions of North America, there has been a considerable increase of such deposits from the island of Cuba. This island, which probably came above the level of the sea in the Mesozoic period, has evidently furnished a very large share of waste to the neighboring sea-floors, as is shown by the extensive erosion indicated in its highlands. A considerable portion of this detritus has doubtless been accumulated in the region now occupied by the Straits of Florida, and by the deep water between the Bahama Islands and the greater land masses of Cuba and Hayti. I am disposed to consider the extensive recent elevation on which rest the coral islands of the Bahamas as possibly due to the down-bearing of the crust caused by these sediments.

The Caribbean Sea has likewise long been a seat of extensive sedimentation. A number of great rivers draining from old mountain districts subject to energetic erosion have contributed their detritus to this basin. The line of the Antilles appears to me to mark the phenomena of counter-thrust due to the accumulation of deposits off the coast of South America, much as the peninsulas of Florida and Yucatan mark the effects of sedimentation in that sea and in the Mexican Gulf. To the down-thrust caused by sediments derived from the island of Cuba, and deposited on the sea-floor to the northward, we may perhaps attribute the sudden termination of the Florida elevation on the south. The general tendency to counter-thrust uplift produced by the growth of strata in the Gulf of Mexico, and manifested in the peninsula of Florida, is here interrupted by the process of local sedimentation. It is probable that, at the present time, the considerable energy with which the Gulf Stream moves through the Strait of Florida may hinder the process of deposition of sediment derived from the Cuban land mass; but, as I shall endeavor to show in the sequel of this paper, this limitation of the Gulf Stream is probably a matter of very recent geologic time.

Turning now again to the Cincinnati axis, let us note its relations to the geography of the district at the time when it was formed, to see what light it may throw upon the development of the curious elevations about the Gulf of Mexico and the Caribbean Sea. The Cincinnati axis, as is well known, is a singularly broad fold, which was developed on the floor of the palæozoic sea at a distance of two hundred miles or more from the then shore of the Appalachian Islands, and generally parallel with the ancient land. At first, in the period of the Lower Trenton, this floor appears to have been tolerably level. Before and during this period in the history of the earth, a vast amount of detritus was borne from the Appalachian land, and deposited on the sea-floor near its eastern shores. Thus, along these old shores we had a vast thickness of sandstones of the Okoee and Chilowee age, and above them a great thickness of rocks belonging to the Knox group, which, though partly of organic origin, are largely composed of inorganic waste from the old lands on the east. There is no doubt that these last sediments were derived from the Appalachian land, and they form an extremely massive system of sediments along the ancient shore. Following their onlaying, this portion of the sea-floor which they occupied sank to a great depth, as is shown by the peculiar character of the sediments and the organic forms in the Trenton rocks of Eastern Tennessee. Apparently at this time the Cincinnati anticlinal rose to near the surface of the waters, to a point where it exposed the bottom of the sea to the action of currents sufficiently powerful to break up and pack large shells in the manner accomplished by swift moving waters. It is possible that in part the growth of the Cincinnati anticlinal took place at a later date, but the greater part of its elevation was probably due to Silurian time. It seems to me that it can best be explained in the manner above indicated. It is a noticeable fact, that the Cincinnati axis is most developed along the line to the east of which this accumulation in the palæozoic seas derived from the bordering land was most extensive. Moreover, the general form of the elevation is quite comparable to that of Florida, though the axis of position is widely contrasted in the two cases.

If I am right in my supposition as to the origin of these curious reliefs in the region about the Gulf of Mexico, if the anciently developed axis of the Mississippi valley, the Floridian peninsula and that of Yucatan, and the greater islands of the Caribbean, represent the results of counter-thrust arising from the imposition of sediments on the sea-floor, it is evident that we have in this part of the earth's surface a remarkable exemplification of the effect of weight on the attitude of the crust. It must be confessed that the matter is extremely speculative. I should hesitate to give it note, were it not for the fact that the whole problem as to the effect of weight of sediments is now much under discussion, and it appears to me worth while to call attention to this district, where there may be something like critical evidence as to the verity of the hypothesis.

The detailed topography of Florida is interesting from the light it throws on two important problems, the growth of coral reefs, and recent changes in the path of the Gulf Stream. As to the first of these questions I have little to add to the considerations which have been brought forward by other writers. This little pertains to the distribution of the living and the elevated reefs on the eastern shore between the southern part of Key Biscayne and St. Augustine. Inside the living reef between Key West and the southern part of Biscayne Bay the southern coast of Florida is low. From the reports of others it appears likely that there are ridges, probably in their nature coral reefs, such as Long Key, at a distance of a score or more miles from the swampy border of the land. Near the southern end of Biscayne Bay we find the first distinct reef near the shore. This reef comes above the level of the sea about ten miles north of Mangrove Point, just to the west of Old Rhodes Key. It gradually rises, until at Cocoanut Grove, immediately west of Key Biscayne, it has a height of about twenty-two feet and a width of about two miles. As the uppermost part of the deposit consists of characteristic reef material, and is composed to a certain extent of corals, which have evidently grown in place, this reef gives proof of a recent elevation of the shore to the height of about twenty-five feet. There has been a considerable loss by corrosive action, how great cannot be determined, in the height of this reef. It is throughout honeycombed by subterranean water passages, and the surface of the rock is much disrupted by the overturning of trees in times of hurricanes, when the roots entangled in the crevices of the rock break blocks away from their bedding.

The Miami Reef, as I propose to term this interesting accumulation of coral, extends northwardly with occasional interruptions for a great distance along the eastern shore of Florida. North of Dumbfoundling Bay it appears gradually to lose its character as a true coral reef, and to take on the general nature of coquina. It appears to be the same elevation that is traceable as far north as the northern part of Indian River, near Titusville. I have only observed this ridge at certain points. North of Lake Worth I have not observed any corals in the material. It appears that from Jupiter's Inlet to Titusville it is mainly composed of molluscan remains. It is therefore not certain that it is all of the same age as the Miami Reef, but the fringe of beach material follows continuously on the line of that reef, first in an almost meridional direction, then turning at Lake Worth to the northwest. There can be no doubt that the eastern shore of Florida from Miami to Titusville, and probably all to the northward, has its position determined by the strong resistance which this consolidated beach deposit has offered to the action of the sea.

The steep escarpment which this barrier of old beach material presents, which is now elevated to a score of feet or more above its original position, indicates that it long withstood the beating of the ocean waves. The barrier of drifting sands now lying along the coast between this escarpment and the open ocean has apparently been constructed in very modern times, since the last elevation of the shore. A part of the cutting which formed the escarpments of this reef evidently took place during the process of elevation which brought the reef to its present altitude. This is indicated by the fact that sea caves and other reentrants are formed in the cliffs at a considerable height above the present plane of the sea.

The effect of this reef on the drainage of Florida is very great. Although the rivers at many points have found their way across the elevation, either by subterranean streams or through the low points of the barrier, it serves to retain the land waters, and to bring into the condition of swamp a large part of the peninsula. The St. Johns River, and the extensive swamps in which it heads, are in good part determined by the existence of this barrier. In a less complete way, the waters of Lake Okochobee and of the Everglades to the south of it are likewise prevented from finding a path to the sea by this natural wall. Thus, at Cocoanut Grove, the waters of the Everglades at a distance of only three miles from the shore in their time of lowest level lie sixteen feet above high tide. In the rainy season they often rise to such an altitude that they pour over the reef whenever it is less than twenty feet in altitude. A sufficiently wide canal, having a depth of twenty feet and a length of not over four miles, would drain the waters of the Everglades into Biscayne Bay. The rivers which flow over this part of the reef come down to the sea level over a series of rapids formed upon the harder layers of the reef, and thus the full escape of the Everglade waters is prevented. In the region more to the north, the entanglement of the vegetation about the head-waters of the streams, even where they have no rapids in their beds, likewise hinders the escape of the marsh waters.

The superficial geology of the elevated reefs which constitute the keys, as well as the section to the west of Biscayne Bay, affords an interesting subject of inquiry, which, owing to my brief sojourn in this region, was but imperfectly followed. All the keys are evidently undergoing a rapid corrosion by the action of the rain-water which falls upon their surfaces, as well as a considerable marginal erosion by the mechanical impact of the waves. On all the shores, it is also evident that the sea-waters exercise a considerable solvent influence upon the limestone, but this influence is much less manifest than in the case of the rain-water in the interior portion of the key. In the strip immediately adjacent to the shore, where owing to the steepness of the slope the rain is quickly shed from the surface, the solvent action of the fluvial waters is relatively small; but at a little distance back from the coast, where the vegetation is more dense and the surface nearly level, the solutional work is much more manifest, and is almost always distinctly traceable. In time of heavy rain, the water gathers on the surface, being held there in part by the dense mat of low growing vegetation. While so retained on the surface, it doubtless obtains a considerable charge of carbonic dioxide, which, as is well known, vastly increases the capacity of the fluid for taking lime into solution. In most cases the water is conveyed away through narrow crevices which penetrate the underlying rocks, and discharge through small caverns communicating with the shore, pouring forth their waters at about the level of mean tide. Wherever these underground passages are formed (and they are very numerous upon all the keys), the area about the neck of the orifices takes on the shape of the sink-holes so well known in the great cavern districts of Kentucky. Though these depressions in the Florida keys are never so large nor so shapely as the characteristic forms of a similar nature in older rocks, they are in many cases a conspicuous feature. Good examples of such structures occur on Indian Key.

It is evident that the tendency of this corrosive action effected by the rain-water is to lower the central portion of each island, for the reason that in this interior field this water dwells longest upon the surface, and becomes most charged with carbonic dioxide. If the process were long enough continued, the effect would be to degrade the interior region, leaving the marginal portion where the rain-waters are quickly drained away in the form of a ring-like elevation. That this effect is not more conspicuous in the case of the Florida keys is perhaps to be attributed to the fact that the sea cuts back the margin of the islands so rapidly that time is not allowed for the development of such a topography. If the shores of these reefs had been protected from the action of the waves by the presence of the living coral, the islands would probably exhibit a distinct internal depression.

The most interesting observations which I had an opportunity to make concerning the erosion of the elevated reefs rest upon the section from the western shore of Biscayne Bay into the Everglade district. As before remarked, the western margin of this bay is formed by a ridge of coralline material, which rises quickly from the surface of the water to the height of about twenty-two feet above the surface, attaining that elevation at an average distance of about half a mile from the shore. This versant of the Miami reef, on account of the steepness of its slope, provides a tolerably ready drainage for the rain-water, which in no case rests for any time upon the surface. Owing to the prevailing dryness of this well drained area, the low growing vegetation is small in amount, and the scattered pine blades afford little woody material by the fall of its trunks, branches, and leaves. The result is, that, owing to the absence of the decaying vegetable matter and their brief sojourn on this surface, the rain-water obtains but little carbonic dioxide.

When we pass from this relatively steep slope to the flat top of the reef, where the waters are less rapidly drained away, — where indeed during the rainy season the surface is, as I am informed, very wet. —

the growth of vegetation, and consequently the amount of humus upon the soil, are considerably greater. The effect of the longer presence of the rain-water, and the greater amount of the acids from decaying vegetation, is at once shown in the development of a great number of sink-holes. Portions of the reef are so thickly set with these depressions, that nearly all the rain-water appears to find its way by underground channels to the sea, where we can note its emergence in great springs. Descending from the summit of the reef towards the Everglades, I observed that with each foot in height of descent the corrosive action of the land water increased in amount. All portions of the reef which were so situated as to be exposed to the waves of the lake which in the rainy season covers this district, were very deeply corroded. Such surfaces often presented broad areas of rock so far eaten away by the action of dissolving waters that, for the depth of a foot or more, the remaining portion of the strata resembled the floor of a cavern covered with stalagmitic materials. These decayed fragments of the rock often assume curiously branched forms, and were so attenuated that the pressure of the foot upon them would cause them to break down in such a manner that it was impossible to walk over the surface. As we approach the Everglades, the number of the sink-holes rapidly diminishes, probably for the reason that the elevation above the sea level is not sufficient to impel the water to force a passage through the crevices of the rock. Wherever the sink-holes occur, it is a noteworthy fact that they frequently, if not generally, form the descending shaft which gives exit to the waters in the central portion of some large coral. The imbedded dome-shaped mass of the Meandrinas seem oftenest to be chosen as the seat of these vertical shafts, which lead into the lower lying caverns.

The quantity of material taken into solution by the swamp waters in the rainy season, when the flooding of this area near the top of the Miami Reef occurs, may be judged by the thick coating of limy mud which is deposited in the occasional closed sink-holes, from which the waters have disappeared by desiccation. In these depressions the layer of sediment, composed in large part of lime, often attains a thickness of one fifth of an inch. As it necessarily represents the amount of lime in solution by the waters in a single season of rain, we may fairly take it as a measure of the solutional work accomplished in one year. The facts are not sufficient to permit a quantitative determination as to the amount of this corrosion, but I am inclined to think that we are justified in assuming it to be a considerable fraction of an inch in each year. An inspection of the western face of the Miami Reef leaves in my mind no doubt that the process of solution is rapidly extending the general plane of the Everglades to the eastward. On the floor of the more level and lower lying country which constitutes the eastern margin of the Everglade district, we find a similar deposit of limy matter, which has been laid down during the process of evaporation of the swamp waters. At the distance of half a mile from the face of the Miami Reef, this layer was very much thinner than on the lower portions of the reef itself. In the Everglade district the amount of decaying vegetable matter is great, and there can be no doubt that running waters of this region become heavily charged with carbon dioxide, and are thus enabled to dissolve the limy matter with which they come in contact. In the rainy season, as before remarked, these waters rise to the height of from five to eight feet above their level during the dry season, when I observed the district. As the waters of this swamp rise, they doubtless take a large quantity of the lime into solution. After the rainy season passes, the water is drained away by the numerous exits to the sea.

It is a noteworthy fact that Biscayne Bay, which receives through the Miami and other streams discharging from the swamps of the Everglades on its floor a vast amount of limestone mud. A portion of this mud is composed of the remains of Foraminifera and other organisms; but microscopic examination of it shows that a large portion of the mass does not exhibit evidence of having recently been in the organic condition. It appears to be lime in the form which would be given it by a precipitation from water. The quantity of this mud in the control of the tidal and other currents which sweep through these embayed waters is very remarkable. The volume of the material can best be judged by the conditions exhibited by the deposits of limy matter at the eastward end of the channel passing from Biscayne Bay to the sea, at the point known as Cæsar's Creek. The calcareous ooze moving out from the Bay of Biscayne at this point is so large in amount, that it forms a distinct delta, digitated at its seaward end in substantially the same manner as the mouth of the Mississippi. It seems clear that this great volume of mud comes from Biscayne Bay, and it would be difficult to explain its origin by any action originating altogether in that basin. I am disposed to believe that the surcharge of lime given to the sea by the effluent water of the rivers which drain the Everglades leads to the formation of a portion of this ooze by precipitation.

However it may be as to the origin of the limestone ooze, so plentifully formed along the coast where the Everglade waters discharge, it seems to me there can be no question as to the relatively rapid excavation of the deposits of the Everglade district. There can be no doubt that this region shows in a very clear way how, under certain conditions, the process of excavating the interior of a plateau of limestone deposits may under favorable circumstances be carried forward in an exceedingly rapid manner. That a more distinct reef has not been left around this region of excavation is possibly due to the fact that this region has recently been somewhat lowered above the height to which it formerly attained. There is a good deal of evidence to the effect that the whole peninsula of Florida has undergone a subsidence of ten or twenty feet in altitude since the last period of elevation.

It is commonly supposed that the living coral reefs of Florida cease at Key Biscayne, and that no true reef exists to the northward of that point. Although there is clearly no extensive development of reef deposits north of Cape Florida, my observations, though limited, are sufficient to show that a distinct reef, essentially the continuation of the main reef of Florida, that on which Fowey Rock Lighthouse stands, extends along the shore at least as far as Hillsborough River. In January, 1888, I was so unfortunate as to have my boat capsized on the edge of the Gulf Stream, to the eastward of the mouth of that river. It was necessary to bring the boat ashore bottom upward by swimming beside it. Near the shore, there being a heavy sea on, we came upon a line of breakers, beneath which the water was not more than six feet deep. The effect of the surface of this reef on the bare feet of my party clearly indicated that it was composed of firm coral rock. Subsequent inquiry has shown that this reef is largely covered by living corals, including many Gorgonias and actinoid corals, mostly of the common species of Manacina, fragments of which are abundantly strewn along the beach all the way from Cape Florida to Lake Worth. Between Hillsborough River and Jupiter Inlet the breakers show in times of storm the continuation of a lower reef near the shore, and the fragments of Manacina, often two feet in diameter, lying upon the beach, likewise afford evidence of a living reef in this section. North of Jupiter Inlet, my assistant, Mr. C. W. Coman, found fragments of Manacina scattered along the shore for a distance of twelve miles. Beyond this point, a careful search showed no trace of stony corals. The lessened development of the reef from Key Biscayne to Lake Worth is doubtless in part to be explained by the fact that the Gulf Stream departs from the shore near Fowey Rocks. Its warm, life-giving waters are only driven in the form of a thin sheet against the shore in the time of strong winds. At other times, when winds are blowing from the westerly quadrant, the current is separated from the shore by a considerable interval of water which drifts from the north, and is much cooler than the Gulf waters. Probably the decrease in the growth of the reef north of Cape Florida is due also, in considerable measure, to the southward movement of sands along the beach. A very large amount of this sand is continually pouring around Cape Florida. The history of this migrating detritus appears to be as follows. During the glacial period, a very large amount of arenaceous material was contributed to the sea in the region north of Cape Hatteras. The general trend of the shore of this part of the continent is from the northeast to the southwest, while the prevailing direction of the wind is from the east. The result is, that so far as impelled by the waves, this sand works down along the coast shelf to the southward. Wherever it comes upon the beach and remains within control of the waves the southward movement is quite rapid. Coming upon the coral reef, this sand tends to bury the coral, and thus to limit its growth. North of Cape Florida, the sea-fans, or Gorgonias, which by their habit of growth are in a measure protected from movements of detritus, are the principal representatives of the polyps, the Manacinas occurring only as scattered clumps amid a growth of the prevailing alcynoid polyps. North of Jupiter Inlet, the Gulf Stream departs yet farther from the shore, and it is unlikely that the temperatures are such as to favor the growth of a reef. The difficulties incident to my shipwreck near Hillsborough River made it impossible for me to make more careful observations as to the condition of this reef. I am indebted to Mr. C. W. Coman, who was formerly keeper of the Lauderdale House of Refuge of the Government Life-saving System, for a great part of the facts which are here given. He has kindly followed my directions in observations on the extension of this reef.

Imperfect as these observations are, they appear to me of interest from two points of view. In the first place, they add nearly one third to the known length of the living Florida Reef; and in the second place, they show that while the reef may maintain itself for a certain distance beyond the constant influence of the Gulf Stream, the polyps cannot retain their full vitality when deprived of its current.

There is reason to believe that the marginal reef of Eastern Florida, though it may now be extinct in the section north of Jupiter Inlet, has recently been somewhat developed even as far north as Mosquito Inlet.

In dredging for a canal now under construction on the eastern coast of Florida, in the waters of Mosquito Inlet, near the point known as Oak Hill, the engineers encountered a ridge of commingled shell and coral, through which they were compelled to go for a quarter of a mile or more in a north and south direction. The top of this ridge was somewhat below the level of the waters of the lagoon, and presumably below the level of low tide in the neighboring sea. Some specimens of the dredging shown me by Dr. John Westcott, the President of the canal company, contained fragments of Manacina apparently the same as the living species. It thus appears certain that at least one species of the living reef-making coral has in recent times dwelt along the shore to the north of Cape Canaveral.

The interior of the Floridian peninsula appears to be divisible into three distinct districts. In the south, from the northern part of Lake Okeechobee to Cape Sable, the surface is extremely level, formed probably in the main of organic waste accumulated behind the coral reefs, upon which rests a thin and interrupted coating of current borne sands of inorganic origin. The only portion of this region which I have personally seen is the edge of the Everglades, about three miles west of Cocoanut Grove. From the statements of Dr. Westcott and other observers as to the frequent occurrence of limy material in the Everglade district, it seems to me most likely that the whole of this field above the sea level is substantially composed of organic materials. The northernmost part of the State, down into the base of the peninsula to a point south of St. Augustine, probably consists of an older series of rocks, mostly of Tertiary age, very uniformly covered by a deposit of detrital sands brought to the region from the northward. Going southward from the parallel of St. Augustine, we enter upon a region where the surface is underlaid by the same sandy material as that found in the northern part of the state, but the topography greatly changes its character. In the northern section, the surface is in the main of the gently undulating form belonging to the southern plain from Virginia southwards. The deposits of sand are disposed so as to create gently warped contours, the irregularities in height rarely exceeding ten or fifteen feet within any one square mile. The form is that given by slight marine currents where they act upon shifting sand. As we proceed southward, the irregularities of the surface become gradually more and more accented, until we gradually enter on a field known as the Lake District, where the depressions without an outlet are so deep as to enclose, not shallow morasses as they do in the more northern sections, but basins of water of such profundity that they have not become closed by the swamp-building forces. The section of the lake district extends from near Waldo to Lake Kissimmee, or perhaps yet farther south. It has a length of at least two hundred miles and a width of about eighty miles, though its limits in each direction are obscure; the area of open water basins gradually shades off into the area of the shallower depressions, now entirely occupied by swamps. By my rather untrustworthy barometric observations, the highest point of the surface in this lake district in the region about Apopka rises to near three hundred feet above the sea. The number of basins contained in the area is very great. If all those containing permanent open water were enumerated, the total would probably amount to several thousand. In size they vary, from the larger bodies, such as Lake Apopka, with a diameter of ten miles or more, down to basins a few score feet across.

The most interesting feature in this district is the increase in the measure of irregularity in the hills, as we rise above the sea level. On either side, in passing from the shore, we cross a region which, though occupied by sands, has, as before noted, a gently rolling aspect, reminding one of the undulations of the sea when the waves of a great storm have nearly sunk to rest. This is the condition of surface for a height of from ten to thirty feet above the shore. For each fifty feet of ascent, careful observation shows a decided increase in the amount of the irregularities, until they attain their maximum relief in the uppermost portion of the country. So far as I have been able to ascertain, substantially all of these irregularities are moulded in recent sands. Only occasionally are they affected by the form of the surface which existed before the drifting sands came to this region. In certain cases the underlying rocks are of a calcareous nature, and have been eroded by subterranean waters. Where this has occurred, the pits formed in the sands have occasional *sink-holes* in their bottoms. Some scores of such openings were seen in the course of four days' journeying between Seville and Lakeland, in Polk County. It seems to me, however, that these pits are not in any measure due to the causes which produced the sink-holes. The great variety in their size, the lack of order in their disposition on the surface, as well as the chance sections afforded by railways, all indicate that the sink-holes are occasional concomitants of these depressions, and in no sense their cause. My observations show, moreover, that the sink-hole openings are often in eccentric positions in relation to the pits, in some cases being actually above the lowest point of the depression.

The gradual increase in the measure of this irregularity of the superficial sands, as we proceed from the shore towards the higher country, clearly indicates that it is due to some cause the energy of which was measured by the elevation of the surface above the sea. Moreover, the fact that these ridges lie upon subjacent rocks of somewhat varied age and composition, appears to indicate that they are not dependent on any subterranean influences, such as the erosion or corrosion of the underlying rocks.

When I first came in sight of the lake district of Florida, the immediate impression was that I had entered upon a kame district, a region of pitted plain analogous to the kame belts along the New England shore near the ancient frontal moraines, but on a far larger scale. The surface has almost exactly the topography of the central part of Nantucket, or the field of kame plain to the eastward of the Elizabeth Island moraine, where that lies at the base of Cape Cod between Wood's Hole and Sandwich. It seems to me certain that any geologist familiar with this topography would, if taken blindfolded and ignorant of his route to the lake district of Florida, at once come to the conclusion that he was in a kame district of New England. Whatever were the other circumstances under which our kames were formed, there can be little doubt that they are the product of water flowing. I have elsewhere argued that ordinary kames are in the main, if not altogether, due to the tossing about of glacial waste under the influence of strong currents pouring from beneath the glacier into a water area where mobile sediments were being laid down.

Although at first I endeavored to account for the peculiarities of the surface in this lake district on the hypothesis that the warped surface was produced by subterranean erosion, I was in the end forced to the hypothesis that these ridges represented the action of strong currents, which served to move the sands, either in air or water. I then addressed myself to the task of determining which of these two agents of transportation had given shape to the surface. I found myself quickly driven from the hypothesis that these hills were due to the action of the wind. In the first place, the gradual increase in the measure of relief, as we go from the sea to the higher lands, is obviously against the hypothesis of wind action. Next we note the fact, that on the existing coasts of Florida the dune building is slight in amount, though the sands have in many places substantially the same character as those which compose these hills. Furthermore, the shape of the hills is not that presented by any of the extensive dune districts which I have examined. Hills formed of blown sand are prevailingly sharper, and are more in alignment, than are these ridges of Central Florida. In no case known to me do they enclose such large basins as those of the Florida district. Indeed, it is rarely the case that the deposits are sufficiently dense to retain water. Last of all, the fact that these undulations generally disappear as we go to the north, gradually passing into the uniform southern plain, is against the hypothesis of their formation by wind action. There are no atmospheric circumstances which would make this central part of Florida the seat of extensive duning, while such action was absent from the northern part of the peninsula.

It appears to me that the most reasonable explanation of these tossed sands is afforded by the supposition, which is apparently justified by many facts, that the whole of Florida has recently been beneath the level of the sea, and that during this period of submergence the Gulf Stream swept across this portion of the peninsula, drifting the sands by the action of its current into this complicated topography. The recent submergence of the Floridian peninsula is indicated by the presence of this large mass of detrital deposits of Pliocene or Post-Pliocene age. At many points, as along the Indian River and elsewhere, these sands are evidently overlying deposits containing altogether living species of animals. It is clear also that these sands have not been derived from the erosion of sediments of an older date within the Florida district, but have been imported from a distance. On this and other accounts we may assume a recent submergence of the peninsula. Given this submergence without concomitant geographical changes which barred the Gulf Stream from the Gulf of Mexico, we may suppose that the great stream would have poured freely across the surface of the peninsula within the region where we find this peculiar topography. Although the Gulf Stream is confined at present within a narrow passage, where it attains a speed of about four miles an hour, and possibly owes something of its rapidity of movement to the restriction of its exit, it would doubtless, even with a larger opening, have a rate of movement sufficient to exercise considerable energy on the bottom over which it flowed, provided the floor was near the surface of the water.

Nantucket Shoals, near Cape Cod, and other similar regions of shallow sea underlaid by sand where the ocean has moderate tidal currents, show us that a topography in a general way like this of the lake district may be formed under water. The researches of the Coast Survey have shown that rapid movements of submarine sand in this district are taking place. As the currents in this district rarely have a speed greater than two or three miles an hour, it appears that the Gulf Stream may have had sufficient velocity to bring about this arrangement of the sands.

It is true that the arrangement of sands at and about Nantucket Shoals is brought about by reciprocating currents caused by the successive movements of the tide, while the movements effected by such a stream as that which flows from the Gulf of Mexico would be more constant, or in one direction. Nevertheless, it is easy to see that variations in the wind cause even at present a considerable variation in the position of the Gulf Stream off the coast of Florida. Strong winds transverse to the surface of the current affect the flow of the superficial waters, occasionally pressing them in against the shore, and again causing a southward-setting current next the beach line. It is quite possible that the variety of movements of the stream which may be necessary to produce an irregular topography have been brought about by such variations in direction and force of the wind.

The greatest difficulty I find in accounting for the topography of the lake district is to explain the presence in the region of the large amount of sand which has been shaped into these irregular ridges and hollows. These sands have evidently come from the northward. It is not easy to imagine the way in which they could have come into the control of the Gulf Stream. One consideration, however, may aid us toward this understanding. With the northern margin of the Gulf Stream crossing Florida at the head of the present peninsula, its current would have swept against the northern shore of the Gulf of Mexico. It thus might have gained access to extensive deposits of sand, which had been accumulated in the shallows along that shore. These sands it might have borne onward until it brought them upon the Florida ridge. The existence of a similar action is found in the movement of the sands against the eastern coast since the last upheaval of the peninsula. The shore from St. Augustine has received from the floor of the Atlantic an accession of detritus accumulated on the beach which separates the main shore from the open sea. The amount of sandy matter appears equivalent to more than one twentieth of that contained in the sand-hills of the lake district. Within the limits of Florida this recently formed sand barrier has a length of about four hundred miles, and an average width of about three miles, and a probable average thickness of about one hundred feet. It is therefore equivalent to a strip having a length about twice as great as that of the lake district, and a rather greater thickness of material. As the lake district averages not more than sixty miles in width, we see that in a relatively short time, by the action of ocean waves alone, this amount of detritus has been moved. If the conditions had been such that the Gulf Stream had co-operated with the wave action, it is not improbable that we should have had a mass equivalent to all of the sands of the interior of Florida removed from the ocean floor, and brought to near the level of high tide.

If the surface of the lake district, and of Florida generally, was shaped beneath ocean waters affected by strong currents, we are compelled to believe that the elevation of the area above the sea level took place, not in a gradual manner, but with extreme suddenness, at least for all the height above the level of high tide. If the lake district had emerged from the sea by a gradual upward movement, the ocean waves would have produced a total change in the configuration of the surface; the incoherent sands of the hills would have been worn away, and moved into the hollows. The aspect of the surface would be that of sand beaches and plains extending towards the shores. If in the process of elevation there had been pauses in the movement, during which the sea even for a brief time, say for a few months, beat along a particular level, then we should have had long beach lines with inclined aprons in their fronts, such as now mark the elevated borders of our great lakes. So far, I have not been able clearly to determine the existence of such features in the Florida hilly country. At a few points indistinct signs of such action are exhibited, but the wooded and swampy condition of the country makes it difficult to trace these features. They will only become apparent, if they exist at all, on careful study of the field. My observations lead me to suppose that, if such features exist, they are very imperfectly developed, and that, if we assume this surface to have taken shape under water, we have likewise to assume a tolerably rapid elevation, which brought it above the level of the sea.

The problem in this field is substantially like that which we have in the kame districts along the southern shore of New England. I have elsewhere endeavored to show that these forms were clearly formed beneath the surface of the sea, and came above it by a movement so speedy that in the case of Nantucket the most delicate heaps of sand were not disturbed by the ocean surges.

In the present state of my inquiries concerning the recent movements on the eastern shore of North America, the evidence from the kame district and that from the lake district of Florida appear alike to point to the conclusion that a sudden elevation, or a series of such movements, took place during the present geological period, a movement which must be deemed in its nature paroxysmal. It therefore becomes necessary to make a very careful inquiry into the value of the evidence which this case affords as to the speed with which these changes of level were brought about. This problem should be considered by many field geologists. It cannot adequately be solved by one student. On this account, I venture to present the arguments in the case of the Florida lake district, with the hope that they may be carefully reviewed by other students.

NOTE.

THE discovery by Professor Shaler of the northern extension of the great Florida Reef beyond Key Biscayne, on the east shore of the southern extremity of Florida, as far as Jupiter Inlet, throws a good deal of light on the probable mode of formation of the Everglades. An examination of the map of Southern Florida in the Memoirs of the Museum of Comparative Zoölogy, Vol. VII., No. 1, Plate XXIII., or of the map (Plate VI.) in my Memoir on the Tortugas, Memoirs of the American Academy, Vol. XI., 1883, or in the "Three Cruises of the Blake," page 52, shows that in all probability the process of land-making is simply more advanced in the Everglades than in the triangular stretch of mud flats extending westward from the northern keys of Florida beyond Cape Sable, and from that base in a general southwesterly direction to the Marquesas. The presence of fossil reefs more or less concentric with the line of keys induced Professor Agassiz,[1] in his Report on the Florida Reefs, to look upon the Everglades as holding to those reefs very much the same relation which the mud flats to the west of the main line of reefs hold to the latter.

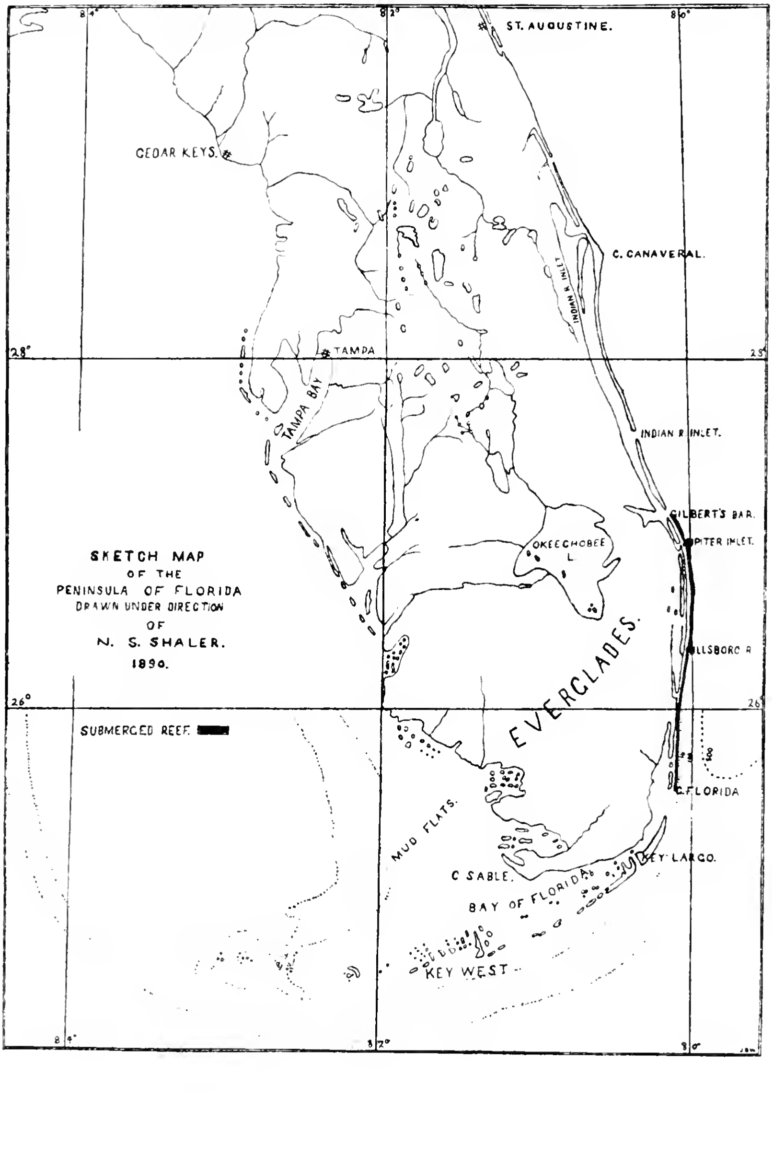
Geologists [2] have, as a general rule, been opposed to this view, but they have only examined the mainland north of the Everglades, and no geologist has as yet penetrated farther into the Everglades than Professor Agassiz and his party. A careful examination of the Everglades alone can determine whether their fossil reefs are built upon a base consisting of the rocks which have been examined by Tuomey and others at Tampa Bay and Charlotte Harbor, or whether

[1] Annual Report of the Superintendent of the Coast Survey, 1851. Report on the Florida Reefs, by Louis Agassiz. Memoirs of the Museum of Comparative Zoölogy, Vol. VII. No. 1, 1880, pp. 31, 57.

[2] Report of Buckingham Smith on the Drainage of the Everglades. Heilprin, Trans. Wagner Free Institute of Science, Vol. I., May, 1887. Heilprin's explorations were limited to the portions of the west coast of Florida included between Cedar Keys and Punta Rassa, and did not touch the Everglade district or the great Florida Reef. Likewise, the earlier researches of Conrad and Tuomey, and the subsequent ones of Smith, Dall, and others, have all stopped short at the Everglades, and the structure of the northern extremity of Florida has nothing whatever to do with the formation of the coral reefs from Key Biscayne south. How far north this reef structure extends is another point, and Shaler's interesting discovery goes far towards giving us a clue to the mode of formation of the Everglades. That the northern part of the peninsula of Florida is not made up of concentric coral reefs is now very clearly demonstrated by geological and palæontological evidence. What is the southern extension of the formations which extend to the northern edge of the Everglades, no one knows as yet.

the outcrops of these fossil reefs at the southern extremity of the Everglades are only outlyers of the southern extension of these northern rocks. To the damming up of the waters in the Everglades, and to the sudden outbursts of gigantic masses of water charged with organic matter and lime, we may trace the immense destruction of fishes which so frequently occurs on the shores of the Florida keys and the waters surrounding them.

ALEXANDER AGASSIZ.



SKETCH MAP
OF THE
PENINSULA OF FLORIDA
DRAWN UNDER DIRECTION
OF
N. S. SHALER.
1890.
SUBMERGED REEF
ST. AUGUSTINE.
CEDAR KEYS.
C. CANAVERAL.
INDIAN R. INLET
TAMPA
TAMPA BAY
INDIAN R INLET.
GILBERT'S BAR.
OKEECHOBEE L
EVERGLADES.
C. FLORIDA
MUD FLATS.
KEY LARGO.
C SABLE.
BAY OF FLORIDA
KEY WEST
28°
26°
84°
82°
80°

No. 8. — *Contributions from the Petrographical Laboratory of the Harvard University Museum.*

II.

On some Occurrences of Ottrelite and Ilmenite Schist in New England.

By J. E. Wolff.

In the series of metamorphosed sediments which, in the many localities, represent nearly every geological horizon, a wide-spread type of rocks are characterized by their fine grain, glistening micaceous aspect, and perfection of cleavage, to which the names of phyllite, micaceous slate, argillaceous mica schist, etc. have been applied. They represent original fine-grained argillaceous sediments, in which the metamorphic development of new minerals combined with the production of cleavage has partially or totally changed the original character. These rocks frequently attract attention by the presence of porphyritic, more or less perfectly shaped crystals, scattered through the fine-grained micaceous paste, which, unlike the analogous crystals of porphyritic eruptive rocks, appear to have formed *later* than the "groundmass." Garnet, biotite, andalusite (chiastolite), staurolite, albite, magnetite, ilmenite, and minerals of the ottrelite group, occur in this way. In this paper some notes are presented on schists or phyllites containing ottrelite or ilmenite plates.

Ottrelite or chloritoid schists of Archean, Cambrian, Carboniferous, and perhaps of later age, have been described from numerous localities in Europe. The Cambrian phyllites of the Ardennes, among which the classical ottrelite schists occur, have undergone a thorough chemical and microscopical investigation by M. Renard.[1] One of these rocks is of particular interest in this connection, namely, the "Phyllade à ilmenite des Forges de la Commune." The bluish gray rock contains numerous small glittering metallic plates which can easily be mistaken for ottrelite; in the section they are transparent on the thin edge, with a brown color,

[1] Bull. Mus. R. Hist. Nat. Belg., Vol I pp. 212-219. Vol. II pp 127-152. Vol III. pp. 84, 85, 230-268

and are bordered by a fringe of sericite. The optical examination combined with chemical analysis led M. Renard to identify these plates finally as ilmenite. In another rock (Phyllite ottrelitifère de Monthermé) they occur with ottrelite. These metallic plates had been observed elsewhere by M. Renard and others, but their true nature not determined.

Minerals of the ottrelite family ("phyllite," chloritoid, masonite, etc.) have been described from the rocks of New England by various mineralogists, and by T. Sterry Hunt from the palæozoic schists of Canada. The occurrence of this mineral in Maryland, in phyllite, has recently been mentioned by G. H. Williams.[1]

In the complex of gneisses, schists, and massive crystalline rocks which cover the larger part of New England, there are certain areas of partially altered sediments, the palæozoic age of which has been established by fossils or stratigraphic considerations. One of the most important of these is the strip forming the western edge of the Green Mountains, which has been proved by the labors of Dana, Wing, Walcott, and others to belong to the Cambrian and succeeding periods of the Palæozoic. These "Taconic rocks" consist of quartzites, crystalline limestone, phyllites of various kinds, and fine-grained gneisses, with occasional conglomerates, especially near the base. That a large part of the more highly crystalline rocks to the eastward, in Massachusetts at least, represent the same series still further metamorphosed, appears to definitely result from the work of the United States Geological Survey done under the direction of Professor Pumpelly, now going to press.

Another important area of metamorphosed palæozoic sediments occurs in the eastern part of Rhode Island, on the shores of Narragansett Bay, extending northward into Southern Massachusetts; it is of Carboniferous age. The rocks are conglomerates, coal-beds, shales and schists of various kinds, which like the Cambrian rocks of the Green Mountains are intensely crumpled and metamorphosed.

There are two well-known localities for ottrelite in or near this region: one that of the Masonite from Natic, R. I., described by Jackson[2] in garnetiferous mica schist which occurred as glacial boulders, the other that of the ottrelite (Newportite) from the vicinity of Newport, R. I. Mr. T. N. Dale says of this occurrence, "Boulders and pebbles of ottrelite schist abound about Newport, but I have failed to

[1] Johns Hopkins Univ. Circulars, September, 1889.

[2] Geology of Rhode Island, 1840, p. 47.

find any outcrop of it."[1] The carboniferous schists abound in little black metallic plates which resemble ottrelite, so that the rock may have been mistaken for ottrelite schist; but since pebbles of this rock are associated with pebbles of the true ottrelite schist, there is little reason to doubt that the latter occurs in place in the vicinity, and probably of Carboniferous age.[2]

Ottrelite Schist. — The ottrelite schist here described was collected by Mr. Dale, occurring as pebbles on Easton's Beach, Newport. The rock is a silvery-gray, fine-grained mica schist, which has a well marked schistosity (and cleavage), the plane of which bears no relation to the distribution of the ottrelite. This mineral occurs in the well known rhomboid or irregular plates, three or four millimeters in diameter, with brilliant lustre and well marked cleavage surfaces. The latter are pitted with little dull spots, which it is seen in the slide are grains of quartz enclosed by the crystal.

Studied in the thin section, the rock is found to be composed of little rounded grains of quartz, closely interlocking, when not separated by the other constituents, and of minute scales of colorless mica with the optical properties of muscovite, which by their parallel arrangement cause the schistosity of the rock. Certain wavy lines oblique to this structure, which contain less mica and more quartz than the average, may represent the original plane of deposition. A darker variety of the rock contains occasional small plates of chlorite and bands of opaque black substances, which are mixtures of graphite and titaniferous iron ore (ilmenite?) for the powdered rock gives a strong test for titanium and also for graphite.

The ottrelite crystals and somewhat smaller black metallic plates are seen to have no connection with either the plane of schistosity or possible deposition plane. The former mineral occurs in plates of irregular outline, appearing as lathe-shaped cross-sections, frequently twinned several times, with composition parallel to the base, blue and greenish pleochroism, and the other usual optical properties. They are generally filled with little grains of quartz of the same size and shape as those composing the rock outside, which were evidently enclosed by the crystal as it formed; it is noticeable that the muscovite never accom-

[1] A contribution to the Geology of Rhode Island, Am. Journ. Sci., Vol. XXVII. p. 222.

[2] Mr. Dale has found ottrelite schist in place on Conanicut Island, opposite Newport, but the rock has not been examined microscopically. Proceedings of Canadian Institute, 1884–85, p. 21.

panies the quartz in the ottrelite, but buts against the edge of the crystal without altering its character or arrangement in proximity to it. Sometimes the quartz grains fill the interior of the ottrelite in hour-glass shape, but this form has no connection with twinning as in the case figured by Rosenbusch (Mik. Physiog., Vol. I. Plate XXII. Fig. 6), but is evidently a case of crystal growth analogous to the forms so well known in the augites of some eruptive rocks: a skeleton crystal of ottrelite first formed, which did not enclose or else assimilated the quartz, while a later growth, which filled out the double funnel-shaped cavity, was able or obliged to enclose it. In the rock next to be described there are skeleton crystals of ottrelite only partially filled up with the quartz-bearing mineral.

The black plates in this rock are somewhat smaller than those of ottrelite, with a jagged outline. They have sometimes a spindle-shaped cross-section, indicating then that they are discoid, but are generally bounded by straight parallel lines; they are not transparent, but have frequently a yellow leucoxene core, indicating titaniferous iron ore. There is no doubt that they are ilmenite, as determined by M. Renard in the similar rocks of the Ardennes.[1]

These ilmenite plates are generally bordered on both sides by a thin sheet of chlorite, the base of which is parallel to the ilmenite. (The similar ilmenite plates described by M. Renard are bordered by sericite.) The plates are often entirely enclosed in the ottrelite crystals, sometimes one half in, the other half projecting out. The chlorite coating disappears when they are found in the ottrelite, but they are then sometimes bordered by a zone of ottrelite free from quartz inclusions, unlike the rest of the crystal, of the same size and shape as the chlorite, suggesting that the latter was absorbed into the ottrelite when the crystallization took place. Small grains of titanite mixed with black ore are scattered through the rock, and there are occasional prisms of tourmaline.

Ottrelite Graywacke. — This interesting rock was found by Mr. Dale in a glacial boulder at "Paradise," Newport, R. I.

The rock contains fragments of blue and white quartz, enclosed in a dark gray micaceous cement, spangled with small plates of ottrelite.

The slides show that the rock has undergone intense dynamometamorphic action; the large fragments of clastic quartz in polarized light exhibit all stages of change from mere straining to breaking and

[1] He mentions the occurrence of these forms in Rhode Island ottrelite schist.

crushing, and at the edges have yielded small broken quartz, which is mingled with the muscovite of the cement. The latter is made up of fragments of detrital quartz, quartz derived from the crushing of the large fragments, and perhaps some quartz formed chemically *in situ*, with muscovite filling the interstices, and even filling the cracks made in the large grains, and therefore evidently of metamorphic origin. There are also larger fragments of quartzite, and rounded aggregates of quartz and muscovite, which represent decomposed clastic feldspar grains.

The ottrelite occurs in this cement in plates of irregular shape, often moulding itself around or enclosing the grains of quartz. It has all the optical properties of the ottrelite described above, and also encloses the quartz grains of the cement, but not the muscovite, and very rarely exhibits the least bending or straining; hence it must have formed after the crushing forces had ceased to act. There are sometimes skeleton crystals of ottrelite, the hollow having the shape of an hour-glass, and transitions to crystals in which the hollow is filled up by ottrelite enclosing quartz. The cement also contains the black metallic plates, small and imperfect, which are sometimes enclosed in the ottrelite.

We may conclude from the microscopic study of these rocks that the ottrelite was the last mineral to form in them: it encloses the grains of quartz of the cement, both when they are easily recognized as clastic in the grauwacke and when of doubtful origin in the fine-grained schist. The muscovite, which is evidently a metamorphic mineral in both rocks, formed before the ottrelite, although not enclosed in it, for in position and arrangement it is not affected by the latter, and it seems necessary to suppose a chemical solution of the muscovite which filled the space between the quartz grains at the time the ottrelite came to fill that space. The ilmenite-chlorite plates also formed before the ottrelite, since they are enclosed in it.

In the grauwacke the muscovite is found penetrating the crushed pebbles of quartz along the cracks, and even penetrating into the substance of the quartz a minute distance where there is no visible break, indicating a marked mobility for the solution from which this mineral formed. The ottrelite, on the other hand, forms in comparatively large unbroken areas enclosing the other minerals, somewhat analogous to a concretionary formation. Such an ottrelite grauwacke illustrates anew the position of ottrelite in the scale of metamorphism, occurring, as it does often, in or associated with rocks that retain at least a part of their original characters. Its late formation in the rock, posterior to quartz, ilmenite, muscovite, etc., may indicate a higher degree of metamorphism than those minerals alone would do, or the presence of some special geological or chemical conditions, to which we have as yet no clue.

Graphite Schist with Ilmenite Plates. — This rock occurs as a boulder on Miantonomah Hill, Newport, R. I., and contains plant impressions (Dale).

It is a soft black graphite schist, containing irregular metallic plates resembling ottrelite, which are two or three millimeters long and 0.12 mm. thick. These plates can easily be split off with a knife, leaving a dull film of chlorite below them. They are imperceptibly magnetic, are attacked with great difficulty by boiling hydrochloric acid, and the yellow solution gives a strong titanium test with tin-foil; they are therefore *ilmenite.* In the slides the rock is composed of small grains of quartz, flakes of muscovite and chlorite, and specks of graphite and iron ore (probably ilmenite). The large ilmenite plates have frequently a spindle-shaped cross-section (i. e. discoid plates), and have a kernel of leucoxene (titanite). Some are bordered on each side by a thin plate of chlorite, some by brilliantly polarizing muscovite. The rock is evidently of Carboniferous age.

Occurrences of minerals of the ottrelite group in the region of schists and gneisses of Central and Western Massachusetts are mentioned in mineralogies, but the writer has found no microscopical descriptions of the rocks. A part of the so called ottrelite schists, such as the "spangled mica-slate" of Hitchcock (Geology of Massachusetts) are probably ilmenite schists.

In the Western or Green Mountain region, ottrelite and ilmenite plates occur in schists or phyllites investigated by the writer for the U. S. Geological Survey, both in specimens collected by Mr. T. N. Dale from the Western Cambrian (or younger) rocks (Taconic region), and also from the Cambrian series of Hoosac Mountain in the axis of the Green Mountains, full descriptions of which will appear in the forthcoming memoir.

The ottrelite schist of Hoosac Mountain occurs in several places in the albite-phyllite series which overlies the basal Cambrian conglomerate. The ottrelite rock is a silvery greenish schist, containing crystals of red garnet and small prisms of tourmaline, and spotted with plates of ottrelite. In the slides the rock is composed of muscovite (sericite) in the usual interwoven aggregates, irregular plates of chlorite, grains of quartz, occasional crystals of albite and the ottrelite, in small irregular plates with the usual pleochroism, etc., which sometimes appear spindle-shaped in cross-section (discoid). Small, irregular black metallic plates also occur in the rock.

The Taconic region of Greylock Mountain, the highest summit in Massachusetts, lies immediately west of the Hoosac series, extending west in turn to the Taconic range, which forms the boundary between New York and Massachusetts. The rocks of this area are in large part phyllites of many varieties and colors, often dotted with crystals of albite like the similar rock of Hoosac Mountain, containing garnets, tourmaline, etc. The black metallic plates are wide-spread in these phyllites, exhibit the same properties, such as very feeble magnetism, difficult solubility in hydrochloric acid, presence of titanium, etc., that those from the Rhode Island graphite schists do ; they are therefore *ilmenite.*

In the slides these rocks are composed of sericite, generally intimately interwoven with chlorite, and small grains of quartz. Masses of black ore, prisms of rutile, etc., are abundant. In some varieties the albitic feldspar becomes an essential constituent. The ilmenite plates are commonly sandwiched between two plates of dark green chlorite, exactly as in the Rhode Island rocks. In many of these rocks microscopic plates of ottrelite, spindle-shaped in cross-section, exist enclosed in the meshes of the mica.

April, 1890.

No. 9. — *Contributions from the Petrographical Laboratory of the Harvard University Museum.*

III.

On Keratophyre from Marblehead Neck, Massachusetts.

By John H. Sears.

This interesting rock formation was first noticed by Prof. W. O. Crosby in the American Naturalist (Vol. XI. No. 10, 1877, p. 585), where he says: " Near the middle of the southwest side of the harbor, visible only at low tide, is a hard, whitish, fine-grained sandstone or arenaceous slate. It overlies unconformably the banded petrosilex found on the shore." In the " Occasional Papers of the Boston Society of Natural History, III. Contributions to the Geology of Eastern Massachusetts," Professor Crosby says again of Marblehead Neck (p. 263): " It is not generally known that this rocky peninsula, which may be regarded as lying on the extreme outskirts of the Boston Basin, includes beds probably referable to the same horizon as the slate and conglomerate on the south and west. Briefly stated the facts are as follows: Near the middle of the northwest shore of the Neck, visible only at low tide, is a hard, whitish, fine-grained sandstone or arenaceous slate; it is evidently largely feldspathic and turns yellowish on weathering. Porphyritically interspersed through the rock are clear, almost transparent, rhomboidal crystals, from one eighth to one fourth of an inch long; these have been examined by Miss Hattie A. Walker and proved to be orthoclase."

The next notice of this rock is in the Proceedings of the Boston Society of Natural History (Vol. XXI. Part 3, p. 288), "On the Trachyte of Marblehead Neck," by Dr. M. E. Wadsworth, in which he says, " Near Boden's Point, on the northwest shore of Marblehead Neck, there is to be seen, exposed between high and low tide, the remains of a trachytic overflow." On page 290, Dr. Wadsworth says: " One of the feldspars, porphyritically enclosed in the groundmass, was obtained in the section. This is clear, glassy, and contains only a slight amount of the groundmass and a few full fluid cavities. It is a simple crystal of sanidin."

Dr. Wadsworth's field-work upon this formation was very thorough, and but little is required in addition to his clear description of it. A few notes, however, taken from his description and the observations of the writer, may be of interest. This formation, now determined to be keratophyre, can be seen at low tide near the residence of Mrs. Harding on Boden's Point, Marblehead Neck. It appears as the much eroded remains of a surface flow, and extends two hundred yards in a north-easterly direction, with a width of sixty feet at the lowest point of observation. There are smaller masses of this rock three hundred yards from this point in the same strike (northeast), which are exposed only at extremely low tides. About five hundred yards south of Boden's Point, near Flying Point, the eruptive granite cuts the metamorphic slate of the Boston Basin series, and near this point also the granite is cut by dikes of quartz-porphyry (felsite). Near the keratophyre, and dipping under it, is a banded felsite. Both the granite and the felsite are cut by diabase dikes. The felsite tends to the northeast, and forms the larger portion of the bed rock of the Neck. The banding of this felsite dips towards the harbor nearly north, and lying upon it is the keratophyre. Between the lowest points of observation and the banded felsite, a conglomerate of varying thickness composed of fine felsitic débris, holding rounded and angular fragments of the felsite, is found in several places enclosed in the keratophyre. In some places the keratophyre rests directly upon the felsite, while in others the conglomerate intervenes between them. The line of contact between the keratophyre and the felsite débris is well marked; specimens of the keratophyre detached at this point show a basal surface very rough and pitted where it conforms to the irregularities of the conglomerate. The keratophyre, being exposed to the sun, rain, and the action of the frost and the ocean waves, is much decomposed on the surface; but the least altered specimens obtained are of a brownish or bluish gray color, having a conchoidal fracture and a compact groundmass, holding, occasionally, large glassy crystals of anorthoclase, some of which are one fourth of an inch in length, and, rarely, plates of biotite. The groundmass in thin section under the microscope is shown to be filled with lath-shaped feldspar crystals, which are somewhat decomposed. The base is an earthy kaolinized mass, with irregular masses of quartz and earthy limonite.

Dr. Wadsworth described the rock from microscopical study as consisting of a groundmass composed of ledge-formed crystals of feldspar, either in single crystals or simple twins, which had the optical properties of orthoclase (although some might be triclinic) and enclosed between them varying amounts of a decomposed base, and of quartz which he regarded as secondary. The porphyritic crystals were determined as orthoclase (sanidin). The rock varied considerably in freshness in the several specimens. This rock, occurring thus as a surface flow, was called "Trachyte" under the classification used by Dr. Wadsworth, corresponding in this case to the "Quartzless Porphyry" of Rosenbusch.

During the season of 1889–90 eight sections of the keratophyre and several sections of the detached anorthoclase crystals have been prepared for microscopic study. Numerous crystals from the groundmass have also been detached for the purpose of obtaining the specific gravity and chemical analysis. Biotite mica is often found in hand specimens, and occasionally augite, although the latter has not as yet been detected in any of the sections cut.

In the light of our present knowledge and with further investigation it is possible to supplement Dr. Wadsworth's accurate descriptions, and to determine the feldspar phenocrysts as *anorthoclase*, and the rock as a *keratophyre*. The phenocrysts occur as crystals elongated parallel to $\breve{a}$, with a square cross-section owing to the presence of the base and brachypinacoid; in addition to the two cleavages there is a rough transverse fissuring. The crystals are quite glassy when fresh. In the rock slides, in polarized light, the different feldspar sections show marked optical peculiarities; there is often a very fine single, or double (microcline) twinning; sometimes the whole of one section of the mineral consists of irregular areas not extinguishing in common, which resemble the phenomena produced by mechanical causes; these areas contain very fine lines crossing each other at various angles in the different areas; in other cases there is a very fine zonal structure. Sections prepared parallel to the base show this fine irregular double twinning, and give an extinction 1° to 2° oblique to the line of the second cleavage (∞ P $\breve{\infty}$), and sections parallel to the latter cleavage give an extinction about 9° oblique to the line of the first cleavage, with an obtuse positive bisectrix about perpendicular to the face, the acute bisectrix a making the angle of 9° with the basal cleavage. These sections also show sometimes a very fine indistinct microperthite striation. The angle between the two cleavages was determined in the reflecting goniometer as approximately 89° 12′, about that of microline. The specific gravity of fragments, determined by Westphal balance and Thoulet solution, was between 2.570 and 2.572.

The following analyses of the feldspar (I.) and the rock (II.) were made in the laboratory of the U. S. Geological Survey at Washington by Dr. Thomas Chatard.

	I. Feldspar.	II. Keratophyre.
H_2O at 110° C.	.04	.91
H_2O at red heat	.37	1.28
SiO_2	65.66	70.23
TiO_2*	. . .	.03 ?
P_2O_5	. . .	.06
Al_2O_3	20.05	15.00
Fe_2O_3	traces	1.99
FeO	traces	
MnO	.13	.24
CaO	.67	.33
MgO	18	.38
K_2O	6.98	4.99
Na_2O	6.56	4.98

	III. Gmelin, No. 1.	IV. No. 2.
SiO_2	65.90	65.19
Al_2O_3	19.46	19.99
Fe_2O_3	.41	.63
CaO	.28	.48
MgO		
K_2O	6.55	7.03
Na_2O	6.14	7.08
H_2O	.12	.34

Specific gravity 2.587.

It is evident from the analysis and optical properties that this is a triclinic soda-potash feldspar of remarkable purity, and very evenly balanced percentages of Na and K, belonging to the anorthoclase group of Rosenbusch. For comparison, analyses (III. and IV.) by Gmelin are appended of anorthoclase from the augite syenite of Norway (Brog-

* The TiO_2 was not very pure, and its presence is not absolutely certain.

ger, "Die Sil. Etagen 2 und 3," etc., p. 261). In the rock as a whole the same even balance between Na and K is noticeable, and the insignificant quantity of lime and magnesia. Allowing for the free quartz, base, and decomposition products as causing a relative increase of silica and iron and decrease of the alumina and alkalies, it is evident that the feldspars of the groundmass are closely allied chemically to the porphyritic crystals, and are probably also anorthoclase. The rock is therefore a very pure type of keratophyre.

The microscopical structure of the sections made are as follows: —

No. 21. Keratophyre with anorthoclase crystal cut obliquely to an optic axis. Groundmass made up of minute twinned lath-shaped crystals of feldspar, somewhat kaolinized, some quartz, and an earthy fibrous kaolinized base. In the centre of the porphyritic feldspar crystal are numerous microliths and a few ferritic masses, similar to and probably composed of the base, which penetrates the edges of the crystal.

No. 21 A. Keratophyre and an aggregate of the porphyritic crystals. Groundmass nearly as in No. 21. One of the phenocrysts shows twinning after the Carlsbad type.

No. 21 B. Keratophyre with one porphyritically enclosed crystal. The crystal is cut nearly parallel to the second cleavage, and gives an almost perfect interference figure of the positive bisectrix. The basal cleavage is well developed, and the striæ, or fine twinning, are well marked in polarized light The groundmass is more generally composed of the minute lath-shaped feldspar crystals, some of which are clearly twinned anorthoclase of the same form as the larger crystals. There are also small patches of quartz.

No. 21 C. Keratophyre with one large porphyritic feldspar crystal cut obliquely to the brachydiagonal, which in polarized light shows a microperthitic intergrowth and a very perfect example of fine and interrupted twinning. Through the crystal are several fluid cavities and a few microliths of a reddish color. The groundmass is more kaolinized, and the minute lath-shaped crystals are less distinct. Small irregular masses of quartz and considerable limonite and earthy matter pervade this section.

No. 21 D. Keratophyre section cut across a joint plane which is filled with vein quartz; numerous irregular patches of quartz are scattered all through the section. One mass is a basal section of original (?) quartz; it gives the uniaxial cross, and is shown to be positive by the mica plate. Some scales of biotite and numerous small grains of magnetite are seen in the groundmass, which is composed of a fibrous feebly polarizing kaolinized mass of the decomposed minute lath-shaped feldspar crystals. One of the enclosed phenocrysts cut nearly parallel to the base shows numerous microlithic inclusions, and several fluid cavities in which the bubble movement is seen The outer edge is deeply penetrated by the groundmass

The occurrence of this keratophyre as a surface flow in close proximity to the large intrusive masses of elæolite- sodalite- zircon-syenite of Salem Neck and the islands in Salem Harbor, and the augite- zircon-syenite of Marblehead and the Beverly shore, is interesting, as showing the various forms assumed here by the alkaline magmas under different geological conditions or at different periods.

June, 1890.

No. 10. — *Metamorphism of Clastic Feldspar in Conglomerate Schist.* By J. E. Wolff.

In the complex of metamorphic rocks which occupy the region of the Green Mountains in Western New England, two rocks are of importance from their wide distribution in Vermont and Massachusetts, and their striking appearance. These are the metamorphic conglomerate and the albite schist.

Both rocks occur in typical development in Hoosac Mountain in Western Massachusetts, exposed to perfection both in place and in the great masses of fresh rock removed in the construction of the Hoosac Tunnel. Here the conglomerate, representing the base of the Cambrian, rests on the underlying Archæan gneiss, with peculiar relations to the latter, both as to mineralogical character and structure, whose importance, as bearing on the origin of certain crystalline schists, has recently been stated by Professor Pumpelly.[1]

This conglomerate attains a thickness of six to seven hundred feet, and is then overlaid conformably by the second rock, the albite schist, possessing a great but as yet undetermined thickness.

Detailed geological and petrographical descriptions of these rocks will appear elsewhere, and are not presented here; but the truly detrital character of the conglomerate should be stated, containing as it does true pebbles of quartz, feldspar, gneiss, or granite in a thoroughly crystalline matrix, and also the necessary detrital origin of the conformable albite schist, now entirely crystalline. The latter rock is not confined to the axis of the Green Mountains, but occurs abundantly in the fossiliferous "Taconic" region immediately west, associated with limestones, quartzites, and finer-grained schists or phyllites. The albite occurs in irregular porphyritic grains of variable size, dotting the rock with its glassy crystals, often twinned in two simple halves according to the albite law. In thin sections it is strikingly clear and fresh, containing in the different specimens inclusions of muscovite, biotite, or chlorite, grains of quartz, grains or crystals of magnetite, epidote, rutile, etc., which are so

[1] The Relation of Secular Rock-Disintegration to certain Transitional Crystalline Schists. Bull. Geol. Soc. Am., Vol. II. pp. 209–224.

similar in character and arrangement to the same minerals outside that we have to suppose they were all formed together where we now find them. This is the well known character of these pseudo-porphyritic feldspars in phyllite-gneiss or feldspar-phyllite in general, and in the present case their character as albite has been proved by chemical and optical analysis. That they should have some connection with the grains of true detrital feldspar found in the less metamorphosed phyllites of this region is easy to see, but difficult to prove.

It should be mentioned that the Hoosac conglomerate in its fine schistose portions contains little glassy feldspars with albitic characters.

This conglomerate occurs at intervals for more than a hundred miles to the north, well into the centre of Vermont, lying between the Cambrian quartzite of the Taconic region and the underlying gneisses on the east.

One of the most striking localities is on Bear Mountain in Wallingford, a few miles southeast of Rutland, Vermont, which was described and figured in the "Geology of Vermont," Volume I. pages 32 and 34. The conglomerate character is exhibited in wonderful perfection, the pebbles varying from almost boulder size to that of the grains of the finest sandstone. They are principally quartz (often blue) and feldspar; the latter are generally of a dull white or reddish color, due to kaolinization. One of the large feldspars, tested by the ordinary methods, proved to be microcline. In the Hoosac conglomerate this feldspar also occurs in the pebbles and in the underlying coarse gneiss from which they were derived. In the finer grained layers of the Bear Mountain rock the cement predominates, so that the rock is a crystalline schist containing little pea-sized angular grains of quartz and feldspar. This cement rock here and at other localities glitters with small glassy feldspars, as does the albite schist of Hoosac Tunnel.

In the finer grained portions of this conglomerate schist the detrital feldspars show interesting changes, which may throw some light on the formation of albite schists. The descriptions which follow are based on material from one hand specimen, so that it will be understood that the changes observed are progressive only by comparison, feldspars side by side having been affected to a varying degree by the forces of metamorphism, obliterating partially or else completely the original characters.

In the hand specimen the rock is a silvery green schist, the color due to large scales of a light green muscovite, which are arranged in parallel layers, and enclose between the meshes little elongated masses of quartz, and little glassy feldspars, which are barely visible with the lens. Grains of dull reddish or white feldspar and of blue quartz are evenly distributed through the rock. The quartz grains predominate, having their longer axes parallel to the schistosity, and often forming the cores of the lenticular bands of quartz. These quartz grains average the size of small shot, while the feldspars vary from the size of a large pea to that of the smallest shot.

The feldspars are often distinctly angular in shape. Even with the unaided eye it is seen that they have a rim of clear glassy feldspar surrounding the inner dull red or white core, the latter sometimes preserving its boundary, made by straight lines or sharp angles, the former having a ragged edge which merges imperceptibly into the cement. In other cases the clear rim, instead of representing only a small proportion of the diameter of the feldspar, occupies half or more of the whole grain, and little tongues of the clear substance then ramify into and across the red core. The shape of these feldspars and their occurrence with the larger feldspar pebbles of the coarse conglomerate make their detrital character evident. The same is true of the grains of blue quartz.

Small prisms of tourmaline, octahedra of magnetite, and rare grains of apatite, occur as accessories.

In the slides these elements are easily recognized. The mica is entirely a greenish yellow muscovite in thick plates, which in the thicker slides exhibits a pleochroism varying from yellowish green to colorless, is free from inclusions excepting a rare grain of magnetite and of titanite (?), and has the large axial angle of muscovite. The clastic grains of quartz are recognized by their large size, and by the fact that in polarized light they are seen to have been strained, this effect increasing until some grains pass into a peripheral cataclastic mosaic of quartz grains produced from the original grain by crushing, between which flakes of muscovite make their appearance. Quartz also occurs abundantly in the meshes of the mica, in aggregates of interlocking grains, which sometimes enclose muscovite, and hence must have formed by chemical action *in situ*.

Here and there little areas of clear feldspar occur, evidently the little glassy crystals of the hand specimen. They often have a lenticular form, flattened parallel to the schistosity of the rock, and the inclusions which they commonly contain have their longer axes parallel to this direction, and are distributed in rough parallelism to the same direction. The inclusions consist of little flakes of muscovite and round or elongated grains of quartz and of magnetite. One of these feldspars is represented in Figure 8 with black inclusions of magnetite and clear ones of quartz and muscovite, and having the typical irregular flattened shape. The feldspars of this type have a low even polarization tint, yellow of the lower order even in thicker slides, where other feldspars show red and blue. Often without twinning, or else twinned in single halves, less frequently multiple twinned with few lamellæ, they have the characters of the albite of the schists. Some of these areas of glassy feldspar with the same general characters show the double twinning of microcline.

A variety of these feldspars is seen in Figure 7, which, having the same flattened irregular shape, with inclusions of muscovite, quartz, etc., in parallel arrangement, the same even low polarization and fresh glassy look, are clouded in the centre by an aggregate of dots which form a central area with vague boundary, but having the same polarization color as the outer area. With the high power these are seen to be fluid inclusions with moving bubble, little flakes of colorless mica or kaolin, and black opascite masses.

We now come to the clastic feldspars, which are generally larger than those just described. Figures 1 and 2 represent typical cases.

In Figure 1 the enlargement is fifty diameters. The feldspar polarizes in one low color and has a homogeneous extinction. One cleavage is well developed in the slide parallel to the short edge; the other, indistinctly parallel to the right hand edge. From the obtuse angle made by the two cleavages, it is evident that the section is oblique to the zone of either cleavage. The outer shape of the grain, as well as that of the inner cloudy portion, is evidently determined by the two cleavage lines, which is some evidence of clastic character when compared with the irregular shape of the albitic feldspars. The cloudy look of the central portion is owing to streaks of opaque kaolinized (?) feldspar containing fluid cavities, specks of black opascite, and stained by yellow limonitic products, which lie in the clear feldspar arranged parallel to the second cleavage. These are evidently areas of decomposition. As seen in the figure, these bands die out in the clear feldspar rim. The whole feldspar shows in polarized light indistinct multiple twinning parallel to the second cleavage, which runs almost to the outer boundary of the clear rim. There occur also, scattered through the central core, little brilliantly polarizing flakes of muscovite, in part arranged parallel to the first cleavage. These become less abundant, but of larger size, in the clear rim, where they are apt to arrange themselves parallel to the outer boundary; near the boundary they become still larger, and sometimes connect with the mica outside. The outside boundary of the whole feldspar, as can be seen in the figure, is irregular, the quartz grains and muscovite of the cement encroaching upon it. This is noticeable in the upper left hand corner, where a flat grain of quartz intrudes parallel to the cleavage. It cannot be determined from this oblique section to what variety of feldspar the grain belongs. The twinning excludes orthoclase; it may be microcline.

Figure 2 represents a section of another red clastic feldspar. This also polarizes as one crystal, and, as the section happens to be normal to an optic axis, it is easy to see by the position of the axial bar that the cloudy centre and clear rim are in like crystallographic position. No twinning is visible. The cleavages are not visible in the figure, although present in the section. The principal cleavage is parallel to the long dimension, and the second cleavage parallel to the narrow side of the grain; here again the outlines are determined by cleavage cracks, or by the corresponding crystallographic planes, unlike the albitic feldspars. The substance of the inner cloudy core is filled with little flakes of kaolin or muscovite arranged parallel to the second cleavage, fluid cavities, and opascite specks. Here and there is a large, brilliantly polarizing flake of muscovite. The boundary against the clear portion is generally quite sharp, and parallel to a cleavage line. The two large black cracks crossing the specimen obliquely seem to be secondary weathering cracks filled with limonitic products. In the clear rim the larger mica plates are seen here and there, arranged parallel to the edge of the crystal and to the general schistosity of the rock. The ragged form of the outer edge is very marked in comparison to the even inner boundary. The precise nature of this feldspar cannot be determined from the section.

In the case of two other clastic feldspars (not figured) the following method was employed. The rock was sawn through so as to cut the feldspar in two; from one side a thin section was made, while from the other a thin slice containing a section of the feldspar was sawn, the rock surrounding the feldspar cut away with a penknife, and the specific gravity of the fragment thus obtained determined, while a part of it was crushed on a glass slide, and the cleavage sections thus developed studied under the microscope.

The first had a Sp. Gr. of 2.585, and among the crushed material cleavage pieces with the microcline double twinning are seen. In the thin section the crystal has an elongate shape, but the general outline is much less regular than in the previous cases (see Figs. 1 and 2). The central portion has the same opaque clouded appearance, owing to fluid inclusions, plates of kaolin, and limonitic masses, but the boundary is less distinct against the clear edge, which surrounds only part of the crystal. The microcline twinning is seen in spots irregularly distributed among areas of single twinning or without visible twinning. The twinning runs into the clear feldspar rim a short distance, then dying out; this feldspar of the rim, however, does not stop at the clouded edge, but extends into the clouded portion in irregular areas, which extinguish together. Outside the entire feldspar grain, but often touching it, there are areas of fresh glassy microcline, and also aggregates of little clear feldspars in rounded grains of the albite type. Little tongues of this fresh microcline penetrate the clastic feldspar grain, and little veins of the albitic feldspar also cross its corners. Quartz grains and muscovite plates also occur isolated in the feldspar; this grain seems to be microcline associated with glassy microcline and albite, and possessing a clear boundary, which cannot be separated from areas within the cloudy portion.

The second feldspar (No. A), studied in the same way, had a Sp. Gr. of 2.578 and indistinct microcline cleavage in the powder. In the slide it shows a faint double (microcline) twinning; as before, the central part is cloudy with the little kaolin or muscovite plates arranged in parallel lines, and also fluid cavities and irregular masses of brown limonite and black iron oxide. The core is surrounded on the two long sides by a clear glassy border of feldspar, about one eighth the width of the entire grain. It has a single multiple twinning, which is parallel to and extinguishes with one of the sets of twins in the core; the boundary between the rim and core runs in a general straight direction, although jagged in detail. The rim contains flakes of muscovite, droplets of quartz, and little singly twinned albitic crystals. At one end of the grain, but outside, there occurs a large irregular area of doubly twinned microcline, fresh and glassy, and distinct from the cloudy core which it touches, the clear rim being absent. This fresh microcline, which is evidently the same as that found in isolated areas in the rock, contains mica and quartz inclusions. It extends as a vein half across the clastic grain, quartz and mica mingling with the microcline. At the opposite end of the grain a little vein starts from the outside and entirely crosses both the clear rim and the core; it is at first composed of quartz and muscovite, then in the interior it changes to glassy microcline.

This grain seems to be microcline from the specific gravity and optical tests; it has freshly formed microcline adjoining it and crossing it in veins; it has a rim of clear feldspar in optical continuity with the whole grain, containing muscovite, quartz, and albitic feldspar, which may be itself microcline.

Figures 5 and 6 illustrate the case of a clastic feldspar in which the clear feldspar rim ramifies through the grain, entirely crossing it. Figure 6 represents the left hand middle portion of the grain, which is shown entire in Figure 5. The shape is roughly trapezoidal, with an irregular edge bounded by the muscovite of the cement. The whole feldspar polarizes as a unit, but in different tints. The clear rim and the little connecting cross branches (see Fig. 6) polarize in green, while the cloudy portion polarizes in blue, the two parts passing gradually into each other. The cloudy portion with high powers is seen to be filled, as usual, with fluid inclusions, flakes of kaolin and limonitic products, which, as seen in Figure 6, are linearly arranged; in polarized light the cloudy material is seen to be arranged in spindle-shaped masses. Two black lines which in both figures occupy the centre of the clear tongues are aggregates of muscovite, which connect with that outside the grain; several smaller tongues of muscovite also run in a short distance from the outside. Here and there in the clear feldspar there are isolated large flakes or aggregates of the same mineral; minute colorless grains with high single and double refraction occur, which are probably calcite. The relations of the clear and cloudy feldspar are such that the latter occurs in little isolated areas encroached upon by the clear mineral. In one patch only, the clear feldspar shows twinning in a few isolated stripes. The cloudy portion shows none whatever, and there is no means for determining its original character, since only small residual patches remain.

In Figure 4 there is represented a small feldspar which polarizes with a low even tint, is clear and glassy throughout, contains flakes of brilliantly polarizing muscovite similar to that by which it is surrounded, and has in general all the characters of the "albitic" feldspars with this exception, that the left hand portion is cloudy; this is due to the same cause as before, namely, fluid inclusions, flakes of kaolin, and limonitic masses.

The feldspar of Figure 3 polarizes in the cloudy portion blue; in the outer clear glassy portion, a red of a higher order, the slide being thick. The cloudy and clear portions have the usual characters; the latter shows here and there a single twin lamella.

In Figure 7 a small feldspar is represented of the albite type; that is, it polarizes in an even low tint absolutely without twinning, and contains comparatively large flakes of muscovite arranged parallel to the minerals outside. The centre, however, is cloudy, owing to fluid inclusions and particles of limonitic material. Compared with the cases previously described, the cloudy area is of less importance ; it not only occupies a smaller portion of the whole grain, but the inclusions are not in such close aggregates ; there is also no difference in polarizing tint between the clear and cloudy portions.

In Figure 8, already referred to, we have the type of the pure "albite" variety of feldspar ; namely, a homogeneous area of feldspar without a linear boundary, having a somewhat longer dimension parallel to the schistosity of the rock, glassy clear, and polarizing with a low tint. In this case the black inclusions are magnetite, the others flakes of muscovite. Muscovite bounds the grain on either side.

In order to determine more accurately the nature of these feldspars, a portion of the rock was powdered and a separation of the constituents made by the Thoulet solution. From the powder thus obtained slides were prepared by scattering a little of each powder in balsam on a glass slide and cautiously grinding down to the required thinness ; the thin sections thus obtained could be examined microscopically nearly as well as in ordinary slides and with a predominance of cleavage sections. With the first falling, the muscovite, magnetite, and tourmaline came down.

Between the specific gravity of anorthite, 2.76, and that of quartz, 2.65, a little material was obtained, which was found to be feldspar and quartz weighted by mica or magnetite as impurities. At 2.65, the bulk of the powder came down, which was found to be quartz ; between this and 2.60, the lower limit of plagioclase, a considerable quantity of pure feldspar came down, which in the slides exhibited the properties of what has been described above as the albitic feldspar ; that is, the grains are untwinned or simply twinned, clear and glassy, with occasional muscovite or quartz inclusions. Sections could be found cut parallel to the basal cleavage, twinned in two single halves and giving an extinction 4° oblique to the second cleavage, while other sections cut apparently parallel to the second cleavage have an extinction 17° oblique to the first cleavage, and show a bisectrix slightly oblique. Without chemical analysis this is as complete a determination as was possible, and by Sp. Gr. and optical properties indicates *albite*. With this albite there occur some grains of a multiple twinned plagioclase, and some microcline apparently weighted by inclusions.

Another feldspathic portion of the powder was obtained between 2.60 and 2.56, and the larger portion of this was microcline. A part was of the fresh glassy variety, free from inclusions, with distinct double twinning in many of the grains, and was evidently the glassy feldspar with these properties described as occurring in the sections of the rock in little areas associated with the larger clastic feldspars, or in independent flattened areas like those of the albite. Another portion of the microcline contained fluid inclusions, mica or kaolin flakes, and masses of iron oxide, and seemed therefore to represent the clastic feldspar. Orthoclase was not identified.

The interpretation of these facts is not easy, and they do not seem to the writer quite parallel to the cases of feldspar enlargement heretofore described.

Van Hise[1] described an enlargement of clastic feldspars in certain Keweenawan sandstones in which the original orthoclase or plagioclase grain, charaterized by its kaolinization and a border of ferrite following the original rounded shape of the grain, was surrounded by a zone of clear feldspar with ragged outer edge, which extinguished with the core, and in which twinning bands were continued when present. The new feldspar was therefore crystallographically co-ordinated with the old.

In the numerous cases of feldspar enlargement in eruptive rocks described by several writers, the new feldspar sometimes extinguishes with the old, sometimes does not, and appears then to be a more or less distinct variety. Professor Judd has lately described feldspar enlargements[2] in a "labradorite-andesite," which he believes to have been formed *after* the consolidation of the rock and its alteration by weathering, the new feldspar having formed through the alteration of the glassy base. The original labradorite grain is surrounded by a clear feldspar fringe across which the twinning planes of the core are prolonged, but in which the optical constants have a different orientation, appearing to belong to a more acid feldspar. Tongues of this feldspar sometimes penetrate the old core, which is kaolinized.

Van Hise mentions the fact,[3] that in the mica gneisses of the Black Hills the only microscopic clue to clastic origin of the rocks is found in the presence of particles of iron oxide in the outer portions of the (enlarged) quartz grains, but that this is evenly distributed through the feldspar, which hence has entirely formed in place.

The feldspars described in the present paper seem to represent both this completed stage, and intermediate stages in which more or less original clastic feldspar remains.

[1] Am. Journ. Sci., Vol. XXVII. p. 399.

[2] Quart. Journ. Geol. Soc., Vol. XLV. pp. 175–186.

[3] "Pre-Cambrian Rocks of the Black Hills," Bull. Geol. Soc. America, Vol. I. p. 227.

It does not seem possible that the contrast of clouded kaolinized core and clear rim could be due to selective decomposition acting on one homogeneous grain, by which the centre was attacked, while the rim was left clear. The clastic outline of the kaolinized portion, the inclusions of mica, quartz, etc. in the clear part, showing a difference of origin, and the intricate manner in which the clear portion sometimes ramifies through the core, seem to negative this supposition.

It seems necessary to regard the kaolinization as antecedent to the formation of the clear feldspar.

What then is the relation between core and rim? In all the cases described in this paper, the two parts extinguish together, and, as in the cases described by Van Hise, seem to be crystallographically and optically continuous. Twinning sometimes runs from one to the other, sometimes dies out in the clear feldspar. In many cases, however, the polarization tint of the core is different from that of the rim, and observed with the highest powers this seems to be inherent in the feldspar of the core and not due to the visible products of kaolinization; in cases such as that of Figures 5 and 6 the kaolinized portions are simply little areas which grade imperceptibly into the clear feldspar, which permeates them in every direction. It does not seem possible to explain all these cases by mere outward growth of the feldspar grain by addition of fresh feldspar of the same species to the core; but rather by an actual replacement of the detrital core by the feldspar of the enlargement, which even in the least advanced stage in this rock has gone so far as to leave but little beyond traces of the original feldspar, and the kaolinization products. The whole series by which, if this explanation is the true one, even the kaolinization products are seen gradually to disappear, could only be described and figured here by isolated cases, although there is an intimate gradation in the slides. The smaller feldspars generally show this absorption most completely, until the perfectly clear type of Figure 8 is reached, which is undoubtedly *albite*. The feldspar of the intermediate cases has entirely similar properties aside from the presence of the fluid inclusions, kaolin, and iron oxide. In some of the larger feldspars the core is microcline, and the rim is perhaps the same (No. A) and this rim encloses small crystals of albitic feldspar and is adjacent to glassy microcline, which even penetrates the whole grain; therefore it is necessary to suppose a partial replacement of the original grain by microcline (or regeneration if the clastic grain itself was originally microcline), with enlargement and subsequent formation of microcline outside the whole enlarged grain, which had been fissured.

Both microcline and probably albite have also formed independently of any pre-existing nucleus, as far as their outline gives my clue; but in other cases, if the facts are correctly interpreted above, the albite areas owe their position to replacement and accompanying enlargement of detrital feldspar cores of undeterminable species.

It has been stated that this conglomerate of Bear Mountain passes into an albite schist in places, and that the Cambrian conglomerate of Hoosac Mountain also passes into a similar rock conformably at the top of the conglomerate series. The nature of the feldspar in the Hoosac rock and in the similar schists westward in Greylock Mountain has been proved by analysis.

In the slides of several specimens from the latter region the albites show an apparent enlargement, not uncommon in the albites of albite-phyllites in general. These albites are in large rounded grains, either simple crystals or singly twinned. Each crystal polarizes homogeneously, having a very ragged outer edge. They contain a black material disseminated through their substance, which is apparently black oxide of iron mixed with graphite; this substance is sometimes evenly disseminated through the feldspar, or may be arranged in bands, sometimes wonderfully curved. These bands may be parallel in two adjacent crystals separated by the mica of the cement, showing a formation in planes independent of the single albite crystals. Sometimes these bands occur only in the core of the crystal, and are bounded by a zone of clear albite, forming one crystal with the core. The outline of the banded core is then sharp and bounded by straight lines, producing an angular outline. In other cases the black material is irregularly disseminated through the core, but bounds it against the clear rim by a more or less continuous black line, which gives the core a rounded outline bounded by gentle curved sides, simulating quite closely the well known iron oxide bands which mark the limits of the original quartz grains in quartzites, enlarged by new silica. These are therefore apparenly enlargements of albite grains by new albite. Would it be possible instead to regard them as replacements of original feldspar grains by albite which grew beyond the limits of the original grain, did not entirely resorb the iron products, and sometimes affected their distribution by any pressure and movement which may have accompanied the chemical process by which the albite was formed?

Harvard University, June, 1891.

DESCRIPTION OF PLATES.

Reproduced by the artotype process from microphotographs in polarized light. The enlargement is given under each figure. The eight figures which are described in the text represent a partial series exhibiting the supposed progressive changes in original detrital feldspar grains until complete obliteration of the original characters is attained.

Figures 1 and 2 represent the earlier stage in undoubted clastic grains.

Figures 3, 4, 5, and 6 represent an intermediate stage. Figure 6 is the left hand central portion of Figure 5, more highly magnified, in order to show the ramification of the clear feldspar in the cloudy feldspar.

Figure 7 represents the almost completed stage, and

Figure 8 the albitic type of feldspar in which there is no trace of clastic origin.

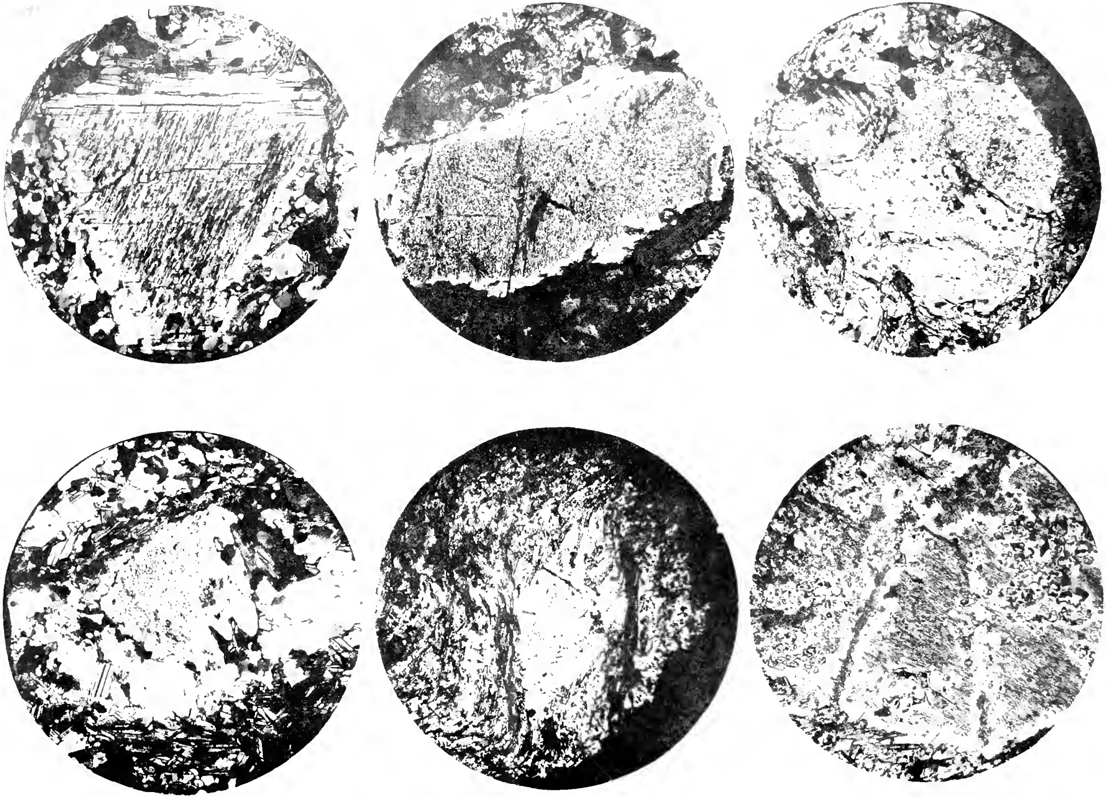


PLATE II.

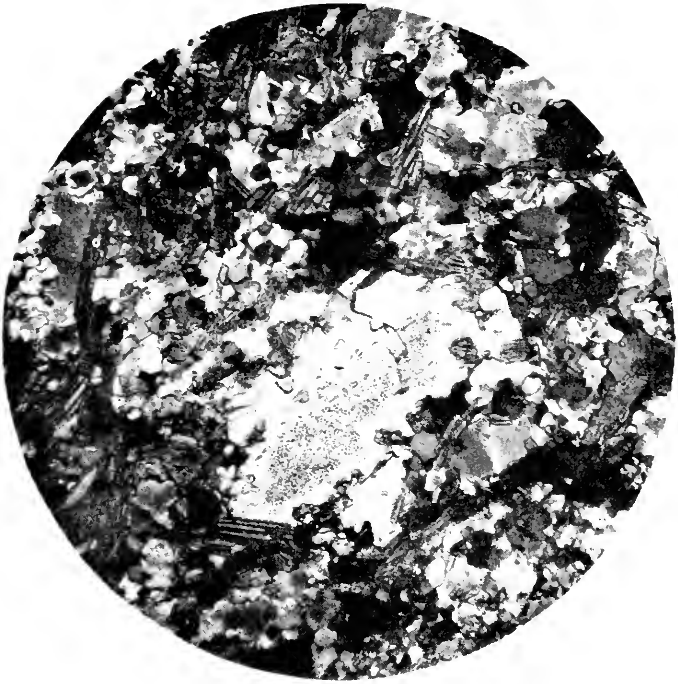


FIG. [illegible] X 46

FIG. [illegible] X 46

No. 11.—*The Conditions of Erosion beneath deep Glaciers, based upon a Study of the Boulder Train from Iron Hill, Cumberland, R. I.* By N. S. SHALER.

THE conditions which determine the erosive action effected by continental ice sheets are as yet imperfectly understood. We are not able to penetrate beneath the existing accumulations of this type; their position makes even their superficial phenomena matters of difficult inquiry. All that we can hope to ascertain concerning the work done beneath these massive glaciers must be inferred from the effects which they have exercised upon the surfaces over which they once moved and from which they have passed away.

Certain of these effects are so clearly indicated that there is no difficulty in interpreting the actions to which they were due. Others as yet remain extremely obscure. As the following inquiry was undertaken with the hope of clearing up some of these obscure problems, I shall preface this essay by a brief statement as to the present condition of our knowledge concerning certain features of the mechanical work done beneath the ice during the Glacial Period. The following described points may be regarded as fairly well established, viz.: —

1. That the continental glaciers of the last Ice Period, though they clearly moved forward in the direction of the ice front, did not always, or even generally, accumulate large bodies of morainal matter at their margins; the frontal moraines being on the whole small in amount as compared with the evident depth of the ice, and the distance over which the materials were moved.

2. That wherever the rocks over which the ice moved were of a nature to furnish hard fragments, these were plentifully removed, and the consequent erosion of the surface went forward in a tolerably rapid manner.

3. That the fragments loosened from the bed rock by the action of the glacier were often borne to a considerable distance from their points of origin, and that in this journeying the amount of erosion to which they were subjected varied greatly, some of the erratics evidently remaining in contact with the bed rock, and serving to score or abrade its

surface as they were urged forward; others were lifted into the body of the ice. Thus there were two kinds of glacial wear: the one effected by the plucking out of large fragments which separated from the matrix along the lines of fracture formed by the bed or joint planes, and the other effected by the rubbing of the bits of stone against the firm set rock or against each other.

4. That there were in certain places beneath the ice considerable streams of water moving between the overlying glacier and the firm set earth, these sub-glacial currents being in many cases competent to move large quantities of detrital materials.

The points above stated appear to me to be all which are of importance, and which have already been established in a conclusive way. The following problems as to the work done beneath glaciers seem to be worthy of consideration, and to their elucidation the matters set forth in this paper have been in the main directed.

First. As to the rate of erosion on a surface of a given hardness during the passage over it of a given length of the ice sheet.

Second. The relative amount of glacial erosion accomplished by the dragging out of fragments, and by the grinding action of such fragments upon one another and upon the bed rock.

Third. The relative distance the above named classes of detrital materials have been transported.

Fourth. The lateral dispersion of the débris on its journey from the point of origin towards the ice front.

Fifth. The relative amount of wearing of pebbles of diverse hardness in the course of their transportation.

Sixth. The effects of pressure melting on the lower lying parts of deep glaciers, and the effect of such melting if it occurs in the process of erosion.

This list by no means exhausts the catalogue of questions concerning the nature and effect of glacial movement. It contains, however, a suggestion of all the problems which it seems to me possible to deal with from the facts which are considered in this paper. In searching for a district in which to prosecute the above mentioned inquiries I sought to find a field where there should be some small, sharply limited area of rock, the material having a mineralogical character so distinct that it would not be possible to confound its waste with that from any neighboring locality. It was also necessary that the rock selected for study should be of sufficient hardness to insure it against speedy destruction in the rough conditions of glacial transportation. It is furthermore necessary that there should be a sufficient distance between the selected locality and the sea to afford a chance for the display of a bowlder trail of such length as to afford indications of value. After much preliminary search of various localities in New England, I found that the boulder train from the so called Iron Hill in Cumberland, R. I., presented by far the most satisfactory basis for the proposed study.

General Description of the Train.

The accompanying map will afford the reader a sufficient idea as to the geographical conditions of the district in which the trail from the Iron Hill lies. It will be observed that the iron deposit is situated in the town of Cumberland, which lies on the eastern margin of the valley of the Blackstone River, at a point about fifteen miles north of Providence, R. I. Although the contour map which accompanies this report, and which is reproduced from the plates prepared by the U. S. Geological Survey, will afford an excellent idea of the topography, the scale on which it is printed is somewhat smaller than is desirable for the complete display of the matter with which we have to deal. It would have been possible, from the original maps of the Survey, to have made this illustration on a more considerable scale, but the chart would have then been too large for convenient use.

It will be observed that, except for the occurrence of a few somewhat isolated hills, the reliefs of this district have no great height. They rarely, indeed, exceed one hundred feet of elevation above the neighboring valleys. For about thirteen miles from its point of origin, this glacial trail lies upon a surface of bed rock of varied hardness, which still retains in good part the topography given to it by erosive agents which operated before the advent of the last Ice Age. The boulder clay or ground moraine of which the train forms a part is, except where it crosses these ancient valleys, usually not more than ten feet thick. It is likely that in this district there may be many deep valleys in the bed rock which have been entirely effaced by the thick deposits of drift which mantle this part of the coast between Valley Falls and Aquidneck Island. On that island the bed rock is again near the surface, the drift being rather more than fifteen feet in average depth, and except next the shores, where some washed drift occurs, consisting altogether of boulder clay. In this part of its course the movement of the glacial stream which bore the material deposited in the train may have been somewhat guided by the long ridge which forms Aquidneck Island, and by the deep trough which constitutes the eastern part of the fiord known as Narragansett Bay. At present there is about three hundred feet difference in the altitude of the bottom of the channel and the top of its eastern wall. It is likely, however, that the débris which has accumulated since the Ice Period has diminished the depth of this trough to the amount of a hundred feet or more. The axis of the depression lies approximately in the path of the ice stream. It was, indeed, partly excavated by the same glacial movement which conveyed the fragments of the boulder trail, and therefore it naturally has the same general direction as that followed by the glacier.

An important effect of the channel which forms the main or western part of Narragansett Bay has been to hide a great part of the surface of the train beneath the waters of the sea. As will be seen from the map, the train appears on the shore upon both sides of the Narragansett main channel, and upon the islands in the bay wherever they exhibit deposits of till. It is evident, however, from the distribution as shown on the map, that the ice stream, while pretty closely following the path of the depression, inclined to surmount the eastern border of the channel. This tendency becomes more marked as we approach the seaward end of the bay, for at that point we find the train inclining away from the mainland, or western shore of the embayment, and crossing Aquidneck Island to its eastern side. It will be observed that this eastward tendency is probably increased in the part of the train which lies below the level of the sea. This is indicated by the fact that the area occupied by the boulders touches the southwestern end of Martha's Vineyard. A glance at the map will show that this requires a very sudden turn of the train to the eastward on the area beneath the sea between the mouth of the bay and the district occupied by Martha's Vineyard.

At first sight, it seems improbable that such a sharp flexure in the path of the ice as is above noted would have been likely to have occurred. There is evidently no barrier in the region beyond the mouth of Narragansett Bay which could have served to bring it about. While still in a state of doubt concerning this feature I had occasion to observe a similar sharp eastward turn in the ice which escapes from the southern end of the fiords at Mt. Desert, Maine, where we have valleys comparable to that of Narragansett Bay as regards their direction, debouching into the open sea. In the Narragansett Basin we are not able to find very clear evidence as to the path of the ice after it escapes from the groove between Aquidneck and Conanicut Islands; but on Mt. Desert we can see on the islands which lie to the southeast of Somes

Sound distinct proof, afforded by the numerous glacial scratches, that the ice turned sharply to the east through about the same angle as would be necessary to lead the train we are considering to the western end of Martha's Vineyard. The same eastward turning is observed in the direction of the glacial scratches at the west end of the mountain range of Mt. Desert, where a change of over fifty degrees of arc in the path followed by the ice evidently took place within a north and south distance of about one thousand feet.*

A glance at the map which accompanies this report will make it evident that by far the larger part of this boulder train lies beneath the level of the sea. At least nine tenths of its area is so hidden from view. Fortunately for the inquirer, a considerable, and perhaps the most important, part of the evidence which it affords remains open to inspection.

Description of the Source of the Train at Iron Hill.

The conditions of the deposit whence the boulder train was derived deserve special attention. They are eminently peculiar, and singularly well suited to be the subject of an inquiry such as is proposed in this writing. The material of which the Iron Hill is formed is a peridotite, a phase of olivine gabbro. The percentage of metallic iron in the ore varies between 25 and 45 per cent. The remainder of the mass consists in the main of olivine and felspar: the olivine is in small rounded grains, but the felspar generally occurs in the shape of considerable crystals. These are irregularly scattered through the mass, appearing in the greater part of the deposit: they constitute a very striking feature in the rocks, and enable the observer with great certainty to recognize a fragment derived from it. Under the influence of the weather, the surface of the boulders derived from this locality assumes a dark rusty brown color, while the felspar crystals retain a whitish hue. Pebbles of this material, on account of their conspicuous features, are often visible at a surprising distance, and present such peculiarities that the trained eye will never mistake them for those formed from other deposits.

The area occupied by the peridotite deposit of Iron Hill is singularly limited. It appears as a unique boss of rock rising from the tolerably level country about it to the height of sixty feet above the base. (See Plates I., II., and III.) The greatest length of the mass is about 1,200

* See Report on the Geology of Mt. Desert, Eighth Annual Report of the Director of the U. S. Geological Survey, p. 1004.

feet, its greatest width about 500. The precise position of its flanks is more or less hidden by deposits of drift, but a careful survey with the dipping needle indicates that the deposit has a rudely elliptical form of the above named dimensions, and with the major axis in an approximately north and south position. The rocks which border this deposit are not disclosed at the contact. There are no outcrops within some hundreds of feet of its base. Where found this "country rock" consists of syenitic and granitic gneiss and mica schist. These are, indeed, the only materials which have been observed in the immediate neighborhood of the hill.

All the evidence which has been obtained tends to show that this mass of ilmenite is in its nature a dike. The considerations which lead to this conclusion cannot well be discussed in this memoir. They are in general as follows. The rocks of this section of country are evidently steeply tilted. All the exposures which have been observed show dips exceeding thirty degrees of declivity. Therefore, if this iron ore were a bedded deposit, it would probably appear along a much longer line than that on which it occurs. We should expect, even allowing for possible faulting, to find the bed repeated at other points in the field. It is true that bedded iron ores sometimes occur in thick pockets, but in no case known to me do these accumulations have the solitary character or the proportions indicated in this deposit. The studies made by M. E. Wadsworth appear to afford good petrographic arguments in favor of the hypothesis that this ore has been injected into its present position.*

A very careful search with the dipping needle. over the fields for a distance of some miles from Iron Hill has failed to show anything which could excite suspicion that similar deposits exist beneath the thick mantle of drift which covers the greater part of this country. A yet more careful exploration for boulders has shown that only a very few small pebbles of this ilmenite exist in the district north, east, or west of the hill, and these are all of a size and shape which make it eminently probable that they have been conveyed to their present site by the aborigines or by the white occupants of the country.

Pebbles of the Iron Hill peridotite have been more or less employed for various useful purposes, and so have secured a certain measure of artificial distribution. They serve remarkably well for weights, especially those used for fastening horses. They make excellent ballast for boats. They are adapted for heating water, where the heat is communicated to

* This Bulletin, Vol. VII. (Geol. Series, Vol. I.), p. 183 *et seq.*

the fluid by hot stones, — a method much practised by the Indians and other primitive people, and still in use by our farmers. Therefore it is not surprising that occasional specimens are found beyond the limits of the boulder train, but in many weeks of search I have never discovered a fragment away from the trail which did not by its present use or its association with other objects indicate that it had been artificially transported. Only three boulders have been found to the north of the hill. These were rounded bits, such as may have been used by Indians or whites in various simple arts. As will be seen from the description of the glacial trail, the pebbles within its belt are extremely numerous, constituting for some miles of distance a considerable percentage of these drift materials. Therefore these sporadic fragments, always of small size, but not the smallest, and of a form likely to commend themselves for the before mentioned uses, need not excite suspicion that there are other and unlooked for sources of this material which may serve to confuse the indications which the train affords. The form of the train, so far as it is traceable, and the condition of the fragments at equal distances from the apparent source, alike indicate that all the materials which it contains have been derived from one locality. Throughout the observable portions of its extension, the train steadfastly and uniformly widens, and the fragments of peridotite grow smaller with the increase of distance from the source of the material.

At no other point in New England has an ore which could be confounded with this from Iron Hill been discovered; nor, so far as I can learn, has a rock of like aspect been observed in any other part of this country. It seems therefore safe to assume that this boulder train affords excellent evidence as to the conditions which brought about the transportation of its fragments.

The rock of which the Iron Hill is composed has been a good deal used in making pig-iron. From time to time the material has been quarried and exported to furnaces in New York and Pennsylvania. The large amount of ilmenite which it contains makes it an unsatisfactory ore, but the absence of phosphorus and the small amount of sulphur tempt manufacturers to essay its use. The result has been a sufficient amount of mining operations in the form of open pits somewhat to change the original aspect of the hill. Moreover, a large part of the boulders near the source of the train, and at various points in its length, have been gathered and shipped to distant parts. The illustrations (Plates I., II and III.) give the general form of the mass as it now appears. In its original aspect it had the regular arched shape which is common to isolated masses of hard, homogeneous rock which has been worn by glacial action. At the close of the Glacial Period this region probably was for a time below the level of the sea, and during the re-elevation of the land the surface of the hill appears to have been exposed to the washing action of the waves, by which the covering of drift materials was in good part removed from its summit and accumulated about the base of the elevation. The slightly undercut cliffs on the eastern face of the mass may likewise be due to wave action. The expansive effect of frost acting in the frequent open joints, which plentifully occur wherever the rock is not covered by the drift, has somewhat disrupted the superficial portions of the mass. Notwithstanding these natural and artificial changes, the elevation still retains the general aspect which it had at the close of the Glacial Period. It has probably not, on the average, lost more than six inches in depth of material since the ice passed away.

In the details of its structure the iron ore which constitutes the Cumberland Hill is remarkably uniform. There are relatively few joints, and these, except in the upper parts of the hill, are usually latent; that is, they are generally developed only where the rock is subjected to a considerable rending force. At one place on the western side of the hill, near its northern end, there was until recently a large surface of rock exposed by the artificial removal of the drift, preparatory to quarrying work. This surface, containing an area of about five hundred square feet, was in precisely the condition in which it was left at the close of the Glacial Period. The finest scratches made by the moving ice were not in the least effaced (see Plate IV.). From this and the other small and imperfectly preserved glaciated exposures which the hill affords, I have sought to determine the nature and measure of the ice action on its mass. Of the several possible problems, two were selected for discussion; first, as to the direction of movement of ice over the surface of the hill; and secondly, the proportionate amount of wearing done by the plucking out of fragments and by the rubbing down of the surface.

The data for determining the general direction of the ice movement in the region to the north and west of this district are imperfect, for the reason that the rock is not of a nature to have formed or retained glacial striæ, and is generally covered with glacial detritus. The scattered observations which are obtainable, serve to show that the average movement was the same as that which is indicated by the central line of the boulder train. When, however, we study the scratches exhibited on this hill, especially those which occur on the large artificially exposed area on its western side, we see that the general motion was accompanied by local and subordinate movements which were of a very complicated nature. In the lower part of the large exposure just referred to, the scratches, which are peculiarly well preserved over the entire surface, have the general direction proper to the normal movement of the ice in this field; but within the space of a few feet they turn abruptly in the manner indicated in Plate IV. The change in the direction of the movement of the ice, which is indicated by the scratches in the distance of about five feet, is as much as eighty degrees of arc. Unfortunately, at the time of the observation the mass was broken away at the point where the turn was made, but from the remains of the surface it is clear that the total change in direction was accomplished within the distance of ten and probably within less than five feet. It is difficult to account for this sudden change in the course of the ice movement. The general inclination of the surface on which it occurred is slight, the hill rising on the eastward with a slope of not more than fifteen degrees, and to a height of only about thirty feet above the place where the turn occurs. The decline of the surface toward the valley on the westward appears to have been equally gradual.

It may be remarked, in passing, that sudden turnings of the ice where it came in contact with slight obstacles appear to be much more common in Southern New England than in the more northern parts of the continent. This may possibly be explained by the fact that the glacier during the last stages of its movement in this southern district continued to advance even after it became relatively thin, and that in this condition it was more influenced by local and slight irregularities than was the case in the regions where it had a profounder depth. It is not at all likely that the steadfast flow which conveyed the materials of the great boulder train belongs altogether to the same part of the Ice Period as these, the last formed scratches on Iron Hill.

The surfaces of the hill which remain as they were left by the ice are generally smooth. They exhibit, as is the case usually with massive rocks, a breadth of level or gently curved faces on which are incised the shallow depressions of the glacial scratches. Here and there we find cavities out of which large fragments have been plucked by the dragging action of the ice. Wherever these depressions left by the violently separated fragments exist, we observe that the angles of the depression have been more or less rounded by erosion subsequent to their removal. They occur in all states of obliteration, some retaining their originally sharp outlines, others being so far effaced as to be almost indistinguishable.

About one fifth of the surface is occupied by the pits which were left by the removal of these larger fragments, the remainder being, except for the post-glacial wear to which it has been subjected, in the planed down condition resulting from the attrition of the fragments embedded in the moving ice. We have therefore to conclude that at least four fifths of the down-wearing of this mass during the later stages of the glacier's action was accomplished by the scoring and scratching action of the glacier, and not by the plucking out of large masses such as constitute the boulders in the great train. The portion of the eroded matter removed from the grooves was, at the time of its formation, broken into the state of sand, the grains of which, like the larger fragments, were borne on by the glacial movement.

For reasons which will appear hereafter it is important to consider whether or no this relative excess in the quantity of the fine-grained material removed by the ice was limited to the closing stages of the Glacial Period. At first sight it seems likely that the thicker the ice moving over a rock surface the greater would be its tendency to rend the rock over which it flowed. The pressure of an ice sheet upon its base is directly as its depth, and up to a certain point the abrading power of a glacier must increase with its vertical section. When, however, the ice has attained a certain thickness, it must attain the maximum effect which it can exercise upon the surface over which it moves. After that, the shearing action of the upper upon the lower parts of the ice must cause the superior part to flow over the lower without proportionately increasing the erosive action.

In corroboration of the view that there was probably no great diminution in the plucking action of the glacier in the later stages of its work, we find that the boulders of the train which lie nearest its source are the largest which appear anywhere in its path, and that from its origin to its extremity the fragments in the train gradually, and rather uniformly, diminish in size through the process of rending by attrition to which erratics are commonly subjected in the process of glacial carriage. We furthermore note the fact that almost everywhere within the glaciated district where we can examine a large surface of any of our massive rocks, we find, as here, that the proportion of the scored away or ground down to the rent surfaces is generally very great. From these considerations I am disposed to assume that the material removed from Iron Hill in the form of boulders was very much less than that which was carried away in the form of sand or yet more finely divided matter.

The reason for this relatively large wear of the rock surfaces by the process of scratching and grooving is easily seen: every part of the base of the ice was armed with bits of stone, which, held in the moving glacier, were dragged over the subjacent surface. When one fragment was worn out in the rude work, another was pressed down in its place. Each bit of rock worn from these grooves in turn became a cutting point: even the finest served to polish, and in so doing to remove, a portion of the rocky matter over which the ice moved. Thus the scoring and grooving work continuously went on, but the plucking out of fragments took place intermittingly. In order to have a mass thus plucked out from its bed it was necessary to have the strain which the moving ice applied to it so disposed as to lift it from its bed place, and in most cases this movement required that the detached rock should be overturned in a manner which required it to rise up into the lower part of the glacier. It is evident that the disruption of blocks of rock from their bed places would be more easily accomplished on a slope which inclined away from the course of the ice than in other conditions of exposure to the glacial flow, for in the first named position the blocks would have less support, and would need to rise to a less distance into the ice, than where the slope faced a current. To these conditions we may fairly attribute the ruder character of the surface observable on the southern slopes of many rocky hills as compared with the northern aspects of the same elevations. Unfortunately, the southern end of Iron Hill is so much covered with glacial waste that it is not possible accurately to determine the relative amount of plucking which went on there. The exposed surfaces, though limited in area, appear to indicate, however, that the amount of degradation due to this cause was not materially greater than upon the northern and more visible part of the hill.

Although in its present condition the surface of Iron Hill exhibits but few boulders of its own material, the history of the place makes it clear that in its natural state it was plentifully scattered over with these erratics, the greater portion of which have been removed to be used in the manufacture of iron. Within the period of my own memory of the locality a large part of the erratic material has thus disappeared, and at the same time a large number of boulders from the southern end of the train have likewise been taken away. There still remain upon the surface of the elevation a number of considerable erratics, which being from parts of the deposit where the ore was of low grade have not been deemed worthy of export. The evidence goes to show that the process of plucking out boulders from this exceedingly firm set rock continued down to the very time when the ice ceased to act upon the surface. I have found these facts very difficult to reconcile with the common view as to the circumstances under which the glacier passed away from this part of the country. The opinion is, in effect, that the ice gradually lost its energy of movement, and slowly came to an inactive or stagnant state.

The evidence as to the suddenness with which glacial action ceased at this point is paralleled at many other places in New England which lie at elevations within a few hundred feet of the shore line. It seems to me that this feature may be accounted for on the supposition that this region was considerably depressed beneath the sea at the time when the ice lay over it, and that the glacial mass was not removed by gradual melting, but floated away in the form of icebergs. The transition from the conditions of the ice sheet between the time when it rested on and moved over the surface to that in which it disappeared in the form of icebergs, may well have been brought about suddenly by the progressive melting of the mass. I cannot discuss this hypothesis as to the conditions under which the glaciers of this district ceased to act, but I may be permitted to remark that this view seems more consonant with the evidence than that which holds the glaciers in this part of the country to have gradually stagnated and passed away by sub-aerial decay.

Detailed Description of the Iron Hill Boulder Train.

The general course of this boulder train, and its relations to the surface on which it lies, are fairly well shown by the map which accompanies this paper. The most striking feature of the train is the progressive widening of the belt of country which it occupies from its source to the sea. At the point of origin the train is not over 900 feet in width, and saving a few small scattered blocks which may owe their dispersion to the action of sea waves during a post-glacial submergence or to the interference of man, the width of the trail at its source does not exceed 700 feet; yet near Providence, R. I., a point about 75,000 feet south of Iron Hill, it has widened so that the distance between its borders slightly exceeds 20,000 feet, and at the sea the belt occupied by the erratics is probably more than 40,000 feet in width.

Throughout its extent this boulder train is in its central part most distinctly marked by the erratics. From this middle line the boulders progressively diminish in numbers towards the boundaries of the area over which they are scattered. Thus in the more definitely indicated portions of the train, say at a point five miles south of its origin, it is possible, in favorable positions, to find a dozen or more fragments on the surface of a square acre, while on the margins the average number may not be one to ten acres of area. As indicated on the map, the boundaries of the train denote the limits within which fragments have been actually found. It is likely that occasional bits of the rock occur at considerable distances to the east and west of the points where they have been actually observed. From Iron Hill south to the city of Providence, field observations indicate that the margin of the train has been tolerably well defined. South of that point the boundaries become constantly more and more obscure.

The obscuration of the margins of the train between Providence and the open sea is due in part to the fact that in the more southern district the boulders are to a great extent worn out by the attrition to which they have been subjected, but it is mainly attributable to the fact that a large part of the trail is covered by the waters of Narragansett Bay, or by the deposits of terrace gravels which have been formed since the ice moved over this district. The only part of the boulder train which is distinctly traceable in the region south of Providence are the marginal portions of its field. The central axis of the accumulation lies in the main channel of the bay. Not only is this southern portion of the train to a great extent hidden beneath the sea, but the portions of it which are exposed to view have been more exposed to the interference of man than the section north of Providence. Along the shores of Narragansett Bay the forests have been mostly cleared away and the land brought under tillage. These conditions have been favorable for gathering the boulders of iron ore, which could thence readily be shipped by water to the furnaces along the Hudson and elsewhere. Moreover, next the shores, the pebbles of convenient size have been much sought for boat ballast, for which use their great weight admirably fits them.

Trusting the indications given by occasional fragments found in fields on either side of Narragansett Bay, the trail in the parallel of East Greenwich, R. I., is about 27,000 feet wide, and near the mouth of Narragansett Bay it has a width, as before remarked, of about 40,000 feet. Thus, in a distance of thirty-five miles, the average widening of the path occupied by these boulders is about 1,000 feet for each mile of distance from the source, or in other words the lateral or excursive movement of the rocks from the central path of the train is about one tenth of the direct forward movement.

At the source of the train the peridotite boulders are plentifully intermingled with, and to a certain extent overlaid by, materials brought from the region which lies to the northward of Iron Hill. It is evident that these schistose rocks yielded an abundance of erratics, and it is therefore not surprising to find that even at the outset the train has not more than one tenth of its mass made up of the fragments of ore. The remarkable fact is that the boulders of peridotite rather plentifully occur on the surface of the drift in the section immediately to the south of the place whence they were derived. This thorough commingling of the débris from different parts of the erosion field clearly indicates that there was some feature of movement in the ice which tended to comingle the detritus which it bore, and to effect the combination in a very rapid manner. In other words, the vertical scattering of the fragments in the body of the glacier evidently went on simultaneously with the horizontal dispersion which brought about the widening of the belt over which they were dispersed. At the distance of not more than half a mile from the source of supply the intermixture of the peridotite boulders with those derived from the bed rock appears to be complete. The occasional artificial sections in road cuttings and wells show this feature in a clear manner.

It should be noted that the average distance between the pebbles of ore rapidly increases as we depart from the source of the train, and that this increase is accompanied by a somewhat proportionate diminution in the size of the fragments. This is approximately represented in the following table, which assembles the observations made on many thousand erratics in the section of the train between Iron Hill and Providence. South of that point, as before remarked, the greater part of the trail is covered by the waters of Narragansett Bay.

Place.	Average Diameter.	Largest Fragments observed.
At source.	3 feet.	5 feet.
2 miles south.	2 " 6 in.	4 "
4 " "	1 " 6 "	3 "
6 " "	1 foot.	2 "
8 " "	10 in.	1 foot 6 in.
10 " "	9 "	1 " 3 "
12 " "	8 "	1 " 2 "
14 " "	7 "	12 "

It should be observed that this table must not be taken as representing accurately determined data at the several points on the train designated by the distance from the source. It indicates, however, in a diagrammatic way, the average of the observations, and may be taken as a fair approximation to the facts. In this connection it is well to note that one of the three fragments of ilmenite which have been found on the western extremity of Martha's Vineyard had a mean diameter of about five inches.

The greater part of the fragments of peridotite which constitute the Iron Hill boulder train are contained in the till deposits which occur in its path. All those of large size are found in the drift of this nature. A few smaller bits, however, and these generally much rounded, have been discovered in the washed gravels along the shores of Narragansett Bay. The infrequency of the occurrence of this material in the stratified deposits of glacial waste is doubtless due to the fact, which has been well observed in this part of New England, that these water-borne sands and gravels have always been conveyed from a much greater average distance than the matter contained in the till or ground moraine. Observations which I have made in this field indicate that the average distance to which the ordinary rocks in the till have been transported is probably not more than three miles, while the mean carriage of the stratified materials is at least four times as great.

A careful inspection of the fragments observed in the trail shows that the diminution in size of the erratics in their southward journey has been mainly due to attrition. Not one per cent of the fragments indicate by their form that they have been subjected to division along joint planes since they parted from the original bedding. As they decrease in diameter they become more and more spherical or subovate in form, until they attain a size no greater than an ordinary billiard ball. It is a noteworthy fact that none of these bits have been found having a diameter of less than an inch, and the number of those which approach this size is remarkably small. As a deliberate and extended search has been made for these smaller fragments, it seems likely that their apparent absence is not due to their inconspicuousness. I am inclined to explain it by the supposition that the smaller the erratic the more likely it is to be crushed into fragments by the rude strains which have served to round the larger bits. It is evident that the resistance to pressure arising from being squeezed between other boulders, or between erratics and the bed rock, is in a measure proportional to the diameter of the pebble. A strain which would be withstood by a fragment six inches in diameter might crush to the state of powder one which contained only two or three cubic inches of material. It may in general be assumed that the resistance which rocks of this intensely hard nature oppose to crushing strains is inversely as their size, and in this way we may account for the rapid manner in which most of the observed boulder trains disappear, so that they are not traceable for more than a few miles from their origin.

After observing the deficiency of small pebbles of material derived from Iron Hill, I endeavored to trace the comminuted material within and near the evident path of the trail by determining the quantity of magnetic sand which the glacial deposits afforded. Examinations for this purpose were made at several hundred points by carefully separating the grains of magnetite attracted by a horseshoe magnet from the other débris with which it was mingled. At first it seemed likely that this method of inquiry would give important results, for it was at once made evident that the till material of the district contained from two to six per cent by weight of magnetic sand. It soon, however, became certain that this material could not be accepted as an indication of the trail, for an extended search showed that something like this amount of magnetic sand commonly exists in the glacial waste derived from the metamorphosed schistose rocks of Southern New England. The fact is that these ancient strata throughout contain a notable percentage of crystalline magnetite. An effort to discriminate the fine-grained material from Iron Hill by the amount of titanium it contained also proved fruitless, for the reason that this substance very commonly occurs as an ingredient in the ferruginous sands of the drift. Thus the result of about a hundred assays made by my assistant, Mr. Robert Robertson, was purely negative, so far as the study of the boulder train was concerned, though it served to throw a good deal of light on the mineralogical constitution of our glacial deposits. It proved that this heavy and little oxidizable iron ore is in a measure concentrated by the actions which have brought about the formation of our glacial deposits.

I have now set forth the most important features concerning this train which are not made sufficiently evident by the delineation of its path on the map. I next propose to make these facts the basis for some considerations as to the nature of the actions which distributed the material over the surface between Iron Hill and Martha's Vineyard.

Cause of the Fanning out of the Train.

I have already noted the fact that the Iron Hill boulder train widens from its source to the sea, or for a distance of about thirty-five miles, at the rate of about a thousand feet for the mile of distance. It is evidently a difficult matter to determine the cause of this remarkable feature. At first sight it seemed to me possible that the result was due to the action of floating ice, operating during the retreat of the glacier, and more or less aided by the action of the ocean waves during the submergence which apparently continued in this field throughout the closing stages of the Ice Period; but the fact that the fragments with rare exceptions are found in the till renders it difficult, if not impossible to accept this explanation. Moreover, the gradual widening of the trail at the uniform rate above stated seems of itself to make this hypothesis quite untenable.

There is another apparently possible cause of dispersion to be found in the successive advances and recessions of the ice during the closing stages of the Glacial Period. We might conceive that the successive forward movements varied somewhat in direction, and that the waste from Iron Hill might thus have been shoved about so as to widen the field which it occupied. In the region in which this boulder train lies there is no distinct evidence of such successive movements of advance and retreat of the ice, but in a region about twenty miles to the east of this line, in the valley of the Taunton River, we find from the sections along the line of the Old Colony Railway abundant proof that there were many successive, though slight movements of this nature. In a portion of the valley of the above named river corresponding in length and position to that extending from Iron Hill to Providence, there is good evidence of at least six of these successive movements of advance and retreat. These oscillations were slight and temporary, as is shown by the fact that the ice in each southward going did not clear away the previously formed incoherent deposits, nor were there any distinct frontal moraines formed at the margin of the ice field. The facts indicate that these variations in the position of the ice front amounted to only a few hundred feet of distance in the axis of the motion. In these successive advances and recessions of the glacial margin there may possibly have been some alterations in the direction of the ice flow. It is a well observed fact that the margin of a glacier, if the ice sheet have a considerable front, is apt from time to time to put forth lobes which push forward in directions somewhat independent of the general course of the ice field. Moreover, we often find, in a district where the glacial scratches are well preserved, that the last scorings inflicted on the rock lie at a considerable angle to those which were antecedently formed.

It will be easily understood that a uniform shifting in the course of the ice over the whole trail would not necessarily alter its width. It is necessary to suppose, if we are to account for the widening of the field in this way, that the movements were at once so numerous and so organized in relation to each other that they resulted in a dispersing action on the boulders, which was the greater the farther they were away from their source. In other words, the difficulty with this hypothesis is that it will not account for the gradual and essentially uniform widening of the train from its source to the sea. This feature seems to indicate some dispersing agent which has served in a constant manner to increase the distance between the fragments during their long southward journey, without at the same time deflecting the path from a tolerably direct line. I shall now submit the hypothesis which it seems reasonable to frame to meet these conditions.

Where a continental glacier rests on and moves over a surface of rock it is clear that its bed is subjected to powerful abrading forces. The energy of position of the glacier breaks up the rock, grinds the greater part of it into small fragments, and thereby converts a certain amount of energy into heat. The experiments made by Robert Mallet, which are set forth in his paper in the Philosophical Transactions in 1873, show that the energy required to crush certain of the harder kinds of rock is sufficient to elevate the temperature of the material to about 200° Fahrenheit. This amount of heat appears to be sufficient to melt somewhere near an equal bulk of ice, provided the ice was at the temperature of 32° when the melting began.

The effect of this rock crushing, which is accomplished at or near the base of the glacier, is necessarily to bring about the melting of a certain amount of the ice. Another and doubtless a more important supply of heat in this deeper part of the ice arises from the shearing movement of the particles of the glacier over each other. There can be no doubt that the principal part of the energy of position of the glacier is expended in the work of impelling the particles of ice by each other in the unceasing movement to which they are subjected in the lower portion of the sheet. Some part of its energy is doubtless expended in the differential movement which takes place in the upper part of the section, but by far the greater portion of it must be spent in bringing about the tortuous shearing motions which we know from the glacial scratches occurred in the section immediately adjacent to the bed rock. The value of this heat-giving action cannot be well estimated, but there is reason to believe that in amount it is many times as great as that derived from the disruption of the rock which occurs at the base of the glacial mass.

To the above mentioned sources of heat we have clearly to add a third element of action; that which arises from the constant escape of temperature from the earth's interior. The amount of this is not well ascertained. It is probably not sufficient to melt more than a few millimeters of ice each year, but it has to be reckoned on in estimating the influences which are at work to bring about melting at the base of the glacier. From these three direct heat-giving actions, we are entitled to assume that a certain amount of the ice at the base of a moving mass of the material will inevitably be melted. In addition to these direct influences we must also take into account the probability, indeed, we may say the certainty, that the pressure of the superincumbent glacier indirectly favors the liquefaction of the ice at the lower parts of the section. As long ago as 1849, James Thomson theoretically established the conclusion that the effect of pressure was to lower the freezing point of water.* Shortly after, Wm. Thomson experimentally proved the verity of these theoretical considerations, and it now appears that where a glacial sheet has a thickness of three thousand feet, the freezing point of water is lowered to about 30°, or approximately two degrees below that at which it congeals in ordinary atmospheric conditions.

It may be regarded as fairly well established that the ice in several points in Eastern New England attained a thickness of more than three thousand feet; it is possible, indeed, that when the glacial envelope was most completely developed its depth much exceeded this amount. As we do not yet know the temperature at which ice enters a glacial mass such as recently covered the northern portion of this continent, we cannot make sure that this pressure alone would be sufficient to bring about melting at the base of the mass, even if it had the thickness of a mile. There can be no doubt, however, that the effect arising from the lowering of the melting point would be greatly to favor the liquefaction arising from the sources of heat before mentioned. It seems to me, therefore, that we are justified in assuming, at least as a working hypothesis, the existence of large amounts of molten water next the bed rock on which a deep glacier lies. This hypothesis seems to be adequately supported by the physical conditions of our drift deposits. Wherever these have been observed, we note the existence of many accumulations of washed sand and gravel, commonly known as kames or osars, which distinctly map out the position of subglacial streams of fluid water, which often coursed for scores if not hundreds of miles under the ice arches before they escaped at the margin of the glacier.

* See Transactions of the Royal Society of Edinburgh, Vol. XVI., Part 5.

In some cases, notably in the somewhat continuous kame belt which extends up the Genesee valley from its mouth to its source, we are compelled to believe that the stream flowed beneath ice which probably had, at least over a part of the path followed by the current, a depth of half a mile or more. It is impossible to believe that the water supply of this stream could have been furnished by the descent of the fluid from the surface through crevices to the bed rock, for owing to the ease with which ice moves under pressure the weight of the superincumbent materials would make the maintenance of such passages for the descent of the waters impossible. We are therefore driven to the conclusion that these subglacial channels occupied by the rivers which flowed upon the bed rock were fed from the melting which occurred at the base of the glacier.

The foregoing considerations make it appear likely that the water lying at the base of a continental glacier would be subjected to the very great pressure of the overlying ice. With ice having a depth of three thousand feet this pressure would amount to near ninety tons to the square foot.

It appears tolerably evident that, notwithstanding the pressure of the superincumbent glacier, the water which flowed beneath it passed through continuous arches leading from the interior portions of the ice field towards its margin. We may, therefore conceive that this water, for doubtless it had to wrestle with the ice for passage, moved irregularly towards the margin of the glacier, making its way in a violent manner by the obstructions which it encountered. The position of the kames of serpentiform outline which mark the position of these ancient subglacial streams clearly indicates that the course of the ice-covered waters was liable to much change; as is shown by the eskers, their paths shifted in a somewhat sudden manner from one side of the valley to the other. Near the margin of the ice where the depth of the sheet would permit the formation of crevasses which for a time at least would remain open, the erratic movements would doubtless be greater in amount than in the sections where the ice was so deep as to prevent the formation of fractures. We may fairly conceive that the motion of these subglacial streams, urged as they were by a pressure of many tons to the square foot, would, at least near the margin of the ice sheet, take place with paroxysmal violence. Quantities of the débris which came in the path of these vigorous currents would doubtless be urged laterally away from the axis of motion of the glacier, or borne up from near the bed rock into higher lying parts of the ice. Each considerable disruption of the glacier, by thus favoring the movements of the imprisoned waters, would be likely to bring about the transverse scattering of the rock débris.

When first laid down, after transportation by these currents of water, the detrital materials would naturally have the washed and bedded character proper to deposits such as occur in kames, but we know by observation that it often happens that such accumulations were soon disrupted by the motion of the glacier, the fragments taken into the mass of the ice to be redeposited with the aspect of ordinary till. Much of the drift material in Southeastern New England evidently consists of débris which has recently been in the form of washed and stratified gravels. A careful study of the drift in this section of the country has convinced me that by far the greater part of its mass has been at least once, and probably again and again, assorted by water before it was finally taken into the ice for the last time, to be laid down in the shape in which we now find it. It therefore seems to me that we are justified in supposing the horizontal dispersion of the materials contained in the boulder train from Iron Hill to have been mainly brought about by the violent movements of subglacial water.

Attention has already been called to the fact that the fine débris derived from the scoring and polishing of Iron Hill, and from the comminution of the boulders which are plucked from it, is not distinctly recognizable in the path of the boulder train. The evidence of wearing afforded by the hill itself clearly shows that at least three fourths of the erosion which took place upon its surface delivered the iron ore to the glacier in the form of fine sand, such as is ground out from glacial striations or worn from the polished surfaces between the grooves. Moreover, by far the greater part of the mass of the erratics which were plucked from the rock was reduced to a similar state of division by the attrition to which the fragments were subjected. If this iron sand had been transported in substantially the same manner as the larger boulders, we should be entitled to expect evidence of the material in the path of the trail; but, as before noted, this comminuted magnetite is scarcely, if at all, more abundant in the field occupied by the boulders of the substance than in the other parts of the country to the north, east, and west of the train. The only way in which I can account for the disappearance of the fine débris is by supposing that it was borne away to a considerable distance by the subglacial currents of free water.

Although there is considerable difference in the measure of wear to which all glacial material is subjected, the débris from Iron Hill affords the best indication of such variation which I have ever found. It is a noticeable fact, that within half a mile of the source of the material we occasionally find boulders which have been completely rounded commingled with others which have been subjected to such slight attrition that their original form and size has hardly been altered at all. Proceeding down the train, we note the fact that gradually all the fragments become more and more rounded, but even at thirty-five miles away some of the bits appear to have retained some share of their original outline. It is true that the angularity of these fragments may in part be attributed to the successive fracturing to which they have been subjected, but for some miles from the source it is evident that many of the erratics have been in a manner preserved from attrition with the bed rock, or against other moving fragments. This has probably been brought about by a process which uplifted the well preserved erratics into the body of the ice.

Before passing from this part of our inquiry, it is worth while to note the striking contrast exhibited by this train of peridotite boulders as compared with certain other trains of softer material which are traceable in this section. In the region to the southwest of Iron Hill in the town of Smithfield, R. I., there are several outcrops of a crystalline limestone which are sufficiently limited in area to afford distinct boulder trains. Although this highly metamorphosed limestone has the hardness of ordinary marble, and by its structure affords erratics which are on the average larger than those plucked out from the ice at Iron Hill, the trains which are formed of it cannot be traced for more than five or six miles to the southward of the outcrops. We thus perceive the measure in which the singular hardness of the rock from Iron Hill favors the preservation of the boulders derived from that locality, which has been able to journey more than ten times as far as the hard marbles of the Smithfield district.

I may allude, in passing, to the fact that the relative hardness of the bed rock of any district, as compared with that of the fragments borne over it by glaciers from other fields, is of much importance when we seek to explain the distribution of glacial drift. Where the bed rock of any locality is hard, and the rocks lying just above it in the path of the glacial flow are soft, we generally find the surface of these hard materials occupied by little coarse detrital waste, and this for the reason that the fragments are readily ground out against the nether millstone. If the conditions are reversed, and the rocks from which the glacier came are very resistant to erosion, while the given field is underlaid by soft deposits, we usually find the area thickly covered with boulders. This consideration will explain the very distant carriage of the erratics which we find in Southern Ohio, many of which have doubtless come from the region north of Lake Erie, or from points more than two hundred and fifty miles away from their present site, the whole of their course having been over rather incoherent strata. The reverse of these conditions exist in New England, where the firm set rocks are usually hard, and all the débris which comes in contact with them in the process of glacial transportation is apt to be worn to the state of minute fragments. In this part of the country we can rarely trace a glacial train for more than a score of miles.

The Rate of Glacial Wearing at Iron Hill.

One of the most interesting series of observations which it proved possible to undertake in this inquiry concerned the rate of erosion which took place at Iron Hill during the time it was subjected to glaciation. Although, as will shortly be seen, the results of this research are of a rather discrepant nature, certain general conclusions which appear to be of value were obtained. As will be seen from the map, the part of the trail which lies to the north of Providence has the form of an acute-angled triangle, of which the base may be assumed to have a length of about 20,000 feet and the sides an extent of about 75,000 feet. The area included in this field is about 750,000,000 square feet. Our aim is now to ascertain the amount of the débris from the hill which lies upon this surface. From a careful inspection of the ground, I came to the conclusion that it is reasonable to estimate the quantity of detritus from Iron Hill which lies within this area as equivalent to an inch in depth over its whole surface, or say 60,000,000 cubic feet. Now the visible part of the Iron Hill rock does not exceed 600,000 square feet. It may be prolonged to the southward beneath the detrital deposits for the distance of a few hundred feet, and may extend somewhat to the westward under the drift materials; but if we assign to the mass an area of 1,000,000 feet, we give it all the area which careful inquiry with the dipping needle shows to be probable. On this basis we may say that the train north of Providence contains the equivalent of a mass sixty feet in height which has been removed from the hill.

Attention has already been called to the fact, that not more than one fifth of the eroded matter from Iron Hill went away in the form of boulders, — at least during the closing stages of the Ice Period. By far the greater part of the material was removed in the condition of fine sand, which has been to a great extent swept away from the path of the trail. Accepting this estimate, we have to reckon the erosion of this surface during the period when the trail between the hill and Providence was formed as amounting to about three hundred feet in depth. As the distance between Iron Hill and Providence is about seventy-five thousand feet, the question arises, Can we assume that, during the passage of the ice along this length of its course, anything like this great amount of wearing was brought about at the source of the trail? It is, however, by no means certain that the distance traversed by the ice during the formation of the trail did not exceed the length of the field occupied by the débris which it conveyed. As before remarked, there are reasons to suspect that the ice advanced and retreated several times while it lay on this part of the shore-land, and these advances and retreats may have materially prolonged the time during which the ice continued to move over the surface of the hill. If the ice long retained a stationary front at any point between Providence and Iron Hill, or if its margin were subjected to successive oscillations, at no time falling back to the north of Iron Hill, then the boulders on this field represent the wearing effected by the passage of a much greater length of ice sheet than is indicated by the longitudinal extent of this part of the trail.

After careful examination, I am inclined to doubt whether any considerable irregularities of movement such as have just been suggested ever occurred in this part of the glacier while the train was forming. I can find no trace of frontal moraines, such as would have been caused by any considerable pause in the retreat of the ice or the re-advance of its frontal wall. Therefore, while granting the probability of a certain amount of oscillation in a glacial margin, I am not disposed to think that these accidents could have been of such magnitude as entirely to invalidate the computations as to the rate of erosion which we have just made.

I have before noted the probability that the ice went off from this district, not by the gradual retreat of its front to the northward, nor by stagnation followed by a slow process of melting, but by the floating away of the thinned glacier in the waters of the sea, which at the close of the ice time stood at a higher level than at present. If the ice sheet thus departed in the form of bergs, we may the more readily account for the prevailing absence of small frontal moraines which we might expect to mark the stages of its retreat.

There is yet another way of approaching this question of the rate of erosion brought about by the passage of a given amount of ice over the surface of the bed rock, — a method which is applicable in the study of many glaciated rock surfaces. This may be set forth as follows. The indentations on the surface which has been eroded by the glaciers are divisible into four classes: the pits which were left where disjointed masses of the rock were plucked out and borne away by the moving ice; the grooves, or more or less distinct relatively broad channels, which have been carved in those parts of the rock made particularly accessible to erosion by the local softness of the material, or by the form of the surface, which led to local intensifications of the erosive work done during the passage of many successive cutting points composed of bits of hard rock held down upon the bed by the moving ice; the scratches, which are distinguished from the grooves by the fact that they have been formed by the incisive action of a single point of hard material urged forward by the ice; and, lastly, the general polishing of the surface accomplished by the attrition of very small powdery fragments, which were not large enough to be fixed in the ice or sufficiently hard to make perceptible grooves, but which served to smooth the rock much as a polishing powder acts when rubbed upon a surface of metal by the human hand.

For our present purpose we shall limit ourselves to that form of glacial wear which is effected through the action of the distinct scratches or indentations which are produced by the movement of a point of hard rock over the glaciated surface. On many rocks which are thus eroded it is possible to measure the length and breadth of these indentations, and to determine the relative amount of wear which is in this manner brought about. It is rarely the case that the evidence to this effect is so clearly indicated as on the unweathered portions of Iron Hill. By carefully examining the glaciated surface shown in Plate IV. we find that we may estimate the depth of these scorings at an average of one twentieth of an inch, and we may reckon the channels as covering one fifth of the surface, the intermediate spaces being occupied by parts of the rock which have been polished in the manner above described. The average length of these grooves appears to be about eight feet. It thus appears probable that while these rock fragments which made the incisions moved for the distance of fifty feet, they eroded somewhere about one twentieth of an inch from the surface of the rock which is the subject of this computation. At this rate, while the cutting fragments were moving for the distance of a mile, the aggregate erosion accomplished through the formation of scratches would amount to about one hundred twentieths of an inch, or to near five inches, and during a journey of these cutting fragments to the distance of fifteen miles, to about seventy-five inches. Allowing, as before estimated, that the plucked out material carried away in the form of boulders amounts to as much as one fifth of that removed in the other forms of erosion, the aggregate wear may be estimated during the time when thirteen miles of ice was passing the point as somewhere about seven or eight feet.

There is a manifest source of error in the computation last given, which arises from the fact that no account is taken of the form of erosion which occurs between the scratches, which results in the production of a smooth surface, or in scorings which are so delicate as not to make an impression on the eye. As at least three fifths of the surface is of this character, it appears to me that we must reckon the abrasion due to the rubbing of the rock by very fine particles of detritus to be about twice as effective in removing material as that which produces the scratches. Were this not the case, the discernible indentations would occupy a larger part of the field. We therefore see that to the combined scratching and polishing actions we may perhaps reckon a total lowering of the surface during the passage of the ice over the distance between Iron Hill and the town of Providence at about twenty feet.

The large proportional share taken in erosion effected by the so called polishing work done by the glacier has been generally overlooked. It appears to me that on most hard rocks it has been the efficient means by which they were worn away during the passage of the glacier over their surfaces. A careful examination of any completely smoothed materials, such as our harder granites or the denser clay slates, will make it evident to the eye that the most of the waste which was removed from the surface, at least during the last stages of the glacial erosion, was taken away in the form of a very fine powder, the so called glacial flour, which we know by many observations is likely to be carried to an indefinite distance by the streams which flow from the glacial area. In this way, we can account for the fact that this fine detritus has generally disappeared from the districts about the ice front.

There is yet another evident doubt which serves to diminish the value of the above given rude approximations to the rate of glacial wearing. This is due to the fact that we do not clearly know that the hard points which effected the incision of the scratches were firmly held in the ice as they were urged over the surface of the bed rock. It is well known that a wire suspending a weight and resting upon a block of ice, the mass of which is at or near the freezing point, will, through the effect of pressure in promoting melting, gradually work down through the block without leaving any crevice behind it. It therefore seems not improbable that where the bit of rock which made the incision in the bed was small, the ice which held it moved more rapidly than the tool itself, and that the rate of movement of the cutting points was an unknown fraction of that at which the ice moved towards the margin of the glacial field.

The time required for the passage of a length of the glacier equal to the distance from Iron Hill to Providence, is a matter of almost as much doubt as the amount of erosion which it accomplished. Our only possible source of information is found in the rate of movement of existing ice streams. We are, it is true, tolerably well informed as to the speed attained at the extremities, and at various points on the surface, of valley glaciers of the Alpine type. Such observations as have been made on the larger ice streams in Greenland and Alaska show very clearly that the glaciers of these countries move far more swiftly than the better known streams of Switzerland and Norway. From the observations which have been made on the arctic fields, it seems not unreasonable to compute the motion of the New England ice at not less than twenty feet per diem, or say at the rate of about a mile a year, or from thirteen to fifteen years for the journey over the part of the train which we have endeavored to subject to computation.

Although no kind of final value can be assigned to the results of the computations above given, it seems to me that they serve to indicate that the erosion accomplished by the ice while it lay upon the surface of this part of the continent was probably effected with great rapidity. The impression left upon the mind of the student who attentively considers and carefully reckons the more computable form of wearing which is brought about by scratching and polishing is to the effect that the surface must have worn downward at an annual rate which is certainly to be measured by inches, if not by feet. If after inspecting this evidence he will follow the course of the boulder train which we have been considering, he will find that the quantity of the débris from the hill which it contains forces him to a similarly high reckoning as to the rate of the glacial wear. Even if from the data he obtains he should conclude that the estimate of the peridotite in the train which I have made is five or ten times too great, he will still be compelled to believe that the down-wearing took place in an exceedingly rapid manner. Minimizing the estimates in every possible way, in a manner which need not here be set forth, I have not succeeded in making the amount of the down-wearing less than an inch per annum.

The more accurate our knowledge as to the genesis of the topography within the ice-worn region becomes, the more clearly is it proved that the essential features of the surface are not due, as was formerly supposed, to the erosion effected during the Glacial Period, but are to be ascribed to the ordinary agents of erosion which operated on this district during the pre-glacial ages. Nowhere is this fact more evident than in the district about Iron Hill. The surface of that field still discloses a drainage system which in its main features is clearly very ancient. The valleys have the normally digitated character which is characteristic of the work done by fluid water, and though these depressions are everywhere more or less modified, and sometimes very greatly changed, by the erosive work of the ice, the type of the topography is truly fluviatile, in this regard differing from such characteristically glaciated districts as Labrador, Scotland, or Scandinavia. Only the smaller tributaries of the streams, those occupied by the lesser permanent brooks, have lost their valleys by the process of glacial erosion. Although I have made numerous efforts to secure some basis for a quantitative estimate, however imperfect, concerning the amount in depth of the material which was removed from this district during the Glacial Period, I have not succeeded in obtaining any data deserving consideration here. I can only state the general impression made by a review of the topography, which is to the effect that the wearing brought about by moving ice cannot have amounted to as much as an average of one hundred feet over the region within a radius of thirty miles from Iron Hill. It is difficult indeed to reconcile the hypothesis of even this amount of erosion with the remarkably well preserved details of the river work in this region.

The slightness of the wearing which seems to have occurred in Northern Rhode Island is paralleled at many other points which are much farther within the boundaries of the great North American glacier. I shall note but two instances of the many which I could cite for the purpose of showing that the erosive work accomplished during the last Glacial Period was at certain points even less than I think it was in the neighborhood of Iron Hill. In the region about Pittsfield, Mass., the considerable areas of limestone rock there exposed retain the sink-holes, or shallow pits, which are normally formed where calcitic limestones are exposed to long continued weathering. These depressions have been filled with glacial waste, but the pits have evidently lost but little of their original depth. In the same region the decayed mica schists and other related metamorphosed rocks have not been planed away by the glacier, but remain with the peculiar aspect which is commonly supposed to be limited to the district south of the glaciated field. Again, in the region immediately north of Kingston in Canada, a place situated in what is supposed to have been the very heart of the great glacier, the horizontal rocks of the Silurian Age retain their delicately incised valleys, which were formed before the Ice Period, in a state of preservation almost as perfect as those formed in rocks of the same age and character in Central Kentucky, in a district a hundred miles south of the ice front. Here and there these valleys of the Kingston field are somewhat embarrassed by accumulations of glacial waste, and at other points the streams have made slightly deeper excavations in their old paths, but on the whole the topography is substantially that which existed before the advent of the glacier.

It is evident that, if we assume the rate of glacial wearing to have been rapid, and yet at the same time the amount of effective work to have been small, we are at once compelled to believe that the duration of the cutting action was but brief. Along the margin of the ice the condition of the frontal accumulations of débris at a number of points on this continent leads us to the conclusion that the southernmost part of the field occupied by the ice was tenanted by the glacier for but a short time. Thus in the central parts of New Jersey the morainal accumulations are generally slight, while the margin of the field occupied by the ice in the northernmost point in Kentucky, though the indications which point to the presence of the sheet are unmistakable, shows no frontal moraine whatever. If these peculiar instances of slight wearing were limited to the margin of the glacier, we could sufficiently account for the facts by supposing that a sudden forward movement of the glacier had occurred, during which the fringe of the ice sheet occupied for a very brief time an area which the climatal conditions did not permit it to remain in. Such temporary excursions of the ice, though on a smaller scale, have been frequently observed at the lower extremity of the Swiss glaciers. Owing to the existence of such slightly worn areas as we have noted in the interior portions of the American glaciated field, we cannot account for the facts in the manner just indicated. It appears necessary to suppose the existence of some conditions which would permit the glacier to rest over a surface, and at the same time prevent its abrasive action on the bed rocks.

Having been for some years engaged in preparing a series of maps and reports on the surface geology of New England, I have been led to study a dozen or more parts of the field in which the evidence as to the small amount of glacial wearing is particularly clear. These areas are widely scattered, and from the additions which are constantly being made to the list it is evident that they are numerous. While this essay was in preparation, my assistant, Mr. J. B. Woodworth, discovered a characteristic field of this nature in the region of hill land, on the western border of Rhode Island, where the decayed schistose rocks, the decomposition of which evidently occurred in pre-glacial times, have not been removed by the action of the ice. At first I was disposed to attribute the absence of erosion in these districts to some local arrest of the ice movement, but a careful inspection of the localities has generally disclosed the existence of areas of hard rock, which bore the normal marks of glacial wearing, showing clearly that the ice moved in the ordinary manner over the area. I therefore felt compelled to frame another hypothesis to account for the arrest of glacial wearing during the greater part of the time when the ice sheet lay over the areas in question. While I am still in much doubt as to the value of these suggestions which I have to offer, I may say that they have withstood my own criticisms and those suggested by several of my fellow students of the phenomena for a period of ten years, and it therefore seems well to offer them for more extended debate.

Hypothesis concerning the Conditions of Continental Glaciers.

We have already had occasion in the preceding pages incidentally to note the effect of pressure in lowering the freezing point of ice, but it appears to me that we have by no means exhausted the considerations as to the conditions of deep glaciers which are open to us by the important discoveries as to the effects of pressure on ice which were made by the brothers Thomson about forty years ago. I propose, therefore, to review the matter, with the hope of discovering some explanation of the arrest in the wear of the bed rocks which seems to have occurred during the time when a thick ice sheet occupied the northern portion of this continent. There can be no doubt that pressure melting operates in an effective though slight manner even in the superficial portions of an ice mass. The phenomena of regelation exhibited when two bits of frozen water are pressed together, clearly shows the way, as has often been observed, in which the conditions operate, and many other simple experiments serve to indicate an action of the same nature. There now appears to be little doubt in the minds of those who have inquired into the facts of the ice movement in the Swiss glaciers, that pressure melting plays a considerable part in determining the movement of those relatively small ice streams. So far as I am aware, however, no inquirers have endeavored to ascertain the effect of pressure melting on wide-spread and deep sheets of ice.

It is now tolerably clear that during the last glacial epoch a large part of the field occupied by the continental glacier was buried to the depth of about a mile beneath the accumulations of frozen water. If it were necessary for our purpose, it could readily be shown that the thickness of the sheet was probably much greater than six thousand feet, but the pressure which a mass no more than a mile in depth would bring upon the surface of the earth would be sufficient to lower the freezing point to about 30° Fahrenheit. We cannot ascertain at what temperature the accumulations of snow were built into the mass of the glacier. There is, however, reason to believe that the initial heat was not much below the freezing point of water. It would not, however, militate against the hypothesis to suppose that the mean annual temperature of the surface of the glacier, and consequently that of the accumulating ice sheet, was as low as 25° or even 20°. We have next to note, that, with the progressive deposition of snow, the layers formed each year would be brought nearer to the bed rock, which process would lead to a constant increment in the pressure which they sustained from the superincumbent material. Thus the melting point of the ice would be progressively lowered.

Not only does the progressive descent of the ice towards the bed rock serve, through the influence of pressure, to bring the material ever nearer the melting point, but with each stage of the down-going the particles come nearer to that portion of the mass where several different causes act together to produce a positive increase in temperature. There is little doubt that the shearing movement of the ice due to the friction of its mass upon the surface of the earth progressively, and at last very rapidly, increases as we approach the base of the glacier. This interstitial motion is necessarily attended by the conversion of a great part of the energy of position of the mass into heat, which is communicated to the neighboring ice, and on account of the slight conductivity of the material escapes towards the surface in a very slow manner. Next the bed rock the actual friction of the ice upon the base over which it moves, and the abrasion of the rock, convert yet more of the force which leads to the motion of the glacier into heat. To these sources of temperature we must add the slight but not unimportant effect of the contribution of heat poured forth into the ice from the earth's interior. All these actions tend to promote the liquefaction of the lower part of the glacial envelope.

Although it is easy to perceive the existence of a number of efficient causes tending to bring about melting in the lower portion of a continental glacier, it is difficult to form an adequate conception as to the precise way in which these influences would operate. The facts, however, justify us in supposing that the temperature induced in the lower portion of the ice would to a great extent be retained in the deeper parts of the glacier. It is a well known fact that ice is a poor conductor of heat, and therefore we may fairly assume that a considerable increment of warmth would be likely to be brought about in the lower part of the section, while the upper portion remained substantially unaffected by the condition of the lower parts of the mass. The hypothesis is, in effect, that at a certain stage in the development in thickness of an ice sheet the portion of the mass next the bottom, while still remaining below the temperature of 32° Fahrenheit, becomes converted into water, or into very much softened ice, which cannot escape vertically or horizontally from the field in which the melting was developed, but remains as a fluid or semi-fluid sheet intervening between the solid ice and the surface of the earth.

The conditions of a mass of water at the base of a glacier, owing its essential fluidity to the combined influence of pressure melting and positive contributions of heat, is so peculiar, that it is necessary for us somewhat carefully to examine into its state. At first sight it may seem likely that such a mass of fluid would inevitably be urged by the pressure of the superincumbent ice away from the field in which it was formed, moving in the direction of least resistance, which would generally be towards the margin of the glacial field. It is evident that the motion could not be in an upward direction, for in a deep glacier the yielding nature of the material must prevent the formation of fissures at any great distance below the surface. Even if such crevasses should be made, they would quickly be closed by the pressure of molten water, which would instantly freeze when it entered their free spaces. It is more difficult to account for the hindrance to the movement of the fluid toward the margin of the glacier. We must, however, conceive that as soon as such a movement took place, and for the reason that it did take place, the pressure molten water, having attained to a position where less weight was imposed upon it, would quickly refreeze. It would be aided in making a certain excursion towards the margin of the field by the fact that it was urged forward by the pressure of the overlying ice, and this energy of movement would, to a certain extent, be converted into heat through the frictions which the liquid encountered on its journey.

The migration of pressure molten water towards the margin of the ice would doubtless be somewhat restrained by the plastic condition which occurs in ice when pressure melting begins. In the familiar experiment which is made by subjecting a column of ice to compression, we observe that the melting does not occur simultaneously throughout the mass, but it begins along the planes of junction of its crystalline or fragmental elements, films of water developing along these planes, and gradually extending in width until the whole mass becomes softened to the point where it loses its rigidity without becoming generally fluid. It seems reasonable to conceive that the passage from a sub-glacial area, where the water was melted at a temperature below 32° Fahrenheit, to a thinner part of the glacier, where the solid ice rested on the ground, would be through a belt where the ice was in a semi-fluid condition, which would serve through the frictions which would there be engendered somewhat to restrain the flow. With these preliminary suggestions as to the probable state of the bottom of a deep glacier, we may now proceed to examine into certain corollaries which may fairly be drawn from the main propositions.

As long as a glacier rests upon the bed rock in the form of ice, its foundation seems necessarily subjected to intense erosive action, but as soon as the ice next the bed rock is converted into pressure molten water, this wearing must cease, and the area would probably at once become more perfectly insured from any form of erosion than any other portion of the earth's surface. This exemption from change would continue until, by a process of thinning of the glacier, its base was permitted to return to the frozen state. It therefore seems possible that where a deep glacier is developed upon any area we are likely to have at first active erosion; then a state in which wearing rather suddenly ceases, because the ice thickens and becomes warmed, and therefore melts in the manner before described; and, last of all, with the passing away of the ice, the thinned sheet may come again to move over the bottom, and for a time to repeat the erosive work which was discontinued while the ice retained a great depth.

In case pressure molten water were extensively developed at the base of a great glacier, such as occupied the northern part of this continent, we should have to conceive the bottom of the ice, as regards its relations to the bed rock, divided into three zones. Next the margin there would be a belt occupied by completely frozen water, which lay upon the bottom; within this belt, a section where the pressures were sufficient to produce only a partial melting or softening of the ice; and in the central part of the field, an area in which the ice rested on pressure molten water, or on ice which was made by the combined action of pressure and heat so soft that it could not exercise any erosive effect. I am not inclined to believe that this body of water, reduced from the state of ice to the fluid or semi-fluid condition, would ever be likely to become of any great depth. As soon as the measure of liquefaction was brought about which would prevent the ice from holding firmly to the bed rock, the heat due to the shearing motion of the glacier and to the grinding up of mineral matter would no longer be produced. At that stage I conceive that the motion in the inner parts of the field which conveyed the annual rainfall towards the margin would in part be affected by the gradual working out of the pressure molten water, and in part by the squeezing of the softened ice near the base towards the glacial front. Neither of these actions would serve to convert any considerable part of the energy of position of the mass into heat.

It is commonly supposed that the immediate application of pressure will serve to melt a mass of ice, even if its temperature be a degree or two below the freezing point. Some experiments made under my direction by Mr. R. W. Wood while a student in Harvard College have shown that this is not the case.* If to such a mass of ice even a great pressure is suddenly applied, only a small amount of water becomes melted: this pressure molten fluid abstracts heat from the remainder of the ice in such a measure that, if the pressure be rapidly accumulated so that the ice has no chance to gain in temperature from without, we have a result which apparently contradicts the hypothesis which is here presented. I see no reason to doubt that, if we could at once impose upon a surface a glacier having the thickness of a mile and a temperature of 31° Fahrenheit, we should have but little indication of pressure melting at the base of the ice; but here, as elsewhere, the element of time and the continuity of slight actions have to be taken into account. Reckoning with these, we perceive that the friction of such a hypothetical glacier on the bottom, the grinding of the débris which it will produce, and the vast amount of shearing action which would take place in the particles of ice as they struggled over the surface, and by each other for a great distance above the bottom, together with the heat poured

* See American Journal of Science, 1891, Vol XLI. p. 30.

forth from the earth's interior, would gradually bring a certain thickness of the section into a state of more or less perfect fluidity, — into a condition in which the mass would flow, though with much less ease than fluid water, with such facility that in a slow movement it would in no wise affect the condition of its bed.

The experiments which we are able to make on the surface, either by compressing a mass of ice to the point where a good deal of water appears between its units of structure, or by mingling snow with water, seem to indicate that we may have semi-fluid masses formed containing enough ice to move with a certain speed, and yet, as far as erosion is concerned, behaving like liquids. It appears to me likely that, while in some of the deeper valleys below a continental glacier we might have considerable masses of water in a state of perfect fluidity, the greater part of the material, the cohesion of which was effected by pressure and heat, would, although the water would be water and the ice ice, have as a mass the essential properties of a fluid. As this material, ranging in its rigidity between water and ice, moved toward the zones of diminished pressure, it seems to me that it would, through the reduction of pressure, gradually acquire the normal resistance of uncompressed ice.

The reader has doubtless already perceived the objection which I find suggests itself as an insuperable obstacle to the acceptance of the hypothesis of the central part of the field of ice resting upon water made more or less completely molten by pressure. He will ask how it is possible that this fluid material is not at once driven forward in the direction of the ice front to the point where, on account of the diminished pressure, it would become refrozen. To meet this point, we should attend to certain considerations already presented, though in a somewhat preliminary way, concerning the conditions under which this pressure molten semi-fluid is compelled to advance. It should not be supposed that the central portions of the ice field rest upon a deep sheet of pressure molten water, which would be effectively urged towards the margin of the glacier by the weight of superincumbent material. We have to assume the depth of the ice in the neighboring portions of the glacier which rested upon the bed rock not to differ considerably from that which rested on the fluid material. A very slight difference in the depth of the section would be sufficient to bring about the change from the rigid to the mobile state. The conditions would probably be such as to maintain these two parts of the ice field in a delicate adjustment of their depths. As the central area thickened, thereby increasing the amount of pressure molten water, a portion of the fluid would be squeezed under the ice of the peripheral zone, thereby augmenting the thickness of its section, and at the same time thinning the ice in the central area. In this manner we can conceive the creation of a balance in the impulses and resistances affecting the movement of the ice which was softened by pressure melting, so that the drift of the material toward the margin of the continental glacier would be slow and uniform.

The conditions of our hypothesis require us to suppose that the effects of pressure melting would first be felt in the deeper parts of the glacier, those portions of its mass which lay in the valleys, and that the softening of the ice might there be completely effected while the frozen water was still in contact with the earth at the higher levels of the surface. It thus might well happen that the considerable elevations of the country, those hard parts which had survived under the conditions of ordinary land erosion, would be much more effectively worn down than the rock beneath the river valleys. We can thus account for the destruction of such a prominence as Iron Hill, which was probably a sharp peak of considerable altitude when the glacier began its work, while the neighboring valleys were but little worn by the action of the glacier.

So long as a glacier is receiving a considerable annual contribution of snow which is built into its mass at a low temperature, it may well be that the accumulations of heat due to the work done near the base of the ice would not affect any considerable portion of the central section of the mass. If now for a time the annual snowfall diminished to the point where, by the thinning of the glacier, pressure melting ceased to take place, the whole section of the ice might gradually acquire a relatively high temperature, so that any sudden increase in pressure might bring about very extensive melting. If in this condition of the deposit the amount of snowfall should, for a number of years, be greatly increased, the result might be a great development of pressure molten water, which would be pushed forward towards the margin of the glacier to the point where, owing to the diminution in the thickness of the ice, it could become refrozen. In this way we may perhaps account for those sudden and temporary advances in the margin of the glacier which are so clearly indicated at various points in this country.

No direct verification of the hypothesis above deduced is to be obtained by observation or experiment. The only approach to proof which we can hope to secure is by an inspection of the facts exhibited in the records of glacial action with a view to ascertaining how far they may be explained by the suggestions which we have been considering. Beginning this comparison with the Greenland glacier, the only field where we can find conditions approaching those which existed in the greater ice field of the American continent, we note the following facts. In the marginal portions of the Greenland ice field the slope of the surface towards the sea is tolerably steep, and is rent by numerous crevasses. Gradually, as we pass from the frontal portions of the ice to the interior of the field, these crevasses disappear, and the slope of the glacier becomes slight and unbroken. On the crest there is a wide field where the glacier has the character of a great plain with a slope so slight that we cannot well conceive the movement towards the margin as taking place over the surface of the underlying rocks in the manner in which it occurs near the borders of the sea. These conditions are reconcilable with the assumption that the central part of this great glacier rests upon ice which has been softened by pressure to the point where it no longer behaves with its normal rigidity, but acts substantially as a fluid, while in the peripheral section, that which is beset with crevasses, we have to suppose that the glacier rests upon the bed rock.

Turning now to the conditions of the area on the mainland of this continent, so far as they were effected by the ice of the last Glacial Epoch, we may briefly review the features which are explicable by the hypothesis which we are considering. We note at the outset the fact, to which the reader's attention has already been directed, that the erosion accomplished by the ice in the interior of the glaciated field is often very small. We may now extend this statement by saying that the wearing which has occurred in the central portions of the area occupied by the ice bears no kind of proportion to the depth to which the sheet evidently attained, or to the length of time which it must have remained on the surface. If space permitted, it would be possible to bring up an extended array of instances, such as that cited from the region north of Kingston, Ontario, where in districts in which the glacier must have been very deep and long enduring the erosive work was less than in the marginal parts of the field. These facts do not seem to be explicable on the supposition that the glacier wore the surface over which it lay in a measure at all proportionate to its depth or the continuity of its action. If, however, we suppose that only the marginal zone of the ice prevailingly rested on the surface of the earth, and that a great part of the field lay upon a fluid or semi-fluid stratum of water, the difficulties which we encounter are cleared away.

It seems impossible to explain the motion of a continental glacier on the supposition that the ice throughout the field rests upon the bed rock. Under these conditions it appears necessary for its surface to have a slope towards the margin of some degrees of declivity in order that the sheet may be impelled downward with sufficient energy to overcome the great resistance due to its friction on the bed rock. A slope sufficient to accomplish this purpose would require an inconceivable thickness of ice in the central part of the North American glacier. The hypothesis of pressure melting shows us a way out of this difficulty. We have only to conceive the central parts of the area of the glacier to be freed from the basal friction, to avoid the need of hypothecating a considerable slope of the surface except near the margin of the ice. In this view, the element of friction on the bed rock is substantially reduced to a belt of limited width into which the ice is fed from the areas where pressure melting occurs.

The sudden advances and recessions in the position of the glacial front can be better accounted for on this hypothesis than in any other way. A slight increase in the pressure in the central portions of the field, such as might be brought about by an increased snowfall extending over a term of a few years, would probably lead to the discharge of water rendered more or less fluid by compression into the marginal portions of the area. This would naturally be attended by a sudden outward march of the ice. In this way we may explain the prevailingly wide fringe of territory in the Mississippi Valley which lies to the southward of the southernmost distinct moraine, and which appears to have been temporarily occupied by the ice sheet. This district is covered by a layer of glacial waste, but at its outer margin we find none of those accumulations of detritus which indicate the permanent occupation of a line by a glacial front.

It appears to me that we may by the hypothesis of pressure melting explain the formation of those very thick deposits of till which occur in certain parts of the glaciated area, and this in the following manner. Until a glacial sheet has accumulated to such a depth as to bring about pressure melting, the combined erosion of the bed rock and the irregular movement of the ice near the surface over which it moves bring about the admixture of rocky material with the frozen water to the depth, it may be, of some hundred feet above the earth. If now pressure melting begins, the débris will gradually drop upon the surface, and this action will continue until perhaps all the detritus previously intermingled with the ice has become separated from it. If from time to time the glacier became so far thinned that its solid parts again rested on the bed, the result might be the formation of those striated pavements which have been observed in till deposits. It appears to me not improbable that in the end we may be able to account for the formation of drumlins, those most puzzling of all glacial deposits, by the action of pressure upon ice, the compressive action operating in the following manner.

Let us suppose that a glacier such as covered the drumlin field of Southeastern New England had acquired in the process of its movement a great store of rock detritus, distributed through several hundred feet of the ice which lay next the earth. Let us further suppose that, through the thickening of, the sheet combined with the development of heat near its base, this débris-laden part had been brought to the critical point where very slight increments of pressure would bring the imprisoned water to the fluid state, and lead to the precipitation of the mineral matter, the result would be the rapid formation of a till sheet. Wherever, through the existence of irregularities on the surface of the earth, projections existed of sufficient height to rise into the glacier a little above the level at which complete pressure melting occurred, the ice in its motion would be subjected to a certain amount of strain as it moved over the elevations. As, according to the supposition, the water of the glacier was very near the point of fluidity, we may well conceive that a very trifling resistance, in amount insufficient to exercise any distinct erosive effect on the mass of till, might cause still further melting, and thus bring about an increase in the deposit of débris. In this way the growing drumlin would rise up into the ice to the point where detritus ceases to be supplied, or perhaps to the level where the resistance of the glacial material was sufficient to bring about erosion. Even if the mass did not at first have the shapely lenticular form proper to these elevations, it would, during the subsequent thinning of the ice which probably everywhere preluded the disappearance of the envelope, be eroded to the arched shape which characterizes the deposits.

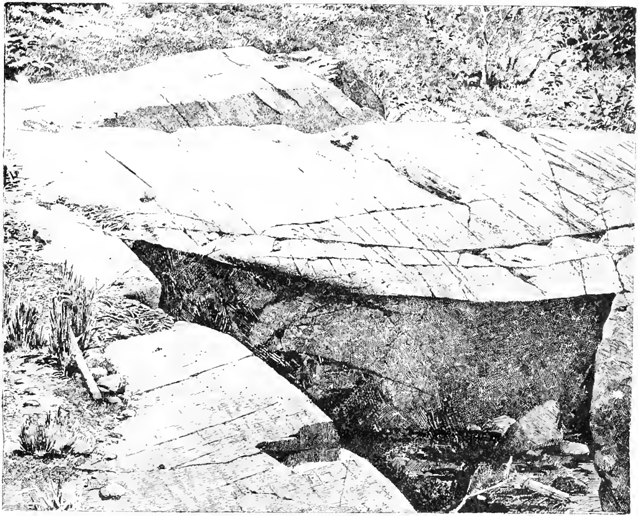
As I propose in this essay only to indicate in a general way the possible value of the hypothesis above set forth, I shall not undertake further to discuss the explanatory value of this view. Enough has been set forth to show that, if it proves tenable, it may serve to rationalize our views as to the mode of action of continental glaciers, by extending our conceptions as to the conditions under which they do their singularly important work. As the considerations which have been adduced are to a certain extent novel and somewhat difficult to grasp it seems to me well in closing to submit them to a brief review. Leaving out of account the minor propositions, we may make the following condensed statement.

In the growth of a glacial mass, the snow is built into it at a temperature below the freezing point, and each annual contribution is ever brought nearer to the surface of the earth, and tends to become molten by pressure. Effective melting near the base of the ice is probably secured by the conditions which make for the development of heat at that level. It is highly probable that, when the ice has attained a depth of a mile or two, its lower part is either converted into water or so far softened that it ceases to be an eroding agent, and may be forced to move in essentially the manner of a fluid towards the zone of less resistance. Arriving at a point where, owing to the thinning of the ice, the pressure is sufficiently diminished, this water gradually refreezes and is rebuilt into the firm glacier, and as such pursues the remainder of its journey. We have thus to conceive a deep glacial envelope, such as that which now covers Greenland, to be divided into two realms; a central, in which the ice does not come in contact with the surface of the earth, and a peripheral, in which it exercises the familiar erosive action on the bed rock.

During the development of a continental glacier, until the sheet had attained a thickness at which the pressure melting action would begin, the whole of the mass would rest upon the surface of the earth. As the inner parts of the field attained the depth which would cause the ice next the ground to become softened or melted, the erosive work would be limited to the peripheral zone. With the further increase in the profundity of the glacier there would be a tendency, rapidly to push outward the peripheral parts of the accumulation where the glacier rested on the bed rock. When, in the closing stages of the period, the ice sheet thinned, this zone of erosion would gradually be withdrawn towards the centre of the field, or towards the point where the glacial conditions lingered longest. In this way we can account for a long continued sojourn of the ice in the fields which we know it occupied, without being required to suppose that the aggregate erosion was very large. If the width of the peripheral zone were, say one hundred miles, and the distance from the centre to the farthest point to which the ice extended one thousand miles, the time during which the eroding zone occupied any part of the surface may have been but a small portion of the duration of the Glacial Period.

The hypothesis of pressure melting enables us to account for various peculiarities of glacial movement which cannot otherwise be readily explained. It seems likely to solve the enigmas presented by the very sudden variations of a temporary nature in the position of the ice front. It appears to explain the way in which the ice journeyed for great distances over surfaces of slight inclination in the direction of glacial flow, or which sloped towards the centre whence the glacial movement radiated, for it limits the friction to the probably narrow zone where the glacier rested upon the earth. The hypothesis will clearly account for the small amount of erosion which is often traceable in the regions which lay in the central parts of the glaciated district, and therefore beneath the deeper parts of the accumulation; for in that part of the field pressure melting was probably first established, and must have continued for the longest time. It furthermore bids fair to explain the very puzzling phenomena exhibited by drumlins or lenticular hills, by showing a way in which, through the thickening of the ice, the rocky matter which it had taken up from the bed rock might be rapidly deposited in the form in which we now find it.

The only justification for presenting such highly speculative considerations as are offered in this writing is that they may serve to explain phenomena which, in the present state of our knowledge, cannot be otherwise rationalized. It seems to me, therefore, that this view may fairly be submitted to debate. I am by no means sure that it can withstand the criticism which it merits, but it seems to me worthy of inquiry on the part of those who are well trained in the interpretation of physical phenomena.

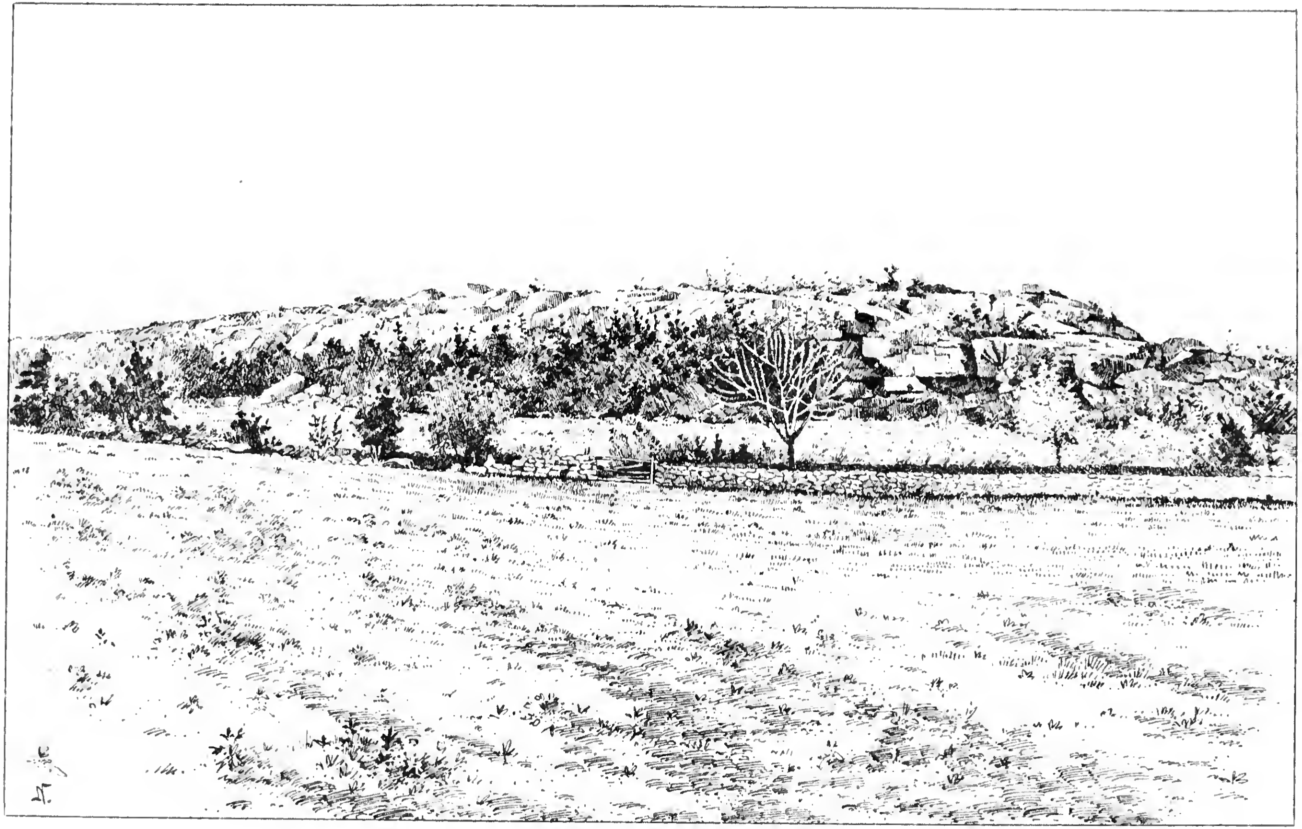


IRON HILL, CUMBERLAND, R. I

SHOWING DIVERSE DIRECTION OF GLACIAL SCRATCHES

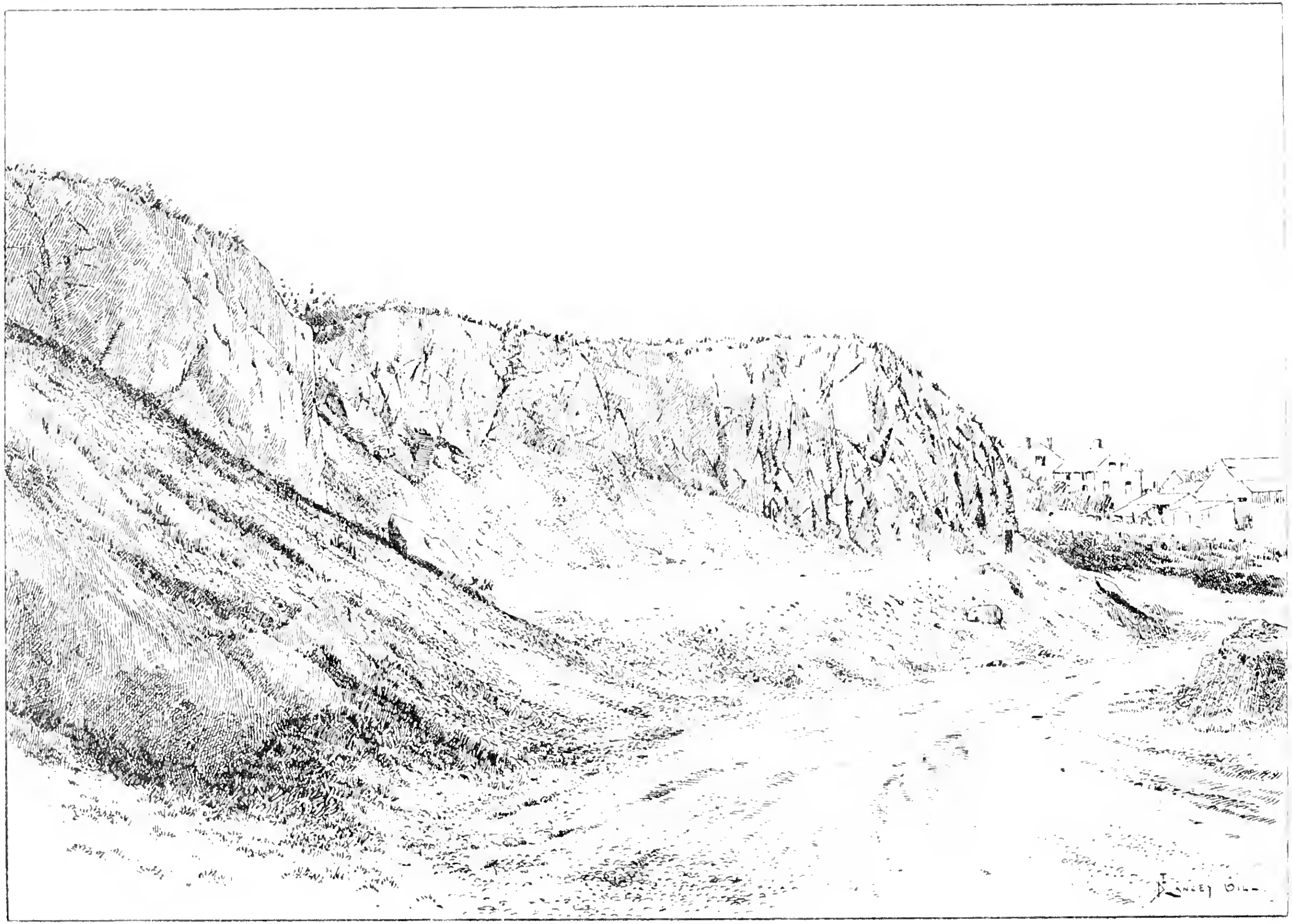
MAP OF A PART OF MASSACHUSETTS AND RHODE ISLAND, SHOWING POSITION OF THE IRON HILL BOULDER TRAIN.

Topography from U. S. Geological Survey 400 ft Contour Map



IRON HILL, CUMBERLAND, R. I.

LOOKING WESTWARD.



IRON HILL, CUMBERLAND, R. I.

LOOKING SOUTHWARD.

IRON HILL, CUMBERLAND, R. I.

LOOKING EASTWARD.

No. 12. — *Contributions from the Petrographical Laboratory of the Harvard University Museum.*

V.*

Acmite Trachyte from the Crazy Mountains, Montana. By J. E. Wolff and R. S. Tarr.

In the progress of the field investigation of the eruptive rocks of the Crazy Mountains, Montana, by one of the writers,[1] in 1889, the occurrence of a group of eruptive rocks was noted, which were distinguished from the theralites and associated rocks by their gray or greenish gray color and somewhat greasy lustre, and of which about a dozen specimens from as many localities were collected for further study.

Field Occurrence. — They were only found in the northern half of the range, in general associated with theralite, and occurring like the latter, and so far as known all the other eruptives,[2] solely as intrusive rocks. The field types can conveniently be classed under three heads: 1st. Dikes cutting the Cretaceous (Laramie?) shales and sandstones; 2d. Small intrusive sheets parallel to the bedding; 3d. Thick, bulging, laccolitic sheets, which may send apophyses into the adjacent shales. In the last form, sheets of the rock have been observed which are a hundred feet thick at the bulge and a mile long, and, conforming with the tilted position of the strata, produce long high ridges with sloping back and steep front. As with the theralite, diorite, and other eruptives of the range, the rock is coarse, almost granitic in the thick sheets, fine-grained and porphyritic in the smaller sheets, dikes, and apophyses.

Acmite-trachyte Type. — When occurring in the latter forms, the rock is of a fresh green to grayish green color, with a somewhat greasy lustre and a conchoidal fracture. Glassy feldspar crystals 5 or 6 mm. long give it a porphyritic character, and smaller augite phenocrysts are com-

* No. IV. Metamorphism of Clastic Feldspar in Conglomerate Schist, by J. E. Wolff.

[1] J. E. Wolff.

[2] Ibid., "Geology of the Crazy Mountains," Bull. G. S. A., Vol. III. p. 445.

mon; in some specimens the rock is dotted with small white crystals of sodalite. In one instance the rock holds large phenocrysts of flesh-colored feldspar in tabular prisms with terminal planes, and is porous owing to the presence of small irregular cavities, whose rough walls are lined with limonite. Plates of biotite are rarely seen. There is a distinct fluidal structure in the dikes and sheets which is visible in the hand specimens by the parallel arrangement of the phenocrysts and a slight fissility parallel to the plane of flow.

Characters in Thin Sections. — *Feldspar.* — In the thin sections of this type the feldspar phenocrysts appear in long rectangular sections, or in broader and less regular crystals. Carlsbad twins are as frequent as single crystals. A certain number of these feldspars polarize homogeneously, and extinguish parallel to the length of the rectangular sections, or nearly so, like sanidine; but in many sections a very fine multiple twinning is present parallel to the brachypinacoid (albite law), and sometimes there is present with this a faint double twinning (microcline structure), or segments are multiply twinned in one direction, which is not the same in adjoining segments of the feldspar. Cleavage sections were prepared from one of these phenocrysts with the following result: —

Basal cleavage (O P) extinction $2\frac{1}{2}°$ to $3°$ oblique to the trace of the 2d cleavage ($\infty P \breve{\infty}$).

Second cleavage ($\infty P \breve{\infty}$) extinction about $9°$ oblique to the trace of the basal cleavage.

Specific gravity of the piece 2.583.

This specimen is therefore a triclinic feldspar intermediate between microcline and albite (*soda-microcline — anorthoclase*) and the anomalous polarization of the feldspar sections in the rock is thus explained. These phenocrysts contain as inclusions apatite, sodalite, augite, ægirine, and biotite. The ægirine needles appear to have formed toward the close of the feldspar period, as they are commonly included in the peripheral portion of the crystal.

Sodalite is present in some specimens, occurring either in crystals large enough to dot the rock macroscopically, or only visible in the section. It appears in the slides in the usual apparent hexagons or squares, sometimes rounded or corroded by the groundmass. The mineral is colorless, with a low refractive index and isotropic, unless zeolitization has occurred. It sometimes contains secondary calcite. The mineral gelatinizes easily with acid, and the micro-chemical tests show the presence of Cl, Na, SO_3, and a little Ca; so that there is a mixture of the hauynite molecule. The specific gravity of an isolated piece was 2.19, which is low for sodalite (2.28), and must be attributed to zeolitization. W. Lindgren has described,[1] under the name "analcite-basalts," basic rocks from the Highwoods (a range lying north of the Crazy Mountains and a locus of similar magmas), composed of olivine, magnetite, a little biotite, and a mineral determined as analcite, but no feldspar or nepheline. The analcite appears in the slides in hexagonal or octagonal sections, clear and isotropic, and was determined to be such by specific gravity and chemical analysis. Lindgren considers this primary. Judging from the descriptions, there is some resemblance to the mineral identified by us in the present rock, without quantitative analysis, as sodalite; but as the latter has the form and other properties of sodalite, and is identical with that mineral as occurring in the granular and porphyritic theralite, this seems the correct determination.

Augite. — The porphyritic augite has planes developed in the prismatic zone, sometimes terminal, and the common orthopinacoidal twinning. In sections the pale green of the centre of the crystals gradually increases in depth towards the edge, which is formed of deep green ægirine, as in the theralites, having the characteristic small obliquity of extinction in the prismatic zone and axis of elasticity, a, near the vertical axis. The augite is generally fresh, and includes crystals of magnetite and sodalite.

The slides contain occasional plates of biotite and grains of magnetite.

Groundmass of the Acmite-trachyte Type. — This is composed essentially of slender lathe-shaped feldspars and acicular crystals of ægirine, which lie either between the feldspars or included in them, and by preference in the outer portion. These minerals appear in sections transverse to the flow with perfect fluidal arrangement; but when cut parallel, many of the feldspar sections are broad and rounded, and contain the ægirine needles in a network without parallel arrangement. The feldspars are therefore somewhat tabular in the plane of flow. Single crystals, Carlsbad twinns, or multiply twinned crystals occur, with extinctions parallel or but slightly oblique to their length, and are doubtless also anorthoclase in part. With the green ægirine a few brown needles of acmite occur. Apatite and magnetite are found in the usual form. The combination of nearly parallel feldspar and ægirine needles gives the former a peculiar feathery look in polarized light with low powers.

1 "Eruptive Rocks from Montana," Proc. Cal. Acad. Sci., Vol III. p. 51.

There is a variable amount of interstitial matter between the feldspars of the groundmass which fills the triangular spaces left by their divergence, or appears as irregular areas in sections parallel to the flow. This substance is colorless, has a low index of refraction, is sometimes fresh and glassy, sometimes clouded by a fibrous substance, showing rarely traces of a rectangular cleavage, and containing scattering ægirine needles. In some cases it polarizes so strongly as to be evidently a tabular feldspar section (or a third generation of feldspar), but generally polarizes feebly, or is completely isotropic, and then gelatinizes with acid. The feebly polarizing part is probably nepheline, and the isotropic clear areas analcime, derived by alteration from the nepheline. The ægirine needles occurring as inclusions in the nepheline or analcime can hardly be regarded as secondary, since they are identical in size and parallel or network arrangement with the ægirine needles so abundant in and between the feldspars, and evidently a primary constituent. Brögger[1] describes undoubted cases of secondary ægirine in analcime, and J. Francis Williams[2] ægirine needles in the analcime of the "gray granite" of Arkansas as secondary, similar in occurrence to those of the Montana rocks. The interstitial element varies greatly in quantity, and may become so considerable as to give the rock a phonolitic character.

All the specimens have the typical trachytic structure.

(Elæolite) — Syenite Type. — This coarse variety occurs in the thick sheets. The rock has a gray color, passing into white as the decomposition of the feldspars increases, and has a tendency to porphyritic structure. The feldspar phenocrysts, unlike this mineral in the groundmass, are in part fresh and glassy, — a fact which assists the optical determination, — and have a fine striation on the basal cleavage. The minerals have an indistinct parallel arrangement, due to flow. The rock is about half as coarse as the "gray granite" (elæolite syenite) of Fourche Mountain, Arkansas, which it resembles.

Character in Thin Sections. — In thin sections the structure is panidiomorphous, the angular spaces between the feldspars being occupied by nepheline. The large feldspars are glassy clear, having the peculiarities of twinning previously described. The outer zones are sometimes opaque, owing to decomposition, and filled with ægirine needles. The extinction angles on basal cleavage sections (O P) (Specimen No. 145) were 2° to 4° to the trace of the second cleavage; and on second cleavage sections (∞ P $\breve{\infty}$) from 7° to 9½° oblique to the first cleavage. The

[1] Mineralien d. Syenitpegmatitgänge, p. 330.
[2] Igneous Rocks of Arkansas, pp. 68 and 79.

specific gravity in most determinations was 2.621, but went as high as 2.623. A sufficient quantity of this feldspar was carefully selected, freed from visible impurities, and analyzed in the laboratory of the United States Geological Survey at Washington by Dr. W. F. Hillebrand, with the following result: —

SiO_2	62.31
Al_2O_3 (containing a very little iron)	22.63
CaO	.63
SrO	.57
BaO	.77
K_2O	4.79
Na_2O	7.68
H_2O at 100° C.	.16
H_2O above 100° C.	.72
	100.26

The optical characters show the triclinic nature of this feldspar, and an apparent homogeneity, even with high powers, excludes its reference directly to a microscopic mixture of microcline and albite (microcline-microperthite of Brögger); it appears to belong in the anorthoclase group of Rosenbusch (soda-microcline of Brögger). The per cent of strontia and baryta is unusual, and only comparable to the baryta and strontia sanidin from the nephelinite from Meiches, analyzed by Knop.[1]

The smaller feldspars occur in long lathe forms, and are more decomposed than the others; in decomposing they become opaque and fibrous. The augite crystals are similar to those of the fine-grained rock, and have the same ægirine border. Independent acicular crystals of ægirine, and sometimes of acmite, also occur. The angular spaces between these minerals are occupied generally by a feebly polarizing substance, which gelatinizes with acid, and is evidently nepheline. In decomposing, it breaks up into strongly polarizing fibrous zeolitic aggregates. Sodalite is rare in the coarse rock, except in the apophyses, or near the contacts of the sheets, where it occurs in small crystals between the feldspars. The coarse rock under these conditions assumes the acmite-trachyte character of the dikes and smaller sheets.

The following analyses of these rocks are presented here, but the discussion of their relations to the other alkaline rocks of the Crazy Mountains is deferred to the monograph in preparation. Nos. 65, 131, and 297, represent the Acmite-trachyte type, and No. 145 the Elæolite-

[1] N. J. Min., 1865, p. 688.

syenite type. These analyses were made by Dr. W. H. Melville in the laboratory of the United States Geological Survey at Washington. For comparison, Analyses I. of Theralite,[1] II. Elaeolite-syenite[2] ("gray granite," Fourche Mountain, Arkansas), and III. Acmite-trachyte[3] (from the Kühlsbrunnen Siebengebirge, Germany), are introduced for comparison : —

	65.	131	207.	145.	I.	II.	III.
SiO_2	58.70	62.17	64.33	59.66	43.17	59.70	64.21
Al_2O_3	19.26	18.58	17.52	16.97	15.24	18.85	16.98
Fe_2O_3	3.37	2.15	3.06	3.18	7.61	4.85	6.69
FeO	0.58	1.05	0.94	1.15	2.67		
MnO	0.10	tr.	0.35	0.19			
CaO	1.41	1.57	0.56	2.32	10.63	1.34	0.49
MgO	0.76	0.73	0.34	0.80	5.81	0.68	0.18
Na_2O	8.55	7.56	7.30	8.38	5.68	6.29	5.13
K_2O	4.53	3.88	4.28	4.17	4.07	5.97	4.41
TiO_2	tr.	tr.	tr.	tr.			
P_2O_5	0.10	0.11	tr.	0.14			
Ig	2.57	1.63	0.95	2.53	3.57	1.88	1.00
Loss at 105°	0.07	0.07	0.04	0.07	SO_3 0.94		
	100.00	99.50	99.67	99.56	99.39	99.56	99.09

Comparison with other Acmite-trachytes. — In chemical and mineralogical composition and habitus, the fine-grained rocks are almost identical with the classical acmite-trachyte from the Kühlsbrunnen in the Siebengebirge. The microscopic characters of the German rock are given in Rosenbusch, (Mik. Physiog., Vol. II. p. 599,) where it is stated that the rock, when weathered, is filled with peculiar round pores, which do not exist in the fresh rock, but are there represented by areas of a brownish yellow isotropic, or partly cryptocrystalline substance, which is occasionally developed in radially built spherulites of positive character, a single spherulite occupying the space of a subsequent cavity. In slides from a very fresh specimen of the German rock collected by one of the writers, the yellowish brown color of these areas is very faint or

[1] J. E. Wolff, Petrography of the Crazy Mountains, 1885.

[2] Williams, *loc. cit.*, p. 81.

[3] G. Bischof, in Von Dechen's Geogn. Beschr. d. Siebengebirges. Ver. d. Preuss. Rh. und West., Bd. IX. p. 340.

lacking; they are in some cases isotropic, have often a polygonal shape, and the acmite needles, which are abundant in the rock, arrange themselves parallel to their sides when in proximity; they also gelatinize strongly with acid, and thus resemble the small irregular sodalite crystals of the Montana rocks. The feldspar phenocrysts of the Siebengebirge rock have the triclinic twinning described above, and thus the two rocks are nearly identical, at least for the American variety with little nepheline.

The *Syenitic type* resembles in appearance and structure the elæolite-syenite ("gray granite") from Arkansas, described by J. F. Williams, in chemical and mineralogical character. It is closely allied to the Montana rock, excepting that it has more nepheline, and that the feldspar was referred by Williams to the microcline-microperthite of Brögger (a microscopic interlamination of microcline and albite), while the reasons are given above for considering the feldspar of the Montana rock a microscopically homogeneous triclinic soda-potash feldspar. Lindgren (*loc. cit.*) has described as "augite-trachytes" rocks from the Highwood Mountains closely resembling these.

The previous descriptions illustrate the dependence of rock structure on physical conditions of cooling, which is so striking a feature of the eruptive rocks of this range, the syenitic or trachytic character of the rock depending on the variation in the thickness of the rock mass.

CAMBRIDGE, MASS., January, 1893.

No. 13. — *Reports on the Dredging Operations off the West Coast of Central America to the Galapagos, to the West Coast of Mexico, and in the Gulf of California, in charge of* ALEXANDER AGASSIZ, *carried on by the U. S. Fish Commission Steamer "Albatross," Lieut. Commander* Z. L. TANNER, U. S. N., Commanding.

[Published by permission of MARSHALL McDONALD, U. S. Fish Commissioner.]

V.

Report upon Rocks collected from the Galapagos Islands. By GEORGE P. MERRILL.

So far as the present writer is aware, the volcanic rocks of the Galapagos Islands have been the subject of but little investigation. Darwin in his "Voyage of the Beagle" (pp. 372 *et seq.*) describes the islands as volcanic, and the character of the material as black basaltic lava with scoria and tuffs. Naturally, his studies did not at that time include an examination of thin sections under the microscope. A more detailed description of the rocks of these islands is given by Dr. F. A. Gooch, in Tschermak's "Mineralogische Mittheilungen" for 1876 (pp. 133 *et seq.*). According to the latter, the volcanic materials examined by him are all of a basaltic character, and in part closely correspond to those at present under consideration. Dr. Gooch's specimens were however from the islands of Bindloe, Abington, Hood, and Charles, none of which localities are represented in the series received from the Fish Commission.

A reference to this paper is however of importance. How well the speicmens now examined represent the sources from which they were taken, the present writer has no means of deciding. It is assumed that they are fairly typical.

Of the numbers given below, the first is that of the specimens as now entered upon the Museum Catalogue, and the second, enclosed in parentheses, is that by which the specimen is known in the records of the Fish Commission.

67526 (8110). Basalt. Wreck Bay, Chatham Island: near hacienda of Mr. Cobos. This is an ordinary basalt, consisting of a dark gray vesicular mass, which in thin sections is seen to be made up of faint wine-colored augites in very irregular forms, lath-shaped plagioclases, small opaque particles of iron ore, and numerous large, clear, faintly greenish blebs of olivine. No. 67527 (8111), from the same locality, offers no difference worthy of note.

67528 (8113). Basalt. Landing on northwest face of Malpelo Island. This rock much resembles the last in mineral composition and structure, with the exception that extensive alteration has badly obscured the groundmass, and given rise to abundant chlorite, epidote, calcite, and sundry ferruginous decomposition products. The presence or absence of a glassy base cannot with certainty be determined. In the hand specimen this is a finer grained, more dense rock than 67526 or 67527, and shows small amygdaloidal cavities filled with a white zeolite. The general aspect is that of an older rock than the others (perhaps a melaphyr) though obviously it will not do to speak too positively from an examination of the section alone.

67531 (8116). Andesite (?). Near Chatham Bay, on Cocos Island. In the hand specimen this is a light brownish gray, fine-grained, in some cases vesicular rock, studded with small (1–2 mm.) white specks indicative of feldspar, but in which none of the constituents are of such size as to be accurately determined by the eye alone, or even when aided by the pocket lens. The thin section under the microscope shows a dense aggregate of stout feldspars which are in part sanidins and in part a soda-lime variety, obscurely striated, and occurring in stout lath-shaped forms. The structure is indistinctly granular, and occasionally slightly porphyritic through the development of the larger feldspar above noted. So far as observed there is no interstitial glass. Abundant red ferruginous and opaque hornblendes, granules of iron ore, minute colorless apatites, and ferruginous decomposition products complete the list of determinable constituents.

A rough analysis yielded results as below. This indicates that the rock is more nearly related to the andesites than trachytes, though abnormally rich in potash. The rock was found to contain a notable amount of free sodium chloride, derived presumably from ocean spray, which may in part account for the high percentage of soda.

	Per Cent.
SiO_2	56.50
Al_2O_3, Fe_2O_3	28.20
CaO	2.83
MgO	.98
K_2O	4.25
Na_2O by difference	6.68
	99.44

WASHINGTON, D. C., October, 1892.

No. 14. — *Contributions from the Petrographical Laboratory of the Harvard University Museum.*

VI.

A Basic Dike in the Connecticut Triassic.[1] By L. S. Griswold.

Occurrence.

Loose boulders of the rock to be described in this paper have been known for some time to Mr. S. Ward Loper, but the rock was first found in place by Mr. J. C. Graham of Wesleyan University while at work for the United States Geological Survey. It occurs as a dike, exposed on the outlet of Beseck Lake, about a quarter of a mile west of the Air Line Railroad at Baileyville. The dike intersects the shale just underlying the "posterior" or uppermost trap flow of the Triassic series of Connecticut. A small fault of about six inches was noted in the dike.

Physical Characters.

The rock is dark colored, almost black, and dense. The specific gravity (average of three determinations) is 3.036. It attracts attention by the great number and large size of the black phenocrysts contained, also to some extent by the small spots of a white mineral. The rock is very fresh immediately below the weathered surface.

Examined with a magnifying glass the phenocrysts are found to be of augite, hornblende, and an occasional large biotite. The maximum diameter of the phenocrysts is perhaps ¾ inch (19 mm.). The spots of white mineral give a brisk effervescence with cold hydrochloric acid, so they represent secondary fillings of cavities by calcite. The calcite frequently occurs in the phenocrysts as a decomposition product.

Microscopical Examination.

With the microscope two divisions of the components of the rock can be made: the phenocrysts, comprising perhaps a third of the total mass,

[1] Published with the permission of the Director of the United States Geological Survey.

and a fine groundmass. Among the phenocrysts augite greatly exceeds hornblende, biotite is rare. The hornblende crystals are brown and strongly pleochroic; they have lost their crystal angles and show rounded resorption outlines. The same is the case with the few pieces of biotite seen. With the augite, however, it is different; this mineral appears commonly with complete or partial crystal outlines, though some show the rounded resorption form. It is evident that most of the augite crystals were formerly rounded and have gained the angular form by a later growth in the magma, for irregularly rounded cores can be distinguished surrounded by portions having different extinction angles. The structure thus given closely resembles zonal structure; zonal structure does sometimes occur in these secondary borders. The older portions of the crystals are pale green in color, the borders are pinkish; in one case the pink border is pleochroic, pink to greenish yellow.

The phenocrysts of hornblende and augite may each contain rounded inclusions of the other mineral, inclusions of the augite in the hornblende being much more common. Thus there seem to have been five stages in the crystallization of this magma: first, a time when hornblende and augite formed in good-sized crystals; second, these crystals were resorbed until they became rounded grains; third, another separation of large crystals of augite and hornblende, which often enclosed indiscriminately and without crystallographic relation the grains above mentioned; fourth, this second generation of augite and hornblende underwent resorption sufficient to destroy the crystal outlines; fifth, a final separation of augite, renewing the crystalline form of the augite phenocrysts, and probably taking place at the same time as the crystallization of the groundmass. The inclusion of hornblende crystals in augite, as well as the converse, has been noted before,[1] but the peculiar association above noted is perhaps new. The accompanying plate shows the essential points above mentioned. Both varieties of phenocryst also contain inclusions of calcite; the frequent occurrence of iron oxide with this calcite may indicate that the calcite fills cavities left by the solution of the iron oxide.

The groundmass is composed chiefly of minute augite crystals of a pale pink or green color, closely compacted together. Magnetite in fine crystals is abundant, perhaps composing a third of the bulk of the groundmass. Small crystals of brown hornblende are common, but compose no considerable percentage of the mass.

[1] J. F. Kemp and V. F. Marsters, Amer. Geol., August, 1889. Also J. F. Kemp, Amer. Geol., March, 1890.

Occasional small structureless areas are seen which with crossed nicols polarize feebly or are isotropic ; one instance was noted where there was the faint appearance of a few minute lath-like forms in radial arrangement, as though plagioclase crystals had separated from a glassy magma. This mineral gives no gelatinization with hydrochloric acid. On separating the rock powder by gravity solutions, grains of this mineral settled between 2.80 and 2.60, and more came down between 2.60 and 2.51. Microchemical tests with hydrofluosilicic acid on these grains gave pretty abundant cubes of potassium and some prisms of sodium, the thorn-like forms of calcium were also noted. This substance would thus appear to be of a feldspathic nature and not nepheline since it did not gelatinize. This determination would be of importance were the quantity of the mineral large, but it perhaps does not compose more than one per cent of the rock mass.

Classification.

Since the study of this rock has begun, a complete chemical analysis has been found necessary to determine its position definitely ; until this has been made, only the possibilities can be given. The rock has much in common with the group of Fourchites of Dr. J. Francis Williams.[1] If it is regarded as belonging to this group, and is named according to the predominating minerals, it would be called an augite amphibole fourchite. The occurrence of a feldspathic constituent rich in potassium in the rock would tend to exclude it from this group, however, since these rocks properly contain a lime-soda feldspar, nepheline or leucite ; for this reason it may seem better, since the amount of this constituent is very small, to associate this rock with those of the pyroxene group (pyroxenite) although these have been regarded as containing no feldspathic constituent. In this latter case this would be the first dike rock of the group.

This dike is interesting as being the first of the group of basic dikes found in the Eastern United States which has a geological age determinably later than the Carboniferous ; the rocks which it intersects being above the middle of the Connecticut Triassic. Of course the idea that it is of later age than the Triassic is not excluded, though the fact that it is broken by a small fault might be brought forward as an argument for the intrusion of the rock before the time of deformation, which is conceived to have followed closely the Triassic deposition. The wide difference in character between this rock and the Triassic effusives may

[1] Arkansas Geol Survey, Ann. Rep., 1890, Vol. II p. 107.

indicate something with regard to relative ages. The effusives are fine-grained olivine diabases, in which the augite crystals are much decomposed. The freshness of the dike rock would indicate that it is much younger.

Most of the basic dikes of the Eastern United States previously described, and having a near relation to the above, have been Camptonite; in Northern New Jersey, however, some dikes have been noted by Prof. J. F. Kemp,[1] which he decides are practically identical with the Ouachitite of Arkansas, and with the Ouachitite the relation of the Connecticut dike is close. If this Triassic dike rock is finally placed in the Fourchite group, it will be the second occurrence outside Arkansas of the rocks of the group.

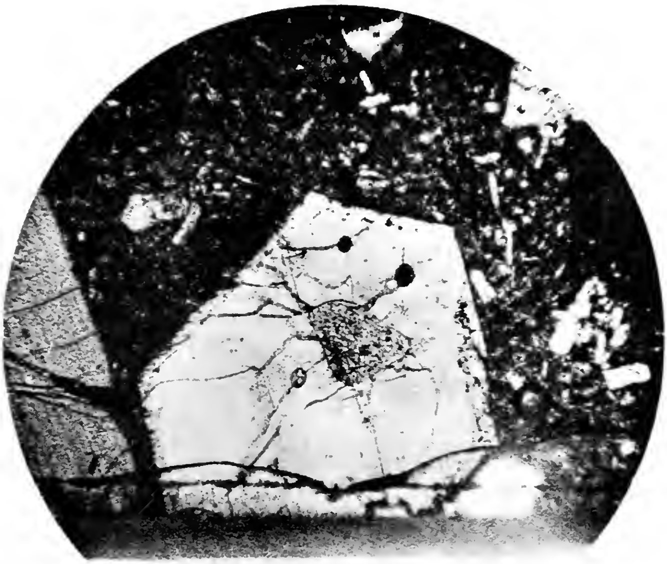
[1] Arkansas Geol. Survey, Ann. Rep., 1890, Vol. II. p. 403. Also Am. Jour. Sci., April, 1893.

Petrographical Laboratory, Harvard University,
June, 1893.

DESCRIPTION OF THE PLATE.

Reproduced by the artotype process from a micro-photograph taken with polarizer only. The enlargement is 23 diameters.

The plate shows an augite phenocryst having a border of secondary augite and enclosing a resorbed grain of hornblende of the first generation. A portion of a resorbed hornblende crystal of the second generation is also shown. Some of the larger augite crystals of the groundmass are distinguishable.



No. 15. — *Notes on the Geology of the Island of Cuba, based upon a Reconnoissance made for* Alexander Agassiz. By Robert T. Hill.

LETTER OF TRANSMITTAL.

Washington, D. C., May 1, 1894.

Dear Sir: — I beg to submit the following report upon my recent studies in Cuba, undertaken at your expense and under your direction.

I left Washington, D. C., Sunday, February 11, arriving at Havana on the following Wednesday. A day was spent in Havana to ascertain the most feasible methods of working. I then made a reconnoissance east to Villa Clara, from which point a reconnoissance was made north and south across the island. This trip was made primarily to obtain some knowledge of the interior of Cuba. I was accompanied by some American engineers who were familiar with the island, and who were of great assistance to me in my subsequent operations. Returning from Villa Clara to Havana, I stopped at several points, including Matanzas and neighboring places. There were many opportunities to study the basal contacts and structure of the limestones in relation to the older nucleal area of Cuba upon which they were deposited. At Matanzas I made a thorough study of the cut of the Yumuri River of Matanzas, and of the limestone formations composing the Pan de Matanzas and the country to the interior, as set forth in the following pages. Returning to Havana from Matanzas, I spent a few days studying the geology of the site of that city and its environs, and in making a north and south section across the island from Havana to Batabanos.

On February 28, a coasting steamer was taken from Havana for Baracoa, which stopped for four or five hours at various points on the way. I arrived at Baracoa on the 4th of March. With Baracoa as a base, I made a study of the country west of Yunque mountain and east to Cape Maysi, taking a trip up the Yumuri River of the east.

I sailed from Baracoa on the 13th of March, arriving at Philadelphia on the 18th.

I wish to acknowledge my obligations to Mr. E. Sherman Gould, of New York, Consulting Engineeer of the Havana Water Works; Rev. Lorenzo J. Arrubla, of Real Colegio de Belen, Havana; Señor S. Fortun, Chief Engineer of the United Railways of Havana; Hon. A. B. Dickey, Consular Agent of Baracoa, and many others throughout the island, for valuable data furnished; also to Prof. W. H. Dall of Washington, for his valuable assistance in paleontologic determinations of the age of the rocks discussed herein.

Looking back at my expedition, I now see many points which I would like to examine again, but I hope that, upon the whole, you will not be dissatisfied with the results.

Very truly yours,

ROBERT T. HILL.

To ALEX. AGASSIZ, Esq., Cambridge, Mass.

INTRODUCTION.

Paleontology, stratigraphy, and physical geography are the three co-dependent criteria by which geologic history is interpreted. A proper study of the paleontology of Cuba requires years of residence and patient labor by an expert in Cenozoic and Mesozoic fossil forms. The structural geology, involving vast petrographic research and tedious travel, likewise demands long study; the thick residual soils, the dense vegetation, and the absence of highways and general lack of exposures everywhere, retard the worker in these branches of geology. While geologic research in these fields has already given us criteria without which the present paper would have been impossible, the topographic forms reveal a story equally interesting and more intelligible, and in the following pages I have endeavored to interpret them, with such assistance as could be derived from the co-ordinate branches of paleontology and structure.

Literature contains many descriptions of the general geography and geology of the island, — especially the works[1] of Humboldt, Salterain, Suess, Crosby, Ramon de la Sagra, Don Manuel Fernandez de Castro, and the various publications of Mr. A. Agassiz. Don Manuel Fernandez de Castro's brief pamphlet, accompanied by a geologic map, is an excellent résumé of the stratigraphy and paleontology of Cuba, and should be consulted by any one contemplating the perusal of the present paper. Mr. Agassiz's investigations have made known to science the wonderful topography of the surrounding ocean floor. M. Elisée Réclus has recently compiled the general physical and political geography of the island as ascertained by previous investigators, and its relation to the surrounding seas and the West Indian archipelago. Professor Suess has compiled a chapter on the Antilles, setting forth the present state of knowledge concerning the geology of the island of Cuba. These, together with Salterain's description of the geology of Havana, have explained in a preliminary way the geography and geology in a manner to prepare for an intelligible discussion of the topographic evolution of the island, by which its history may in part be finally interpreted.

[1] The titles of these publications are given in notes accompanying the references to them.

I preferred to examine the phenomena entirely *de novo*, so as to be influenced by no preconceived hypotheses, and hence made no study of these writers until my report was formulated. After outlining this paper I examined this literature, and I hope that the present discussion of the topographic and diastrophic phenomena will further advance the work so well begun by others. I am also glad to affirm, with a few minor exceptions, the views of the structure set forth by these earlier writers, and I would earnestly request those who read this paper to consult them.

I. ELEMENTARY GEOLOGIC STRUCTURE.

The Pre-Tertiary, Metamorphic, and Igneous Foundation. — This is a floor of ancient (certainly Pre-Tertiary) rocks, consisting of serpentine and igneous material, mostly basic in aspect. These are exposed by erosion at various points throughout the island, but, except in the Santiago region, they seldom, if ever, form the rocks of the immediate coast, although often found quite near it. They now underlie most of the island at no great depth, and are exposed in many drainage cuts beneath the limestones. Wherever I have seen these rocks — at Villa Clara, Havana, and near Baracoa — they had once been covered by the Tertiary limestones, but I cannot speak with certainty concerning the province of Santiago de Cuba, where, according to Kimball, traces of limestone as high as 2,300 feet are preserved on the south side. On the north side, opposite Santiago, they are certainly overlapped far interiorward by the limestones. Some of the igneous and metamorphic rocks of the Santiago region may be of later origin and intrusive through the limestone, but generally throughout the island they have been completely covered by the latter. No Post-Tertiary eruptive sheets were seen by me except one small dike which intrudes into the greatly folded limestone near the water-works back of Havana. (See Plate I. Fig. 3.)

These older rocks consist of diorites, serpentines, schists, and rarely granites, as reported from Santiago; of serpentines, greenstone, porphyry, and basic igneous rocks brought down by the rivers of the north side of the east end of the island; of serpentine and metamorphic rocks with little quartz, as seen underneath the limestone in the vicinity of Villa Clara; and of serpentine, tuffs, and old volcanic material, as back of Havana.

The rare presence of eruptives and of sedimentaries older than Cretaceous, reported by De Castro and occasionally seen by me in this old complex, testifies that in Pre-Tertiary time the old metamorphic floor protruded above the level of the sea as a land area, during a period of active vulcanism. From their composition and occurrence there can be little doubt that they once formed an ancient land area of unknown size and relations, but certainly almost as large as the present island, which was partly or completely submerged during early Tertiary time.

The Pre-Tertiary Sedimentaries. — Resting upon this metamorphic and igneous foundation at various places there is a formation of stratified, non-fossiliferous, sedimentary clays. These are older than the Tertiary limestone, and apparently immediately preceded them in origin. They are not of great thickness, and are void of determinable fossils wherever I have observed them. In the Havana section, in the southern suburbs of the city, only a few feet are exposed beneath the old limestone in contact with the underlying tuffs. They are here green in color, and somewhat unctuous.

In travelling overland toward Villa Clara, I found that the limestones extend beyond Colon, but between that place and San Pedro they are eroded through down to the underlying clay formation, which extends from there continuously east to Villa Clara, being best exposed at Esperanza. Here the railway has cut across a low anticline of clays which show well defined stratification planes and alternate strata of softer and harder beds. In general they consist of (1) an upper division of light colored, laminated, thinly banded clay, with persistent bedding, of which twenty feet are here exposed, and (2) a lower series of coarser beds, the harder persistent strata being loosely cemented and having a mealy consistency, with siliceous pebbles, while the alternate beds are laminated. About one hundred feet of these are exposed. These clays are folded and slightly faulted in places.

I could find in these beds no fossil remains except one poorly preserved plant impression, a monocotyledon, which, with the general character of the material, gave the impression that these clays were deposited when the conditions of sedimentation around Cuba or in Cuba were far different from those of the present, and, to a certain extent, they indicate a previous land. I cannot say positively that the Esperanza clays are identical with the clays of Havana, but both occupy the same relative position between the Tertiary limestones and the metamorphic formation, and both are exposed by the erosion of the limestone from above them.

De Castro refers these clays of Esperanza to the Cretaceous period, upon what ground, except stratigraphic position, I cannot say. He reports other Mesozoic sedimentaries at both ends of the island, together with Ammonites and Radiolites, which would clearly indicate the occurrence of Cretaceous deposits in Cuba.[1]

The Esperanza clays with plants disclose a Pre-Tertiary land accompanied by erosion, but its area and extent I cannot interpret. There are indications that these clays have been metamorphosed into schists in places, as may be seen nine miles north of Villa Clara, where the anticlinal rocks overlying a vast intrusive bed of asphaltum show many evidences of transition. This idea, however, is at present merely a suggestion.

Formations of the Tertiary Subsidence. — In strong contrast with the Esperanza clays and the older metamorphic floor are the Tertiary and later limestones which cover them, and which are the predominant geologic feature of Cuba. These certainly once extended over all the island, with the possible exception of a small portion of the high mountainous region before mentioned, in the vicinity of Santiago de Cuba. They still occupy by far the greater portion of the whole area. The study and classification of the limestone complex is difficult, owing to the folding, induration, and erosion, the thick covering in places of residual soil and vegetation, the universal alteration they have undergone through solution and internal changes, and the general concealment by tufaceous incrustation of well defined stratification planes and partings. The limestones are clearly divisible into the two general categories of the newer and the older, or basal. The former consist mostly of unfolded rocks of undoubted coral reef origin, and occur on the lower levels adjacent to the coast, while the latter, if of coral reef origin, have lost all characteristic features of rocks of such origin, are undulated and folded, and constitute the uplands and high coastal scarps against and around which the later coral rock grew.

The more ancient limestones nearly everywhere constitute the upland of the island, and by alteration and underground decay have lost their coralline structure, if they ever possessed it. These, so far as my observations extended, constitute all the limestones of the island above an altitude of one hundred feet. These older limestones are diverse in texture and composition. Where good exposures are obtainable, they usually exhibit well defined stratification and separation planes, never seen in the undoubted reef rock, and sometimes alternate with more

[1] Pruebas Paleontologicas de que la Isla de Cuba, etc., por Don Manuel Fernandez de Castro, Madrid, 1884, p. 6.

marly or very slightly siliceo-argillaceous beds. The limestone beds have been well described lithologically by Sagra, as follows : —

"It is white in color, or light yellow, with a fracture sometimes smooth, sometimes conchoidal, containing some concretions, — very often casts with petrifactions. The fossil substances enclosed in the limestones are very abundant. . . . The porous beds of the middle part of this locality, as near Batabano, resemble those spongy and calcareous banks of the Jurassic of Francone, near Dondorf, Pegnitz, and Tumbach. These yellow cavernous beds, which show cavities from four to five inches in diameter, alternate with others entirely compact and less charged with petrifactions. The line of hills which border the valley of Los Guines toward the north, and which unite the hills of Camoa and the Tetas de Managua are of this last variety, the color of which is a rosy white, sometimes almost lithographic, like the Jurassic limestone of Pappenheim The compact and cavernous beds contain small ferruginous masses, and are the same formation that Humboldt designated the Calcarie de los Guines, which is exposed on the southeast near Trinidad, on the hills of San Juan, already referred to, and on the north coast, near Matanzas. In these different localities it exhibits grand subterranean cavities, where rain water accumulates, and in which many considerable streams submerge."[1]

I might add to this description the remark that these rocks bear a striking lithologic and structural resemblance to the Neocomian and Middle Cretaceous rocks of Texas.

Although distinctly stratified, the limestone is irregular in texture. While it is, in general, of a cellular structure, a cubic foot of it in any locality exhibits great irregularities in hardness and compactness. There are spots so hard and crystalline that it is difficult to break them with a hammer ; other spots are firmly crystalline and banded ; still others are rounded indurations ; and again there are soft, pulverulent spots. All of this irregularity of texture is secondary, or in a condition of alteration produced by aqueous solution. In some places the cellular cavities are many feet deep, while the remaining portions are indurated into sharp edges of coarse, sometimes crystalline limestone. So completely has the work of solution and interstitial change gone on that it is doubtful whether the original nature of the rock is anywhere well preserved.

This weathering and induration is very similar to that which I have often noticed in the chalky Lower Cretaceous limestones of Texas. On the resisting summit points the rock is hardened and worn into the peculiar Liliputian ridges known in the Alps as "Karrenfelder," while

[1] Histoire Physique de Cuba, Tom. I. p. 109.

the steeper bluffs are thickly coated with "tepetate," or tufaceous deposits. Great caverns abound in these rocks in many parts of the island.

These limestones have been so greatly altered since their original deposition that, from macroscopic examination, it is difficult to tell their original character or the conditions under which they were deposited. They certainly do not anywhere exhibit the enormous proportions or abundance of coral remains so apparent in the reef rock, nor do they show, except occasionally, an abundance of casts and moulds of molluscan shells, and I seriously doubt whether, as alleged by Crosby[1] and Kimball,[2] and formerly by A. Agassiz,[3] they are coralline in origin, as in the modern reef rock. They sometimes contain traces of coral, but I do not think this proves that they were reef rock, for all corals are not reef building, and the organic remains are far more abundantly molluscan than coralline. Neither can they be called chalks, although very foraminiferous in places, for they are too coarsely crystalline, clastic, and molluscan, and lacking in that fineness and uniformity of texture seen in the chalky limestones, which I have had considerable experience in studying. In places at their basal contact they are certainly detrital, showing (as at the reservoir south of Havana, where they are in contact with the older series of clays and serpentines) a distinct conglomeratic structure, and being composed largely of shell fragments and beach wash. Near Villa Clara they contain very small fragments of igneous material derived from the older rocks which they buried. In many places they are distinctly sedimentary, as seen in the Castillo Principe Plateau west of Havana, where they contain alternations of stratified, slightly yellow argillaceous layers, while the several hundred feet exposed in the cañon of the Rio Armendaris, south of Havana, exhibit far more molluscan remains than coral, although some corals are present. Likewise at Matanzas the older limestones exhibit every character of sedimentaries with molluscan remains, rather than coral reef structure. At Baracoa, Nuevitas, and elsewhere on the west coast, the limestones not only appear to be sedimentary, but they alternate with beds of a yellow argillaceous and arenaceous material, clearly sedimentary, and containing great numbers of molluscan fossils. In fact, I do not believe that any of the limestones below No. 2 of the Matanzas section (Plate II. Fig. 4) are of reef rock origin, but am of the opinion that they are mostly organically and chemically derived sedi-

[1] On the Elevated Coral Reefs of Cuba. Proceedings of the Boston Society of Natural History, Vol XXII pp. 124–129.

[2] American Journal of Science, December, 1884

[3] Bull. Mus. Comp Zoöl., Vol. XXVI No. 1, December, 1894

ments of marine lime mixed with the calcareous débris of the life of the ocean's margin, with, in places, an almost imperceptible proportion of the finer physical sediments of the nucleal island.

While these limestones and alternating beds have a great areal extent, it would be a mistake to assign to them a proportional thickness, for accurate measurements will not make their thickness anywhere greater than one thousand feet. I estimated from the dips in the Rio Armendaris section that they were from eight hundred to one thousand feet; the incomplete section in the cañon of the Yumuri of Matanzas reveals eight hundred feet; the canon of the Yumuri of Baracoa shows six hundred feet; the summit of Yunque displays less than one thousand feet; while the section from fourteen kilometers south of Havana to Batabano is not over one thousand feet. (Plate II. Fig. 1.) In fact, they may be said to constitute a comparatively thin veneering over the old metamorphic floor.

The old limestone formations occur from end to end of the island, and extend in many places completely across it down to water level. Their continuity is interrupted only by erosion along the central axial region, and only the low portion adjacent to sea level is covered by later deposits. De Castro's geologic map of Cuba[1] shows in an excellent manner their general disposition. In places, as between Mata and Yumuri, they form the north wall of the coast. They cap the highest eminences of the island seen by me, overlooking all other rocks, being overreached only by the Sierra Maestro, the geology of which is unknown. Their close proximity to the north coast and their abrupt protuberance above the newer formations have an important bearing on the history of the island as a whole. So extensive is this old limestone formation, and so abruptly does it rise above the coast, that, if all the coastal formations were stripped away, or if the island should subside for one hundred feet, its superficial extent would hardly be perceptibly diminished or its outline materially altered.

The greater part of these limestones seen by me are of Eocene and Miocene or of Pliocene age, as alleged by De Castro. In the Armendaris section, near Havana, they are both Eocene and Miocene, as has been asserted by De Castro and others, and as is shown by my collections.[2]

[1] Croquis Geologica de la Isla de Cuba, por D. Manuel Fernandez de Castro, ampliado por D. Pedro Sallerain y Legarra. 1869–83. Printed in Vol. IX. of the Congreso Internacional de Americanistas.

[2] The determinations of age in this paper are based upon the paleontologic determinations of Dr. William H. Dall, of the U. S. Geological Survey, who kindly examined the material collected.

At Baracoa the upper layers are Miocene. Humboldt, De Castro, La Sagra, and others have recognized the Tertiary age of these limestones, and their distinctness from the modern reef rock, or soborուco. Concerning them De Castro says: —

"The Tertiary terrane in the island of Cuba is more important in view of the great extent it occupies, the abundance of its fossils, and various circumstances which are peculiar to it, and which would supply matter for a long discussion. I shall have to confine myself, however, to saying that at one time it must have covered nearly the whole surface of the island, judging by what still remains of it, notwithstanding the denudation which it has undoubtedly suffered. A glance at the sketch will serve for a description or enumeration of the localities where it is found,[1] although it is probable that, when the whole territory of the island is studied as has been the immediate vicinity of Havana, Matanzas, Cienfuegos, and Santiago de Cuba, part of the color representing the Tertiary terrace will have to be replaced by colors indicating older formations, which, like the Cretaceous, have not yet been recognized owing to lack of data.

"The presence of *Carcharadon megaloden*, belonging exclusively to the Miocene period in Europe, although found in America also in the Eocene; the abundance of *Orbitoides mantelli*, a foraminifer which in the United States characterizes a bed belonging to the Upper Eocene; the occurrence of Orbitoides at many points, as in the vicinity of Pinar del Rio, at the western end of the island of Cuba, and at localities on the eastern part of the island of Santo Domingo, forming an extensive horizon, would permit the exact determination of the age of the different beds above and below those containing this foraminifera. For the present I will confine myself to saying that in Cuba there undoubtedly exist deposits of the three periods into which the Tertiary is divided, because among seventy genera and more than two hundred species of fossils thus far found, there are, besides those of the Eocene and Miocene, a great number which belong to the Pliocene.

"The Eocene is perfectly represented, and there are many fossils which, if they are not identical with those referred in Europe and India to the Nummulitic, greatly remind one of them. . . . It may be said that in Cuba the existence of the Miocene and Pliocene has more evidence, in view of the abundance of fossils distinguishing those ages."[2]

It would be desirable to make a complete study of these old tertiary deposits, but it would require years of careful paleontologic and stratigraphic investigation. The observations made by me at various localities were not sufficiently numerous to enable the construction of a generalized section, or to permit deductions concerning the permanency or continuity

[1] Found also by me in the Armendaris section near Havana.

[2] Pruebas Paleontologicas, p. 7.

of the horizons and the alternations of lithologic material shown in the local sections, such as the great beds of fine siliceous and argillaceous mixtures with the lime, as noted at Matanzas and seen from there east to Baracoa, forming thick strata of yellow material, containing, at least at Baracoa, Miocene Mollusca and corals, as determined for me by Dr. Dall and Mr. T. Wayland Vaughan. (Plate I. Fig. 5. 3.)

The slightly arenaceous yellow beds outcrop at Nuevitas, Gibara, and many other places along the coast, and are included between thicker strata of limestone, and I think they are underlain by several hundred feet of that material, and belong near the limestone capping Yunque and the Yumuri bluffs. These yellow bluffs underlie the soboruco reef at Baracoa, and are capped by a thick stratum of old limestone back of the city. The harbor is largely formed by their undermining. They are also well developed beneath the old reef points of Mata Bay.

A peculiar rock material in the old limestone series at Baracoa, and not seen elsewhere, is a hill (Plate I. Fig. 5. 4) of almost vertically stratified siliceous material, which at first sight resembles gray chalk, but has the light specific gravity of some of the diatomaceous earths. Under the microscope this material is found to be composed largely of siliceous remains of minute organisms, mostly of Radiolaria, with sponge spicules and echinoid fragments, but containing no diatoms, so far as I have studied it. This material is distinctly stratified, and contains oocasional thin separation layers of a gray-blue clay and some flint-like siliceous nodules. It has clearly undergone great disturbance, as is shown by the vertical arrangement of its beds, and apparently lies below the yellow beds, which are Miocene, as determined by Dr. W. H. Dall. This material has always been a source of great perplexity to the people of Baracoa, who could not classify it or understand its qualities. The reservoir for the village water-works is located upon the single hill where it outcrops, on the southwest side of the harbor. The beds are over five hundred feet in thickness, and I think they overlie the oldest of the limestones, but this I could not ascertain with certainty. Neither this material nor the yellow beds which together constitute at least five hundred feet of the tertiary sequence can be classified as of coralline origin.

The Post-Tertiary Folding. — The chief feature which separates the older limestones into a distinct system from the modern reef rock is the stratigraphic unconformity between them, and the fact that the former have undergone great folding and disturbance prior to the deposition of the latter, which are always subhorizontal. In no locality have I seen the newer reef rock folded or greatly pitched, but the older limestone is frequently tilted at an angle of forty-five degrees, as at Baracoa, and sometimes intensely folded into anticlines, as back of Havana, and presents every degree of folding and disturbance in the numerous railway cuts between Havana and Matanzas, at Villa Clara, Yumuri, and elsewhere. In fact, it is seldom if ever subhorizontal on the north coast, and the later deposits are entirely unconformable with it. While the details of this disturbance could not be wrought out during the brief time which I spent upon the island, its character can be seen in the various sections and illustrations given on Plate I.

The general lay of the old limestone is that of a low anticline whose axis corresponds with that of the island, with folds more greatly developed along the northern coast. This folding took place clearly near the close of Tertiary time, and prior to the deposition of the Post-Tertiary formations and elevations to be described, and indicates one of the most important epochs in the geological history of Cuba, representing, as it does, an orogenic folding not elsewhere traceable in North American history. This folded condition of the limestone, however, has in no manner influenced the later topographic detail of the surface, and was mostly, if not entirely, antecedent to the great regional elevations to be described later.

The Post-Tertiary Formations. — In strong contrast to the older Tertiary limestones is a more modern group of limestones of undoubted coral-reef origin, which border the coast in most places, or form small coral islets adjacent thereto, and are locally known as soboruco.

M. Ramon de la Sagra has defined this formation as follows: —

> "L'autre formation de calcaire moderne, qui a reçu dans le pays le nom de *soboruco*, se trouve de long de la côte dans plusieurs endroits de l'île; elle est tellement récent, que son agglomération continue même aujourd'hui, et c'est à elle que l'on doit les cayes, les récifs et tous les bas-fonds de coraux. Les parties supérieures s'élèvent parfois à partir d'une profondeur de vingt à trente brasses. Toutes les inégalités de cette roche sont recouvertes d'une couche calcaire agglomérée avec des restes d'animaux, des coquilles, de coraux, et de madrépores."[1]

The elevated reef rock can always be recognized by the perfection and abundance of well preserved remains of reef-making corals, which form the greater proportion of the mass and unmistakably show its origin, and by the absence of subdivisions into lamination and bedding planes. The surface is practically the old level of the submerged reef, the sharper

[1] Histoire Physique, etc. de l'Île de Cuba, Tom. I. p. 110.

irregularities having been levelled by solution. The formation averages about thirty feet in thickness, and usually extends inland only a short distance, often only a few yards, as on the northwest end of Moro Point, or not over an eighth of a mile, as at Baracoa, and is especially well exposed along the narrow points of the numerous small harbors, as shown on Plate II.

The soboruco is a topographic as well as a stratigraphic feature, for its surface is a bench gently sloping to the sea ; it has neither been covered by later deposits nor greatly denuded. It usually forms a cliff at the surf line, about fifteen feet in height, against which the surf beats with great force, wearing deep indentations. The spray breaks over the summit, with the aid of the sun producing the surface induration which is visible wherever rain or other moisture falls upon the hot limestones, or wearing the surface into cavernous Karrenfelder. This solution and induration at Baracoa, for instance, has converted the limestones in spots into a coarse saccharoidal marble, and has aided in the segregation of small lumps of iron ore direct from the coral.

Where I was able to examine the base of the elevated reef rock, mostly at the mouths of rivers, it seems to have been deposited rather abruptly upon a semi-argillaceous terrane of silt, and occasionally very fine pebbles, which have been brought down and deposited by the rivers. (Plate II.) I did not find it growing upon the larger gravel which is deposited immediately at the river's mouth, as is seen off the Yumuri of Baracoa, where the river empties into the sea, and not into a bay. Furthermore, the present submerged fringing reefs do not grow immediately where the rivers send their fresh waters into the sea, but are interrupted there by a barren area simulating a submarine channel, as is shown in the accompanying illustrations of the harbors. This fact has an important bearing upon the origin of the present circular harbors, and upon the theories of alleged subsidence, both of which subjects are more fully discussed in later pages.

Is is impossible to describe all the localities at which the soboruco was observed.[1] Sometimes, as along the Havana coast, it occupies a narrow coastal strip extending from the point of one harbor to another. Again, as on Moro peninsula, opposite Havana, it occurs only as a small patch in a slight indentation in the old headland composed of folded Miocene rocks. (Plate I. Fig. 2.)

At Tanamo and other places on the north coast the soboruco not only

[1] See A. Agassiz, Bull. Mus. Comp. Zoöl., Vol. XXVI. No. 1, Plates XLIV.–XLVII.

forms the border of the mainland, but constitutes many bordering islets of great areal extent. Generally these are low, standing only a few feet above the water. There is a vast elongated archipelago of these elevated reefs bordering the coast all the way from a point east of Matanzas to Nuevitas. I passed most of this region in the night, and I can say little concerning it. At Nuevitas, in the harbor, there are three peculiar islands, known as Los Ballantos, which have very great resemblance to the Keys of the Bahamas, presenting a bold, rounded escarpment at the north point, composed of yellow friable material that may have been either coral sand or the yellow Miocene clays. It was impossible to get ashore to these to examine them, although this was the only locality seen by me where there was a suspicion of wind-blown formation. The greatest areal development of the flat soboruco was found along the outlet of this harbor.

Nowhere have I seen the elevated reef rock folded or otherwise disturbed except by the gently coastward inclined elevation it has undergone. The interior margin I have never observed at a height of over forty or fifty feet. In general, there is only one massive layer of this old reef rock exposed, but at Matanzas there is undoubted evidence of two older underlying reefs, the inner edges of which have been elevated with the modern reef so that they do not form distinct terraces. It may be that the apparently continuous reef around Cuba represents more than one of these layers. Whether one or several alternations of reefs, the soboruco as a whole certainly represents a recent and uniform elevation of the whole periphery of the island at a very recent period of geologic time, but sufficiently long ago to have permitted considerable alteration and erosion. It is found from Cape San Antonio to Cape Maysi on the north side of the island, and at many places on the south side, especially near Santiago, as described by Kimball.[1]

Cantera is a term used throughout Spanish countries for any stone that is soft enough to be hewn or sawed with ordinary carpenter's tools, as distinguished from a stone requiring mason's implements. Much of the cantera in Cuba is composed of a soft molluscan or coralline limestone, which has not the irregularity of composition and density and the varying hardness of the older limestone, nor the unaltered coral structure of the elevated coast reef. It is intermediate between the two, and may represent a stage in alteration between them. It is finely cellular, or porous, not usually saccharoidal, and is filled with small cavities sometimes lined with botryoidal lime coating.

[1] American Journal of Science, December, 1884.

Quarries of cantera are found adjacent to most of the cities on the north coast of the west half of the island. They occupy a slightly higher altitude than the coast reef, and usually constitute the first bench of the island above it at a lower level than the erosion planes in the older limestones. (See Havana and Matanzas sections, Plate I. Fig. 1. 2, and Fig. 4. 1.)

I did not observe any break between the cantera and the older limestone, owing to obscurement, except in the Matanzas section, where it clearly appears that the cantera is mostly old reef rock which has no topographic integrity, and which was unconformably deposited on the older limestone after the latter had been considerably elevated. In other words, it there represents the oldest of the recognizable fringing reefs.

At Havana, in the convict quarry, northwest and at the foot of the Castillo Principe Plateau, which is made up of the older limestone, there is a great cantera that seems more molluscan than coralline. The same deposit is also worked in the banks of the Rio Armendaris, two or three miles southwest. Topographically it here underlies an erosion level intermediate in height between the level of the modern reef and that of the Moro Plateau.[1] No cantera was observed east of Matanzas in the ports of Segua, Gibara, Nuevitas, or Baracoa. It is not here proposed to establish the cantera as a persistent geologic unit, for there may be other cantera beds in the old limestone. The coralline cantera of Matanzas and the molluscan cantera of Havana are not found at an altitude of more than one hundred feet, and they are always near the coast. At the former locality the cantera is the oldest of the rocks of probably coralline origin, and at the latter it is intermediate in position between the modern reef rock and the older limestone.

Throughout Spanish America the term "playa," meaning literally a flat beach, lacustral, or shore deposit, is applied to alluvial flats or mud plains composed of gravel, sand, and clay. In Cuba I found that the term was generally used for an alluvial deposit sometimes lining the inner margin of the circular harbors, as at Havana and Baracoa. These are small in area, and are usually adjacent to the zone at which the rivers come out of the highland into the harbors; they represent delta deposits that have undergone slight elevation coincident with that of the modern elevated reef. Their origin is more fully discussed under the head of Harbors.

[1] Specimens of this cantera received from Havana since this report was written somewhat confirm the impression that they represent a late Post-Pliocene deposit laid down against the older Tertiaries, and prior to the elevation of the soboruco.

Flat, marshy alluvial deposits (cienagas) occur in many places, but mostly on the south coast. At Batabanos, opposite Havana, the coast for a mile or more inland is composed of ancient alluvial material, apparently similar to a calcareous mud now depositing and forming the bottom of the adjacent sea for a mile out from land. These cienagas and cienaga deposits are reported to have considerable extent at various places, especially on the south coast. The elevated portion is synchronous with the soboruco elevation on the north coast.

A striking peculiarity both of the older structures and the coast deposits of Cuba is the scarcity — almost total absence — of arenaceous or sandy deposits. Nowhere is found the fine quartz sand such as accumulates around the northern littoral of the Gulf of Mexico, and the presence of pieces of quartz gravel is very rare, even in the delta deposits. This is owing to two reasons: (1) the formations of the island, both the older metamorphic foundation and the limestones, possess very little free quartz, and (2) the littoral sands or physical sediments of the peripheral drainage of the Gulf, derived from the continental Americas, are not transported as far as Cuba, as Professor A. Agassiz has already pointed out. Even the building sand of Havana and other places is calcareous beach débris.

Reefs. — No description of the geology of Cuba would be complete which stopped at the ocean level, without allusion to the adjacent submerged coral reefs that fringe its shores or lie a short distance away, which, with the adjacent submarine topography, have been so ably described by Mr. Agassiz.[1] So fully has he described these phenomena that it is not necessary to discuss them further, except to call attention to the fact that there are often considerable depths between the barrier reefs and the near-by land. This has important bearing upon the topography of parts of the coast.

II. GEOLOGIC HISTORY RECORDED BY THE TOPOGRAPHY.

General Topography. — Having reviewed the fundamental rock structure upon which the sculpture of the land is dependent, we can now pass to a more intelligible discussion of the general topography and its evolution. It is neither necessary nor possible to give a minute detailed description of the geography of Cuba, but only so much as may relate

[1] Bull. Mus. Comp. Zoöl., Vol. XXVI. No. 1, December, 1894.

to the genesis of the island. Its shape and outline have been described by various writers, notably Humboldt, Sagra, and Réclus, and I shall touch upon only those details or generalities that will help to elucidate its geologic history.

The outline of the island might be compared to that of a hammer-headed shark, the head of which is the culminating range along the straight Santiago coast, from which extends westward the longer, lower, and more sinuous mass of the island, while the fins are represented by pendant coral reef archipelagos. The Santiago coast is excessively mountainous, and is supposed to be in some way genetically connected with the mountain systems of the other Antilles. Concerning the composition, age, and topography of these ranges, we know little except what has been told by other writers, to the effect that they extend aproximately in an east and west direction, towering far above the levels of the remaining portion of the island, and occupy a very narrow strip close to the ocean's margin. Extending away to the north and west from this nucleal elevation is the main body of Cuba, which is primarily a great limestone plateau intensely eroded and terraced, without any well defined axis of higher elevation except as indicated by the headwater drainage that diverges from it and flows into the opposing seas, the latter feature corresponding to the longitudinal axis of the island. The highest elevations do not occur in a continuous ridge, but are irregularly dispersed, as if they were remnants of a dissected elevated plateau, diversified by plains and irregular chains of hills, often nearer the margin than the centre, and seldom over two thousand feet in altitude.

The topographic forms belong to two categories, those of the inland and those of the coast. The former depend upon uplift and erosion, and are mostly the product of superficial agencies. The coastal features, on the other hand, are the product not only of uplift, but are largely influenced by the sea, — its life, its sediments, and its surf erosion. The latter are of little areal extent, especially on the north side, where they form the merest fringe around the island. The uplands extend close to the coast, where they are terminated by abruptly terraced cliffs, or series of successively lower levels.

The Inland Topography. — This includes the whole surface of the island except the narrow coastal plains and elevated reef, and is peculiarly and strikingly different from any topography to which we are accustomed in the United States. Under the influence of excessive humidity, the solvent limestone material of which it is mostly composed has assumed the aspect of an ancient and much carved land surface, while the geology, on the other hand, tells us that it is comparatively new. The peculiar surface configuration of the island is solely due to the decay and erosion of these older limestones. Where they predominate, the interior country remote from the somewhat abrupt coast is marked by extensive flats or Llanuras, upon which rest, without any apparent systematic arrangement, short ranges of abrupt hills or knobs. Both the plains and the mountains are composed of the same old limestone. (Plate III.)

Although the rocks dip at various angles in gentle waves or folds, and in some cases with numerous short anticlines, it was impossible to make out any system of disturbance which influenced the minor topography. This sub-arrangement of the underlying limestone structure does not influence the present surface topography, as the strata are of insufficient induration to create topographic irregularities.

The limestones decay so rapidly at the surface that they can seldom be seen in a freshly exposed condition except in railway cuts and quarries. Everywhere they disintegrate into a rich red residual soil, sometimes of great depth, which contains a large percentage of iron derived from the limestone. This sub-aerial decay is beautifully shown in the cuts of the Havana and Matanzas railway near the latter city, an illustration of which is shown on Plate I. Fig. 7. This iron has great economic value in the vicinity of Santiago de Cuba, under the conditions shown by Kimball. The limestone is also melting away by deep underground solution, and is very cavernous. This decay, proceeding irregularly, being much greater in some spots than in others, produces large sinks, as in the limestone regions of Kentucky, only of a vastly greater area. Thus it is evident that the deep, sloping indentations are produced not solely by surface corrosion, but partly by underground decay, the streams carrying away the lime in solution, rather than as physical débris. A most remarkable illustration of the effect of solution upon the topography is the valley of the Yumuri de Matanzas, a plan of which is shown on Plate II. Fig. 9.

When this rapid disintegration and degradation of the old limestone is considered, it is evident that the ancient limestone summit of the island must necessarily have been greatly lowered in outline. In other words, the present highest levels of the limestones do not represent the altitudes which they formerly attained, but are merely planed off remnants. It is impossible to determine how great a portion of the top of Cuba has been thus removed, except so far as to say that, judging from the present rate of denudation, it must have been a large amount, for in places it has laid bare the old metamorphic floor. Wherever I have seen the latter, it unmistakably shows that it was once covered by the limestone. This is well shown in the accompanying section across the island, through Havana, where the older foundation rocks always appear in the valleys of erosion beneath the escarpments of stratification formed by the adjacent limestones, the latter being so tilted around their periphery that, clearly, they once extended over them, as at Villa Clara. It is easy to conceive that, if erosion proceeds in the future as in the past, without further elevation of fringing coast deposits, the island will ultimately be planed down to its original core of serpentine and allied rocks, without material alteration of its coastal outline.

The most ancient part of the longitudinal limestone arch, as back of Havana, has been removed down to the older metamorphic rocks, and a strip of the older limestone formations running parallel to the coast remains between this valley and the sea. (See Plate I. Figs. 1 and 2.) This, in turn, by a cross erosion of the streams, is serrated into fragmental remnants of the limestone, like the Moro and Castillo Principe Plateaus at Havana. The Pan de Matanzas, near Matanzas, and the peculiar mountains of Moa and Yunque, near Baracoa, are remnants of older and higher levels which have been preserved in this manner. In fact, the erosion has been so great that the limestone is almost removed, except where preserved in isolated mountain buttes like the Sierra Yunque and the Pan de Matanzas, and headwater erosion is constantly destroying the remnants of the original limestone plain by deepening the cols down to the metamorphic floor. Granting that the older limestones once extended over most of the island in the contour of a low dome, and that this arch has undergone several periods of intermittent elevation with corresponding intervals of rest, accompanied by base levelling, the topography can be more easily explained.

Where the limestone is the prevalent formation, as in the sugar country of central Cuba, the surface is marked by extensive level tracts, covered with the deep residual *tierra colorada*, one of which plains is well shown in the accompanying photograph. (Plate VI.) The continuity of these plains is broken by abrupt hills, either single or in groups, some of which seem to have no persistent axis of direction, and are clearly remnants of the higher level below which the land has been degraded. The plains show very little slope to the eye, and project abruptly to the foot of these limestone hills. They vary in size from many square miles to a few acres. Even the small plains, when entirely encircled by mountains, are very flat, and abruptly terminate against short lines of hills, and there is no reason to doubt that they and the limestone hills are the product of the unequal resistance of the different limestones above described, the mountains representing the remnants below which the plains developed on another harder plane. (Plate V.)

The eminences of Cuba called mountains, with the exception of the Sierra Maestra and kindred ranges of the Santiago coast, can now be easily classified. (Plate I. Fig. 8.) They are all either (1) the direct remnants of the old limestone covering carved out by circumscribing erosion, or (2) inequalities of the ancient metamorphic floor from which the limestone has been denuded.

The mountains of the former kind may be placed in two general classes, according to their altitude and degree of erosion. First are the high limestone peaks, mesas, and ridges, having an altitude of from one thousand to two thousand feet. The Sierra Yunque of Baracoa, the Pan de Matanzas, and the Tetas de Managua, are examples of isolated peaks, standing close to the north shore of the island. Each of these is surrounded by deep drainage valleys cut almost down to sea level. They are many miles away from any masses of land of similar altitude, and form conspicuous landmarks along the coast. Their summits are of the sub-horizontal strata of old limestone, while the base of at least one, the Sierra Yunque, consists of the older metamorphic rocks. The high ridges, like the Sierra San Juan, and the high summits of the central portion of the island, are remnants of the same old level, and differ from the more isolated peaks in having been less dissected. Not owing their outline to any structural folding, but being entirely the product of the drainage, these have no regularity of arrangement or trend, but are found in irregular patches throughout the island.

The Spanish language, to which our geographic nomenclature is already so much indebted, has provided an appropriate name for mountains of this class, which have lower altitudes, ranging from four hundred to seven hundred feet. These are the cuchillas, or knives, so called because of the numerous sharp salients marking their slopes, caused by the deep incision of the old plain or general level of which they are the fast fading remnant. These are the hills forming the sharp background to the coasts, especially at the east end of the island. The cuchillas are generally composed of the old limestone, which dips at many angles and degrees, but sometimes they consist of a complex of limestones, yellow beds, radiolarian beds, and the old metamorphic floor. At the Yumuri River of the east and around Cape Maysi they consist of a more massive and unbroken wall of the old limestone, but as we go westward they become more dissected, as in the line of high hills along the coast, and in the background against which the little harbors are cut out as far west as Nuevitas. Still farther westward the contour recedes slightly inland. On the south or Santiago coast, the same level of the cuchillas summits is preserved in diorite and syenite.

In addition to the limestone mountains of erosion described, there are many low hills in the central part of the island adjacent to Villa Clara (Plate IV.) and Puerto Principe which are clearly structural remnants of the older metamorphic floor, from which the folded limestones have been eroded, the latter being often preserved on top of the higher elevations, or sharply inclined around their edges. The series of sharply rounded hills between Havana and Matanzas is also the result of the wearing away of the limestone covering down to a floor of tuffs and serpentines, which, owing to its softer nature, is more deeply and sharply sculptured than the limestone regions proper.

Concerning the geology of the Sierra Maestra of Santiago, Kimball says that the old limestones preserved on their slopes show that at least twenty-three hundred feet of their elevation are Post-Tertiary, and there is no recorded evidence of any Post-Tertiary eruptives or flows. I incline to believe that these ranges belong in the same class with those of the Villa Clara type. Although the close of the Tertiary was marked by much folding, recognizable mountains simulating Post-Tertiary structural folds, or evidences of Post-Tertiary extensive volcanic action, are certainly rare, if they exist at all. The present irregularities are all the result of erosion. I made every possible reconnoissance over the island to study the upland topography, and I think my conclusions are founded on abundant evidence, proving beyond doubt that the higher limestone elevations are solely the remnant of the former area of the older limestone mass. For instance, the sharp lines of limestone summits on the high divide of the island between Havana and Batabano are clearly the old scarps of the Armendaris drainage cut out of a former plateau. The mountains on the road from Havana to Villa Clara and back of Matanzas are either of similar character, or are the perimeters (knobs) of vast basins, like the sink-holes of other limestone regions, only much larger, owing to the more solvent nature of the substructure.

The isolated mountains of high elevation along the north coast, like the Pan de Matanzas and the Yunque, are fragments of the older areal summits, which have been separated by circumscribing erosion from the main body of the upland, and stand as solitary remnants of the ancient and older plateaus, which, when their limestone cap is finally removed down to the metamorphic base, will assume the Villa Clara type.

The drainage system of Cuba is extensive. In general the streams flow from the central axis toward the opposite coasts, and are of the type which modern geographers would term simple consequent or autogenous streams. They have light-colored blue water like that of the limestone springs of Florida and Texas, and in many cases obtain their supply from the underground waters of the limestone region. Where seen throughout the interior upland plateaus of Cuba they are small in volume, and flow in slightly indented channels in wide valleys, and are remarkably free from the incisions of lateral drainage. A typical streamway is shown on Plate IX. They do not possess deep barrancas or cañons until they begin to cut across the edge of the Cuchilla plateaus near the coast. In many cases these rivers are intermittent, disappearing into and reappearing from the cavernous limestones. As they approach the escarpments of the coastal platforms, they reach the sea either by sinking into the limestone, by tumbling cascades, or by cutting deep vertical cañons. They are all slightly tidal at their mouths, the salt water extending at high tide a short distance up them, but never reaching far inland of the soboruco. Most of them bring down to the coast the metamorphic and igneous rock of the old nucleal foundation, but in no case have I observed limestone fragments, although the rivers must degrade and transport in solution far more lime than any other material. The vertical cañons in some cases, like that of the Yumuri of the east, extend to the sea, and testify to the rapid rising of the land, confirming the story of the cliffs and base levels as will be described later. (See Plate I. Fig. 6.)

Perhaps the most important factor in the evolution of the topographic conditions of Cuba is the superficial and underground destruction and alteration of the limestones by solution, heretofore mentioned. Owing to the porosity of the limestone rocks, the drainage of Cuba is largely underground in the limestone regions, and flowing surface streams and lateral drainage channels, such as the dendritic headwater ramifications so common elsewhere, are notably scarce in the higher region inland from the coast, and the upland limestone region seems to be dissolving, rather than corrading, into a sink-hole topography of vast proportions.

The Coastal Topography. — None of the topographic features of Cuba are so peculiar as the innumerable subcircular harbors[1] which indent its

[1] See Agassiz, Bull. Mus. Comp. Zoöl., Vol. XXVI. No. 1, Plates XIII., XIV.

northern coast, examples of which are common on all the pilot charts. Most of these are constructed upon the same fundamental type, consisting of a subcircular or reniform bay outletting through a narrow neck or strait into the sea. Into the back of the bay usually flow one or more of the small rivers of the country. Generally the landward side of these harbors is or has been the elevated, broken Cuchilla highland, while the points of the narrow necks enclosing the outlets to the sea are sub-level plains composed at the sea margin of soboruco or recent elevated reef rock.

On the landward side of some harbors at the foot of the cuchillas, those of Havana and Baracoa, for instance, there is sometimes a playa, or alluvial plain of small area, composed of ancient sediments of the river, which has participated in the general elevation of the coast. The accompanying plate (Plate II.) enables us to discuss more intelligently these phenomena, and their bearing upon the elevation of the island.

There are two possible hypotheses concerning the origin of these harbors. The first is that of subsidence and superimposition, as set forth by Crosby,[1] given more fully in the portion of this paper treating of evidences of subsidence. This implies that the elevated reef rock once extended across the area now occupied by the neck or outlets, and at a former epoch of elevation was eroded through by the rivers, and that by subsequent subsidence the waters of the sea encroached upon the land through the channel thus worn, producing an estuary. A second hypothesis is that they are the result of the growth of fringe and barrier coral reefs adjacent to or opposite the mouths of rivers, which were subsequently elevated and unequally eroded. In my opinion, the harbors were evolved from the simple type of rivers now emptying directly into a fringed reefed sea, like that of the Rio Yumuri of Baracoa and the Limones. (Plate II. Figs. 1 and 2.) The rivers all originally emptied directly into the sea, as do the Yumuri and the Limones of to-day, and the coast line was the precipitous bluff of the Cuchilla highland, now forming the background of these harbors, in front of which was a basal shelving beach. Delta material was discharged off their mouths into a deeper area between the shore and an outlying barrier reef, as now seen in the harbor of Jaragua, or into reefless submarine areas produced in the following manner. The entrance of the fresh water into the sea prevented the growth of reefs immediately opposite the mouth of the river as far out as the freshening influence of the

[1] *Op. cit.*

river water was felt, which includes the delta region of coarser gravel deposit. But it can readily be seen that certain physical sediments, like fine gravel, will receive enough impulse from current and surf to be carried into the margins of the salt water, so that unusually opportune conditions are created for coral growth immediately where the water becomes sufficiently salt and food abundant. Thus it is that fringe reefs do not usually form immediately at the mouth of rivers, but leave non-coralline gaps in the reef simulating an extended submarine channel of the river. This is clearly shown in the chart of Limones (Plate II. Figs. 1 and 2), and other rivers, where the present submerged fringe reefs make a projected channel into the sea.

It is the rule, whether the land is subsiding, rising, or stationary, that the sea always indents the mouths of rivers after they have once reached its level, and tends to wear away the angular points bordering its mouth. This wearing is produced by the diurnal change of tidal level, and the resulting constant corrasion, however small, of the bottoms, whether by fresh or tidal current; so the level of the sea, even in a delta-making stream of perceptible age, will constantly encroach inland and cause small estuarine deposits in the indented mouth at high tide, to be moved outward with the ebb. Thus it is that the steep rivers of Cuba, which are all very old and permanent, have slightly indented base level with deposits of gravel extending inward coincident with the fluctuation of the tide.

The playa deposits found along the interior border of the harbors of Havana and Baracoa represent the coarser gravel and silt thus formerly given up by the rivers upon reaching tide level, before the latest elevation. In the present Yumuri of the east the flood tide extends a mile or less up the river. At the time of the general elevation of the coast reef, the older delta deposits similarly formed were elevated correspondingly, and are now found surmounting the lowest terrace.

Such an elevation as has taken place, and has produced the elevated coast reef, would raise the present growing reefs above the water, so that they would form indurated points at each side of the river's mouth, and if there were a barrier reef its elevation would convert the old inside deep into a land-locked harbor, while the old indented gravel would form playas at the back of the harbor. Probably this is what has taken place. Furthermore, the sides of the narrow necks and sea fronts of the harbors are composed of a harder and more durable stratum of reef rock than the country back of them. The beach-like sides of the harbor within the reef-like points are subsequently widened by undermining, as now seen at Baracoa, where the surf line, which enters the narrow bay with gathered force, breaks against the unconsolidated miocene yellow deposit constituting the sides of the harbor back of the elevated reef, and huge blocks of the latter constantly topple over into the bay.

There is general remark throughout Cuba that the harbors are becoming shallower. Captain McIntyre, a trustworthy mariner, who has been trading at Baracoa for over forty years, assured me that within his memory the anchorage area has steadily decreased, and that ships which formerly discharged their cargoes at a pier, are now dependent upon lighters. While it is very probable that the silt from the rivers is a partial cause of this, it may be probable that steady elevation now going on, as it has certainly gone on in very recent time, may be productive of the shallowing.

The ovoid harbors thus developed from the simple type of river emptying directly into the sea and undermining the contiguous reefs attain a third stage (Plate II. Figs. 7 and 4) in which the regular margins become denticulated and irregularly indented by erosion, as seen in the harbors of Havana and Escondido. In the harbor of Havana the excessive irregularity of the interior margin is increased by the fact that the limestone background has been cut through down to the tuffs, serpentines, and clays underlying it, which degrade into more irregular topography than that of the limestones.

Terraces and Benches.

The most striking feature in the topography of Cuba consists of the well defined terraces and benches which mark its coasts in many places. These are often so distinct, especially at the east end of the island, that their continuity is traceable for many miles, as they rise abruptly from the water's level, one above the other, in a series of cliffs. On the west end of the island they are not so distinctly visible from any single point of view, for the flat benches are much wider, but they are nevertheless traceable. In other places denudation has destroyed them.

Besides these benches and terraces, whose integrity is distinctly preserved, remnants of older and more denuded levels can be traced, and for convenience they may be classified as follows : —

4. The Soboruco, or elevated reef level. 3. Elevated beach and cliff lines and the Havana base levels.	1. Later (Lower) levels.
2. The Cuchilla level. 1. The Yunque level.	2. Older (Higher) levels.

The Soboruco, or Elevated Reef Level. — The general extent and topographic character of the soboruco is explained on a previous page. It forms the lowest bench immediately adjacent to the entire north coast and along the Santiago front, and is topographically and geologically an elevated coral reef. Synchronous with this level are the elevated playa deposits in the harbors, and the elevated cienaga or mud deposit on the south side of the island at Batabano.

The Beach and Cliff Terraces. — On the east end of the island, the north coast is marked by three distinct and abrupt cliffs and terraces cut out of the steep slope of the old six-hundred-foot plain, or the Cuchilla level, which forms the highland. Between Cape Maysi and Baracoa the coast is practically inaccessible. The three terraces seen in this region are so clear and distinct that they are readily visible at one view, and their continuity is clearly traceable for miles. They can be best understood from the accompanying figure (Plate I. Fig. 6), and a description of the coast adjacent to the mouth of the Yumuri of the east. Here the river empties directly into the sea through a precipitous cañon affording a fine cross-section of the benches, so that their architecture and origin can be seen. The coastal scarp consists of three narrow sub-level benches, each surmounted by a vertical cliff. Bench No. 1 is the first sub-level strip above the sea. This in general represents the level of the elevated reef, which nearly everywhere forms the low-lying coastal plain and breaks off at the sea in a surf wall some ten feet in length. Its interior margin against the base of the first great cliff is forty feet high, and it nowhere exceeds one hundred yards in width. Immediately off the mouth of the Yumuri River, however, a gravel delta fan spreads out in brackish water, a hundred yards or so on each side. The present submerged fringe reef does not grow immediately where this delta fan is being deposited across the river mouth, but appears on each side. If the present bottom, constituted as above, should be elevated forty feet, it would produce a beach exactly similar to the elevated one now seen; that is, it would be composed of alluvial gravel immediately where the river once emptied, and of coral limestone a hundred yards or more on each side of it.

This lowest terrace (No. 1), which is usually formed of elevated reef rock, is composed of alluvial gravel immediately off the cut of the river, and of elevated reef rock a quarter of a mile away seaward. This lowest bench consists of several small levels, the uppermost of which is the specially well defined alluvial gravel plain.

This old beach abuts against a cliff (No. 2) about one hundred and twenty feet high (one hundred and seventy feet above the sea) worn out of the lower part of the old white limestone. Its sides are vertical in most places; and inaccessible. This cliff is in turn surmounted by another bench (No. 2), which was likewise formerly an old beach level, from which any remnant of the deposit that may have once existed has been eroded. It is covered by a dense growth of vegetation. The river cañon which cuts across these cliffs and benches shows that they are not elevated built-up coral reefs, but are clearly cut sea terraces in the old limestone. The second bench is about a hundred feet in width, and abuts against a second vertical cliff, the summit of which is nearly as high as that of the first one, or about three hundred and fifty feet above the sea. The level bench (No. 3) mounting this cliff is similar in appearance to No. 2.

This last bench in turn abuts against a third and uppermost escarpment of the highland, which terminates at a height of from five hundred to six hundred feet in the irregular upland plain forming the fourth level above the sea.

The Cuchilla Level. — This fourth level is the general upland plain as it appears from the sea, and represents the old land from which was carved the group of cliffs above described. This highest escarpment forms a comparatively unbroken plateau at the eastern end of the island, overlooking the sea, but westward the increasing drainage cuts it more and more into numerous serrated hills known as the Cuchillas, or "Knives," whose summits have a general culmination of from five hundred to six hundred feet, and are clearly remnants of the Yumuri Plateau. These Cuchillas form a very conspicuous coast feature from Nuevitas to the east end of the island.

The Yunque, or Higher Level. — A single glance at the peculiar isolated mountain known as the Yunque, or Anvil, situated six miles west of Baracoa, is sufficient to show that its sub-level summit is the remnant of an ancient higher level than that represented by the Cuchillas.[1] This is a magnificent butte, whose summit is put upon the pilot chart at eighteen hundred feet, and so estimated by Crosby.[2] The summit is an ovoid mesa, which is apparently level, but which really shows deeply carved drainage ways and ancient topography indicating long exposure. The upper portion is composed of a mass of the older tertiary rocks one thousand feet in thickness, whose perimeter is an almost inaccessible cliff. This rests upon a base composed of the metamorphic rocks of the

[1] A. Agassiz, Bull. Mus. Comp. Zoöl., Vol. XXVI. No. 1, Plate XLI.
[2] *Op. cit.*

old Pre-Tertiary nucleus. From this summit one can look down upon the Cuchillas, the Yumuri terraces, the elevated reefs, and the wide expanse of the ocean; and inland toward a country showing its own level, overreached by still higher mountains of the Sierra Maestra to the south. On every side the drainage has cut deep below this peculiar mountain, carving the low-lying country into an intaglio of serrated hills.

No one can view this summit without being impressed with the wonderful story it tells of the great erosion that has taken place around it, as well as the fact that the difference in elevation between its plateau and that of the lower-lying Cuchilla level represents a vast hiatus in the history of the island's elevation, — a long period during which land stripping and degradation ensued, reducing the surrounding areas to the old Cuchilla erosion level. The relation of this peculiar remnant to similar phenomena in other parts of the island will be discussed later. The accompanying illustration (Plate I. Fig. 5) of the harbor of Baracoa gives a clear presentation of the various levels seen in the east end of the island. Let us now examine the kindred phenomena in other localities.

The Havana Levels. — The western half of the island also presents an interesting series of topographic surfaces that, for convenience, we will denominate the Havana levels, which, although varying in expression, have genetic relations to the cliff phenomena of the eastern end of the island. In the Havana region the wider area of the terraces makes the cliffs less conspicuous than in the east. The highest of the distinctly preserved levels coming under my observation is the one that encloses the harbor of Havana as seen on the summit of the Moro peninsula to the east (Plate I. Fig. 2), and its continuation west of the city, known as the Castillo Principe Plateau. These have an average altitude of fifty meters (or one hundred and sixty-five feet) as determined by Mr. Gould, who has made a contour survey of the region. From the still higher eminences back of Havana, or from nearly any point of view, the contour of this plateau can be easily recognized, and it clearly represents an old level of erosion, — either a very wide beach level, or a base level of erosion. The Castillo Principe peninsula, which represents a portion of the Moro Plateau, is a narrow flat divide of the land extending north and south, lying between Rio Armendaris and Havana Bay. Its structure consists of the gently disturbed older limestone series surrounded by lower beds of cantera and soboruco, constituting the lower levels upon which the main portion of the city of Havana and the suburb of

Carmelo are built. It terminates inland in a limestone escarpment of erosion, which has worn down to the underlying floor of igneous tuffs.

There can be no doubt that this peninsula was once an eastward continuation across Havana Bay of the plateau west of the Rio Armendaris and the Moro Plateau, and that it has been disconnected from them by the streams which flow in the intervening valleys. The plateau in which Moro Castle is situated is similar in surface and structural features to that of the Castillo Principe, and likewise terminated inland in the hilly region north of Regla by an escarpment of stratification which destroys the possibility of tracing its former extent inland. In area it represents an elongated east and west narrow platform forming a vertical coast line as far as Guanos Point, and extending toward Matanzas, where I think its level is represented by some of the terraces in that vicinity, and projecting, in places, as at Moro Point, fully to the ocean's edge. This general level of the Moro Plateau is not an elevated coral reef, but is an ancient level of erosion representing a period in the history of the island when the area it now occupies was approximately near sea level, and which has been subsequently elevated. Its surface in no manner represents a deposition plain or the surface of an old reef growth, but is produced solely by base-levelling erosion, and this in spite of the irregular sinuosities seen in its substructure, the old tertiary limestone.

The Cantera Elevation. — Around the base of the Castillo Principe Plateau may be traced the remnants of another level, approximately twenty-five meters (eighty-five feet) in height, which, for convenience, I will term the Cantera level. This, too, represents another and later epoch of levelling, and has likewise been greatly destroyed by later erosion. Below it, and adjacent to the sea, is the soboruco, or elevated reef level.

Older Levels. — Back of Havana there is a line of still higher, greatly eroded hills, which overlook these levels, and have an altitude of about five hundred feet, merging southward into a plateau constituting the divide between the north and south shores of the island. This limestone plateau gently slopes away to the south coast, and undoubtedly once covered the hilly area back of Havana. The highest point on the railway, which goes through a saddle, is 101 meters (332 feet), the country rising to about two hundred feet above this.

The Matanzas Levels. — Matanzas Bay differs from the general type of the sac-like harbors of the north coast only in that it is rhomboidal in form, and seems more deeply cut into the high background which surrounds it. The topography and geology of this locality alone is so interesting and complicated that it would require a lengthy paper to describe it, and it can best be explained in brief by reference to the accompanying topographic sketch and section. (Plate I. Fig. 4, Plate II. Fig. 9.)

Two diminutive rivers flow into the harbor, the Yumuri of Matanzas and the San Juan, both emerging suddenly from the highland. The highland or sky line surrounding the harbor on the two sides is about one hundred meters (three hundred and fifty feet) in altitude, as determined by aneroid at Mount Serat, and constitutes a flat-topped mesa or plateau north of the Yumuri, and a poorly defined bench against a still higher hilly region south and east of that river. Out of this plainly marked level are carved the sloping and narrow lowlands immediately surrounding the harbor, upon which the city is built. Between the level of the city and the highlands the narrow remnants of a few terraces or pausation planes are faintly traceable. One of these is about one hundred and fifty feet above the sea, and the other, upon which is located the railway station back of the city, and which constitutes the bench back of the Versailles church north of the Yumuri River, is about fifty feet.

The Yumuri enters the harbor valley through a deep precipitous cañon cut athwart the high level above described. Viewed from the city, this cañon appears to be a chasm in a mountainous background.[1] Upon ascending it for half a mile it is seen to open out into a wide and beautiful amphitheatre, some four leagues in circumference, bordered by steeply sloping walls, and with a wide sub-level bottom. The bottom of this valley is only a little above sea level, and if submerged a few feet would become a circular harbor from the inflow of the sea.

Upon climbing to the summit of the cañon to the Church of the Hermit, upon the high level, a grand view of this peculiar amphitheatre is seen. It is clearly carved out of a vast sub-level plateau having the general altitude of the Mount Serat eminences, whose remnants constitute the plateau lying between the Yumuri River and the sea on the west side of the harbor to the north and east of the amphitheatre. Traces of this plateau[2] also surround the south margin of the amphitheatre, forming a bench from which rises a line of higher hills, more serrated, — the same which are crossed and seen between Havana and Matanzas, and which do not exceed six hundred feet in altitude. This remarkable valley and the more remarkable cañon which connects it

[1] See A. Agassiz, Bull. Mus. Comp. Zoöl., Vol. XXVI. No. 1, Plate XLII.

[2] Ibid., Plate XLIII.

with the sea are subjects concerning which I am at a loss to offer explanation.

The geologic section (Plate I. Fig. 4) of the cañon shows that there are at least three alternations of old reefs and thin gravel beds, which in turn rest upon a great thickness, not less than eight hundred feet, of the older Tertiary limestones, out of which the amphitheatre proper is carved. The beds are all tilted to an angle of fifteen degrees, but the highest elevation of the undoubted coral laid down against the old limestone is less than one hundred feet.

That this amphitheatre was once an indented harbor and the Yumuri River cañon its outlet, is a hypothesis which may be suggested. The denuded floor shows no trace of evidence that would convey this impression, but around the walls of the amphitheatre are traces of terraces corresponding in height to the hundred-and-fifty-foot bench outside the harbor, and these may represent the former floor of the amphitheatre when at sea level. If they do, then the Versailles, or highest elevated reef rocks, were formed off the point of an old outlet through the Yumuri. In the cañon itself, however, there is no distinct evidence of planation terraces, such as would indicate pausation periods followed by renewed epochs of cutting, although just out of it on the west side of the harbor, back of Versailles church, old river gravels are preserved about twenty feet above sea level.

Between Havana and Matanzas the interior is a very broken country. The railway runs back of the interior of the escarpment of the old coast limestones, and sub-parallel to them, for thirty-six kilometers from Havana, upon a floor of underlying metamorphics, constituting a very hilly country. At thirty-seven kilometers the railway again cuts the bottom of the limestone at an altitude of two hundred feet, entering a level limestone plain at Aguacate, separated by a deep eroded valley from a range of limestone hills two kilometers to the north. At sixty-two kilometers the road cuts through this range of tertiary limestone hills, which have an altitude of six hundred feet. At Serba Mocha the peculiar limestone hills known as the Pan de Matanzas are seen to the north across an eroded valley. These summits are to the western half of the island what the Yunque is to the eastern, — remarkable isolated remnants of the nearly destroyed older levels which once surmounted the island. The Pan de Matanzas is alleged to be twelve hundred feet high. It consists of a double eminence, the intervening valley presenting precipitous walls. The summits are of limestone, and are clearly remnants of the old limestone mass of the interior, from which they have been disconnected by erosion, while the intervening valleys are cut down to the metamorphic floor. The Tetas de Managua are of similar nature and origin.

The Santiago Levels. — Mr. James P. Kimball has published a paper entitled "Geological Relations and Genesis of the Specular Iron Ores of Santiago de Cuba,"[1] which gives valuable details concerning the occurrences of terraces on the south coast of the east end of the island in the vicinity of Santiago and Guantanamo. Concerning these he speaks as follows: —

"The immediate coast presents a remarkable development of coral rock, or coral limestone, in three terraces, of which the upper is about 350 feet above the sea. The second terrace is at an altitude of about 175 feet, and the present shore, a plateau of comparatively recent elevation, about fourteen feet above tide. These terraces mark successive elevations of the Sierra Maestra range. These stages of elevation were in direct, but probably remote, succession with other elevations which I shall show to be indicated by traces of more ancient corallines (coral formations) about two miles still farther back from the present coast.

"The last terrace, or that of the present shore, falls away vertically into deep water soundings, at the mouth of the Carpintero, 150 feet off shore, giving a depth of 165 feet. It retains to a remarkable degree the structure of solid reef, studded with distinct forms of coral, and is strewn with fragments of coral rounded by the waves, but in good preservation, and numbering a large variety of species."

He also shows that traces of the old limestones are found in the high flanks of the Sierra Maestra. Of these he says: —

"The several terraces of recent coralline mark, as already indicated, successive and in chronological order the later uplifts of the Sierra, in vertical range not less than five hundred feet. These, together with the series of corallines of the second line of foot-hills, as recognized by the bodies of hematite and marble, are proofs of a sum of uplifts of not less than thirteen hundred feet. Obscure traces upon the first range of foot-hills of still more ancient corallines, to which I shall again refer, point to a still more remote succession of uplifts whose vertical range — referred to the latest indicated level of coral formations, some one hundred feet below the present shore — may be estimated at about twenty-three hundred feet. From the syenite hills may have disappeared by subaerial erosion intervening corallines, between those of the present coast and the line of ancient and now metamorphosed corallines traced along the contact or southern margin of the diorite mantle."

[1] American Journal of Science, December, 1884.

Comparison and Correlation of Various Levels.

Let us now compare the various data presented concerning the coast and inland topography at the various localities mentioned, and inquire into their relation to each other. Figure 8 of Plate I. will aid in understanding the presentation to follow.

That the soboruco or elevated reef represents the same general level around the north and south coasts of Cuba is indisputable, and can be interpreted in no other way than that there has been in recent time a uniform elevation throughout the nine hundred miles represented in the length of the island. It is the same formation topographically and geologically, wherever seen, and establishes the fact that the elevation of the island, at least during one epoch, was general, and not local or spasmodic. If such a uniform movement has beyond doubt taken place at a modern epoch, it establishes the principle that similar elevations were not impossible in the past.

The levels represented in the three terraces of the Yumuri of the east have remarkable identity with the levels of the west end of the island, as at Havana and Matanzas, where my detailed studies were made. The only difference is, that the latter are wider than the former, owing to the lower and more rounded character of the country out of which they were cut. The correspondence in altitude is such that no one can doubt that they represent synchronous and identical regional movements and pausations, and that they were once continuous throughout the length of the north coasts of the island, and around Cape Maysi to the Santiago coast.

The Cuchilla, or dissected peneplain of the east, presents a remarkable analogy to the higher dissected summits back of Matanzas, constituting the upland divide of the west end of the island in the latitude of Havana. Here the old levels represented by these summits are less distinct than in the east, probably owing to the fact that this end of the island had not previously been so highly elevated as the east.

The oldest and highest limestone summits, approximating from fifteen hundred to two thousand feet, as typified in Yunque, the Sierra del Moa, the Pan de Matanzas, the table land of Mariel, and the Managua Paps of the west half of the island which follow near the north coast, the highest limestone at Santiago and other places, represent the remnant of the oldest and highest level or levels, which have been so completely dissected and planed down that their extent can only be estimated.

These elevations may be only the remnants of an aboriginal uneven surface, but collectively they generally represent a higher land than existed before the Cuchilla plains were developed. Whether the high summits of the Sierra Maestra adjacent to the Santiago coast contain or preserve traces of still older levels is an interesting problem for the future.

These phonomena may now be grouped into three distinct age categories, one of which is still further divisible into many subdivisions. These are (1) the modern or well preserved tripartite group of lower lying levels, cliffs, or terraces, including the modern soboruco, the highest level of which approximates three hundred feet; (2) the dissected and greatly denuded remnants of the old Cuchilla level, five hundred to seven hundred feet above the sea, the remnant of an old general height whose integrity is almost destroyed, and which is less easily traceable than the first; (3) remnants of the almost destroyed more ancient upland, as preserved in the isolated buttes of the Yunque and Pan de Matanzas type and the higher limestones of Santiago and Cienfuegos, which demonstrate that there was once an old surface at least two thousand feet above the modern sea level.

The obvious history of these levels is as follows: —

(1) In a period near the close of the Tertiary, to be ascertained, long previous to the emergence of the present elevated reef and cantera and the erosion of the Cuchilla plain, there was a great upward movement of the island to the height of at least two thousand feet, which as yet has revealed no history of its details further than that, from the absence of later deposits and from the character of its ancient and much sculptured topography, we may fairly infer that it has not since subsided beneath the sea, but has remained mostly dry land, and that its area and outline were very nearly as great as those of the island of to-day. This includes those portions of the island above the dissected Cuchilla plain.

(2) The Cuchillas at five-hundred-foot level constitute a plain or plains produced by base levelling in the epoch immediately following this oldest period of elevation, and represent the time interval between it and the later movement recorded in the first or lower group. The country was planed down by erosion to near sea level. The Cuchillas summits indicate a long pausation period between the old Yunque and the renewed modern elevation recorded in the Yumuri cliffs cut around them.

(3) The tripartite group of modern cliffs and base levels below and against the Cuchilla escarpment are the product of a renewed and modern upward movement, which elevated the old Cuchilla coastal plain to

a plateau, and subjected it to the erosion which has since dissected it into its present rugged outlines. The Yumuri cliffs were carved from it where it formed a sharp coastal scarp, and the Havana and Matanzas benches represent synchronous levels with the latter in the west end of the island, where the Cuchilla level was of less extent. That this modern group of elevations was intermittent, as shown by its alternate cliffs and terraces, is evident, the modern soboruco representing the latest uplift.

The elevated benches and terraces which border the coast of Cuba, with the single exception of the soboruco, or modern coast reef, are not ancient coral reefs either topographically or lithologically, as has been asserted, but, on the other hand, are beach and erosion plains, produced by rapid elevation of the island in Post-Tertiary time, and carved from various formations, principally the older limestones, regardless of structural arrangement and composition. Even though the old limestones may be remotely of coral origin, which I do not think, and which idea I have discussed on a previous page, these old terraces can in no wise be interpreted topographically as elevated reefs, for none of the original reef topography is preserved. On the other hand, I can give numerous instances where the same benches are carved out of the varying component material, which was much folded or disturbed prior to their erosion, as is shown in most of the figures.

The series of terraces around Cape Maysi and Yumuri are carved out of a massive matrix of old limestone of undulatory structure, as shown in the figures. The terraces or base levels at Matanzas are cut out of a series of beds widely divergent in lithologic composition, all dipping at angles of from ten to twenty-five degrees. The Moro and Principe Plateaus at Havana form a planation surface upon a floor of folded limestone, in which distinct anticlinal structure can be traced. The terrace upon which the Military Hospital at Baracoa is situated is carved across the almost vertically inclined edges of the older Miocene limestones. The summit of the Yunque, instead of being a coral reef, is a greatly degraded peneplain. The soboruco alone of all the levels is topographically an elevated reef, and this, as before stated, does not rise anywhere over fifty feet.

Lack of Evidence of Subsidence.

I must confess my inability to distinguish any positive evidences of subsidence since the beginning of Tertiary time or accompanying these elevations, although it would be rational to think that the movements must have been oscillatory. It is easy to imagine evidences of subsidence, but to prove them is difficult. Geikie has said: —

"It is more difficult to trace a downward movement of the land, for the evidence of each successive sea margin is carried down and washed away or covered up. . . . The student will take care to guard himself against being misled by mere proofs of the advance of the sea on land. In a great majority of cases where such an advance is taking place, it is due not to subsidence of the land, but to erosion of the shores. . . . The encroachment of the sea upon the land may involve the disappearance of successive fields, roads, houses, and villages, and even whole parishes, without any actual change of level of the land."[1]

I failed to find any traces in the upland areas of recent deposits which would indicate any submergence whatever. The soils, especially the "Tierra Colorada," are everywhere residual, and nowhere did I observe any that could be attributed to transported material or overplacement of alluvial matter, and particular care was taken to look for such evidence. De Castro reports extensive upland alluvial deposits in the region of Puerto Principe, but gives no evidence whereby we may determine whether they were produced by inland deposition or by submergence of the land to sea level. Neither do the rivers show any revival or other evidence of such subsidence, but all have continuous downward cutting sections.

Whether there has been recent subsidence immediately preceding the deposition of the elevated coral reef of soboruco, whereby the circular harbors were produced, as Crosby alleges,[2] is also a point which is difficult to determine. In support of his position he points out the structure of the circular harbors and the great thickness of the older limestones, which he believed to be ancient reef rock. I have endeavored to show on a previous page that there is no evidence to support the theory that the older and elevated limestones were coralline reefs in origin, and hence it is not necessary here to discuss this testimony further.

Concerning the circular harbors, however, I must confess that Mr. Crosby has some reason for his argument, although the evidence may be more strongly interpreted to indicate elevation. Concerning these harbors, he says: —

"The coast of Cuba is probably not rising now, at least not at all points. On the beach near Baracoa the erect stumps of large trees may be seen, standing where they grew, near the low-tide mark. The numerous harbors of Cuba are nearly all formed on one plan, of which Baracoa is a good ex-

[1] Text-Book of Geology, p. 261. [2] *Op. cit.*

ample. It is an approximately circular, almost completely landlocked basin, communicating with the sea through a narrow but deep passage between broken walls of the coral rock. The larger harbors departed from this plan chiefly in their more irregular outlines, all agreeing in having deep, narrow mouths. Every harbor is at the mouth of one or more rivers, and their inlets, as I conceive, are the work, not of the sea, but of rivers at a time when the land was higher than now. While the main body of the harbor, in each case, is simply the broader and older portion of the river valley behind the barrier reef, which has been invaded by the rising sea, the circular form of many of the smaller harbors is largely due to the fact that the sand brought down by the rivers is thrown up by the sea into curved bars, cutting off the inequalities of the shore.

"During the formation of the most recent of the elevated reefs, which, as already stated, forms a level about thirty feet above the sea, the mouths of the smaller streams were behind the reef, discharging into irregular channels or basins between the reef and the shore. On account of the turbidity and freshness of the water, the reef, especially on its inner border, grew less rapidly at these points than elsewhere, the basins behind the reef becoming filled with débris from the land. When the reef was finally raised to something above its present level, each river scoured out a large part of the sand and gravel which it had deposited, and cut a narrow channel through the reef itself. During this period of elevation, Cuba, like most rising lands, had few harbors, but when subsidence began the sea occupied the channels and basins which had been excavated and cleared out by the rivers, and thus a large number of harbors came into existence.

"Opposite the mouths of larger rivers, such as the Toar and the Molasses in the vicinity of Baracoa, the reef in question was interrupted, and these streams discharged into broad, open bays, while the lower portion of their valleys show equally with the harbors that the land is sinking. They are half-drowned valleys filled to a considerable depth with land detritus, conditions which could not exist if the land was rising or had risen."[1]

The interpretation of the evidence of the harbors depends upon the correctness or incorrectness of Mr. Crosby's hypothesis that the narrow outlets through the reef rock represent a channel cut by the scouring of the rivers themselves. It may be that they are channels representing originally areas of non-coralline growth, such as are now known to exist in submerged reefs remote from areas with developed land streams and in atolls, and such as biological laws tell us should exist opposite the mouths of rivers, — such channels as now exist off shore around the coast of Cuba, where reefs are growing. Mr. Crosby admits that the reefs grew less rapidly at these points than elsewhere, on account of the turbidity of the waters.

The channel of the Havana harbor and the cañon of the Yumuri

[1] *Op. cit.*

River of Matanzas are certainly eroded in the manner Mr. Crosby alleges, not through coral reefs, but through older rocks which have been elevated across the tracks of the rivers, though most of the harbor necks in the east end of the island are certainly old submarine reef valleys, resulting merely from the fact that the coral has grown up around them. The harbor of Havana is a much better example of supposed subsidence than is that of Baracoa, but even here the channel cut out of the old Tertiary walls of the harbor does not necessarily imply that the land was formerly higher than now, for the heavy surf may be seen cutting many similar indentations into the limestone sea front, which action, with the aid of that of the rivers, could have easily made these indentations.

Concerning the mouths of the rivers themselves, their alluvial deposits and the evidence of their valleys may be interpreted to mean elevation more positively than Mr. Crosby interprets them to mean subsidence, nor can I understand why he calls them "half drowned." There is a singular absence of fiord-like valleys or indentations, or of ancient estuarine deposits, around the coast of Cuba, such as ordinarily indicate subsidence. (Plate I. Fig. 6.) In fact, the rivers in nearly all cases, like the Yumuri of the east, run directly to sea level through almost vertical chasms cut straight across the line of terraces, and are void of any terraces within their cañons, showing unmistakably that they have been cut down to sea level since the terraces and their own deltas were elevated, and that there is no superimposition indicative of subsidence previous to the reef-making epoch.

That some of these rivers do at present reach tide level a short distance from the beach is true, but so short is this distance that vessels can always obtain fresh water from them by sending light boats up stream less than a mile. I think that this slight indentation of tide level up these rivers is indicative, not of "drowning," or of an ancient subsidence, but that, on the contrary, it means merely that the rivers and surf are doing their normal work of degrading the land. If they were really drowned rivers they would be navigable some distance inland, but in the three largest streams, the Armendaris of Havana and the two Yumuris of Matanzas and Baracoa, I found it impossible to go inland over a mile in the shallowest row boat, being soon retarded by rapids.

On the other hand, these streams are new forming delta deposits in places outside their mouths, which is more indicative of present elevation than of subsidence. Furthermore, at the mouth of the Yumuri of the east these deltas were also formed immediately preceding the elevation of the coast reef, which may be accepted as evidence of elevation at that time. At any rate, if there had been any long epochs of subsidence, they would be recorded in great fiord-like valleys or low passages across the central axis of the island, such as do not exist, and to which the oval harbors may not be compared, for the origin of these is due entirely to the pre-existing fringe reefs.

It might be alleged that all the ancient topography showing subsidence is still beneath the ocean level, and that the angular edges of Cuba are indicative of the fact that the present outline merely represents an ancient summit which is re-emerging. The submarine topography, however, is not within the province of this paper, but I agree with Professor Agassiz that its irregularities were indicated long before the period of history herein recorded. The three alternations of gravel and reef in the Matanzas section may also have indicated slight alternations of subsidence and elevation.

Without committing myself to an emphatic negation as yet, I must confess that no evidences of great subsidence are apparent at present, and although I hold my conclusions upon this subject in abeyance to future observations, I seriously doubt its existence.

It is now possible, with the aid of the stratigraphic and paleontologic data previously given, to make a few conclusions concerning the Cenozoic history of Cuba. It has been shown by the stratigraphy that the topographic levels are not old reef levels, but that, with the exception of the modern reef, they have all been carved out of the old Tertiary limestones, which had previously been folded and disturbed by movements that could not have been generally uniform, but which were orogenic, and hence the present bench topography of Cuba is subsequent to this period of Post-Tertiary wrinkling, and represents a different kind of movement, which was regional or epeirogenic. Since the old folding or orogenic movement occupied at least a small portion of Post-Tertiary time, we may reasonably conclude that the two great periods of uniform uplifting recorded in the old levels must have taken place at least since the beginning of the Pleistocene. In other words, they are comparatively modern in geologic time, — some of them absolutely recent.

It is not maintained in this paper that these epochs of regional elevation were continuous and uninterrupted, or unaccompanied by pauses or even alternating epochs of subsidence, but that their general progress has been periodically upward, and that, if there were epochs of subsidence they are difficult to distinguish, and were of short duration, and insignificant in comparison with the great uplifting movement that has generally taken place.

III. RESUMÉ AND CONCLUSION.

The known geologic history of Cuba may be stated as follows : —

1. In Pre-Tertiary times an old land existed, almost as extensive in area as the present island. Whether this old land was insular, multi-insular, or connected with other Antillean areas or the mainland, I will not speculate. The submarine topography indicates that it was not. Its composition and structure, however, show that it was an area of active vulcanism accompanied by great metamorphism and eruptive flows. If there are preserved in it any traces of Pre-Tertiary sedimentation they are largely overwhelmed and almost obliterated by the vulcanism, metamorphism, and later erosion. Paleozoic, Triassic, Jurassic, and Cretaceous sediments have been reported by De Castro[1] in localities, but their physical history is unknown.

2. It is also certain that during Tertiary times, embracing the Eocene and Neocene periods, this ancient nucleal land, with all of its geographic outlines, completely subsided beneath sea level, and that it was covered with limestone sediments, which were organically derived from the sea, not the island itself, for there is no semblance of limestone material in the rocks of the Pre-Tertiary land which could have furnished material for the Tertiary rocks. That this subsidence was profound we may reasonably conclude from the thickness of the older nucleal region, now visibly covered by the limestone beds, which have been horizontally elevated to a height of at least two thousand feet. In other words, the Pre-Tertiary subsidence may have been at least to an equal depth. During this epoch of Tertiary subsidence a thousand feet of Tertiary limestone were accumulated over the old nucleal island.

3. After the close of Tertiary times the Tertiary sediments were greatly warped and folded, concurrently with an emergence of the land from the sea. This movement was orogenic.

4. Following this began the epoch of epeirogenic or regional elevation. During Pleistocene time the island underwent the first of these upward impulses to its present height, with the exception of about six hundred feet represented in still later movements. This older Pleistocene or Yunque elevation raised the main area to a height of at least two thousand feet in its eastern half, and fifteen hundred feet in its western half. How much higher it extended we cannot tell, so great has been the erosion. This elevation was so rapid and general throughout the island

[1] *Op. cit.*

that no coastal accumulations are preserved around its perimeter. This elevation likewise developed the present outline of the island almost in its entirety, and perhaps in greater area, which has since been destroyed by erosion.

5. Following this older and greater Post-Tertiary elevation, and intervening between it and the time of the Cuchilla, or five-hundred-foot level, there was a long period of erosion, cutting down the country to the Cuchilla plain, which was at that time marine base level.

6. Renewed and general elevation of the island commenced in recent time, after the period of rest recorded in the Cuchilla level. The later terraces, sea cliffs, base levels, and modern coral reefs and savanna deposits of the south coast were then elevated. It is also evident that in this later period elevation was intermittent, accompanied by slight pauses. It is difficult to exactly fix the time of this latest elevation. It was certainly very recent, and a considerable period later than the old Yunque elevation. It cannot be older than late Pliocene, and it may or may not be in progress at present.

It is not the province of this paper to discuss the history and origin of the Antillean sub-continent to which Cuba belongs, but I cannot refrain from presenting a few thoughts which may be of service to those who may consider this subject.

The old metamorphic floor represents, beyond reasonable doubt, a land that existed probably in Cretaceous time, and much of its metamorphism and igneous extrusion took place in that period. Similar phenomena have been recorded in Santo Domingo and Jamaica. In fact, it is not proved that any rocks older than Mesozoic existed upon any of these islands. Similar disturbances and excessive vulcanism and metamorphism are known to have been extensive on the Cordilleran region of the North American continent, including all of Mexico and the Cordilleran region of the United States, which have been described by the writer and others, and lately most aptly termed by Lawson the Mesozoic revolution.[1]

As I have shown in a previous paper,[2] the marine waters extended across the isthmian region of the American continent, at least during the earlier half of Cretaceous time (the Comanche epoch). Whether this was by union of the two oceans, or by an eastward indentation of the Pacific, or *vice versa*, I am not prepared to say. It is certain, how-

[1] See the Journal of Geology, Vol. I. No. 6, September-October, 1893.

[2] The Cretaceous Formations of Mexico and their Relations to North American Geographic Development, American Journal of Science, April, 1893.

ever, that during the Cretaceous, at the close of the Comanche epoch, great orogenic forces were active, and that the strike of their corrugations constantly bent eastward until in the latitude of Southern Mexico they were in the direction of this old Antillean axis, and that the latter may have been part of the protuberances marking this line of great orogenic movement, which in general was peripheral or concentric to the old Appalachian land.

How great an area was involved in the upper Cretaceous and Tertiary subsidences it is difficult to say. No attempt has been made to trace the former event in the Antilles. The latter certainly included all the great Antilles, — a region fifteen hundred miles in length from east to west, — and the Atlantic and Gulf margins of the North and South American continents, and probably all the isthmian region, which was possibly land in Upper Cretaceous time, again connecting the Gulf of Mexico.

One of the misty epochs in Cuban history is that of the folding and disturbance at the close of the Tertiary, and I can only suggest that it belongs with the orogenic phenomena which enveloped or overlapped the periphery of the older Mesozoic Cordilleran region, in Central America, and in northern South America. This involved the Tertiary formations of the other Antilles, but there is no trace of it along the northern periphery of the Gulf of Mexico.

I do not mean to say that these vast and apparently uniform regional elevations which have taken place since the earlier folding of the Miocene limestones were unaccompanied by faults or warping, but these are nowhere prominently apparent, and their importance is secondary to the former, which were not local, but general or epeirogenic in character, and involved the uplifting of the whole island approximately, uniformly, and synchronously.

That this uplifting was confined to Cuba alone of the Antilles, it would be preposterous to suppose, and we can in no way avoid the conclusion that it represents only a small portion of a great regional uplift, including much of the surrounding area of the Mexican and Caribbean gulfs. The adjacent islands must have been involved in these great regional movements, the periphery of which must have been some distance from the present island, but I do not allege that the islands were thereby connected.

Whether the movements can ultimately be correlated with those of the surrounding American coasts, or the topographic irregularities of the surrounding ocean floor, is a question which I shall not attempt to answer. We have recorded evidence that similar terrace phenomena occur in Nicaragua, Yucatan, Jamaica, and San Domingo, and the coasts of South America have participated in these regional uplifts of Pleistocene and recent time, to which the slight elevation of the Gulf coast of the United States is insignificant.

In these studies I have found no evidence that Cuba, since its earliest history (the Mesozoic) has had land connection with the United States. Unless there was some profound subsidence in Post-Tertiary time, such as I have been unable to detect, no possible deduction can make such a connection. In fact, I know of no positive evidence that it has been connected with our continent at all, and have only hypothetical evidence that the Pre-Tertiary land may have once extended toward the Yucatan peninsula, and that it was only then, if ever, that the Antillean and Cordilleran islands were united. Neither can we avoid conceiving that the subsequent elevations have brought the isthmian region up with it, making the present land connection between the continents.

The axial direction of the general Antillean Post-Tertiary elevation is approximately east and west, and hence it is presumable that the submarine ridges were more likely to have been extended in that direction, and that to the north and south of this axis, which must theoretically be the remnant of a great east and west swell or fold, there must have existed corresponding sloping sides and synclinal troughs. It is but natural, then, that evidence of the continuation of the Cuban diastrophism must be looked for in east and west lines rather than in lines north and south.

We can also reasonably conclude that the orogenic development of Cuba, begun in some unknown period of antiquity, was practically completed at the commencement of the Pleistocene, — that is, the development accompanied by displacement, folding, and vulcanism, — and that the stage of elevation then began, bringing up the old Pre-Pleistocene architecture and carving the mass into its terraces and present outlines. The group of regional elevations which I have described, although marking a wide interval of time, all occurred in a comparatively recent geologic period. To fix this time exactly would be impossible with the scant data at hand, but we can make some approximations.

The oldest of the elevations, now represented by the Yunque level, certainly followed the period of folding which the Tertiary limestones underwent after their deposition. This folding, we may safely say, was Post-Tertiary, and took place in late Pliocene or early Pleistocene time, approximately, and marks the beginning of the re-emergence of modern

Cuba, and the terraces are all of later age. Before this period, which for convenience we will call early Pleistocene (properly late Tertiary) it must be acknowledged that the area of Cuba, crests and coasts, was at least two thousand feet lower in altitude than at present. We cannot imagine that such a depression was locally limited to the island of Cuba or the Great Antilles, or that it would have abruptly terminated along the east and west axial line, and hence it is not difficult to infer, especially in the light of existing geologic evidence, that it involved the isthmian portion of the continent south of the great escarpment of the Mexican plateau, and that oceanic connection then existed between the Atlantic and the Pacific, as has been already indicated by the paleontology and by the living forms.[1]

[1] See A. Agassiz, The Origin of the West India Fauna, Mem. Mus. Comp. Zöol., Vol. X. No. 1, p. 79, 1883; also, Three Cruises of the "Blake," Bull. Mus. Comp. Zoöl., Vol. XIV., 1888.

EXPLANATION OF THE PLATES.

PLATE I.

Fig. 1. Geologic Section across the Island of Cuba from Havana to Batabano. Scale, 5 inches to 1 mile. (1) Pre-Tertiary Formations. (2) Tertiary Limestones. (3) Soboruco Reef. (4) Mud Deposit of Batabanos.

Fig. 2. Detail of Moro Plateau, North End of above Section. Figures have same reference.

Fig. 3. Dike near Water-Works, South Edge of Havana. (1) Dike Material. (2) The same, more weathered. (3) Supposed Cretaceous Clays. (4) Surface showing Tertiary Limestone on right.

Fig. 4. Geological Section of the Cañon of the Rio Yumuri of Matanzas. (1) Massive Coralline Cantera, Reef Rock, 85 feet. (2) More Arenaceous Limestone, with Molluscan Remains, 15 feet. (3) Stratified Calcareous Clay, with Molluscan Remains, 10 feet. (4) Same, with great number of small Pebbles. (5) A very white Lime Material, with Bands of Clay. (6) At Base. (7) Calcareous Matrix, with Pebble, 10½ feet. (8, 9, 10, 11) Miocene Limestone with Molluscan Remains, becoming arenaceous at Base (12).

Fig. 5. Section at Baracoa. (*a*) Sea Level; (*b*) Elevated Reef Level; (*c*) Military Hospital Level; (*d*) Cuchilla High Lands (1827), Yunque Level; (*e*) Radiolarian Hill. (1) Soboruco. (2) Miocene (?) Limestone. (3) Yellow Clays with Miocene Mollusca. (4) Hill of Radiolarian Earth.

Fig. 6. The Cañon and Terraces of the River Yumuri of the East. Vertical height, 600 feet.

Fig. 7. Section near Aguacate, showing Decay of Limestone into Red Residual Soil.

Fig. 8. Ideal Illustration of the Epochs of Elevation in Cuba. (1) Soboruco or Elevated Reef. (2) Cliffs of the Coast. (3) The Cuchilla Level. (4) The Yunque Level. (5) The Sierra Maestra.

PLATE II.

The Evolution of the Circular Harbors of the North Coast of Cuba.

Figs. 1, 2. Mouths of simple Rivers, with Fringing Reefs growing off their Points. (1) The Yumuri of the East. (2) The Limones.

Figs. 5, 6, 8. The Development of the Circular Bay, by Erosion of the softer Material back of the harder Points of elevated Reef Rock. (5 and 8, Mata Bay; 6, Baracoa.)

Fig. 7. Example of Irregular Outline resulting from still more advanced Erosion. (Harbor of Escondido.)

Figs. 3, 4. Double-mouthed Harbors produced by Elevation of Barrier Reefs in combination with the Fringing Reef. (3, Harbor of Jaragua; 4, Yamaniguey.)

Fig. 9. Matanzas Harbor, showing Yumuri Valley, Cañon, and adjacent Levels.

Note. — The artist has transposed the east and west sides in Figs. 3, 4, 5, 7, and 8.

PLATE III.

Limestone Mountains south of Matanzas.

PLATE IV.

Villa Clara, Metamorphic Mountains.

PLATE V.

Contact of Upland Plain with Limestone Hills.

PLATE VI.

Typical Plain, Central Cuba.

PLATE VII.

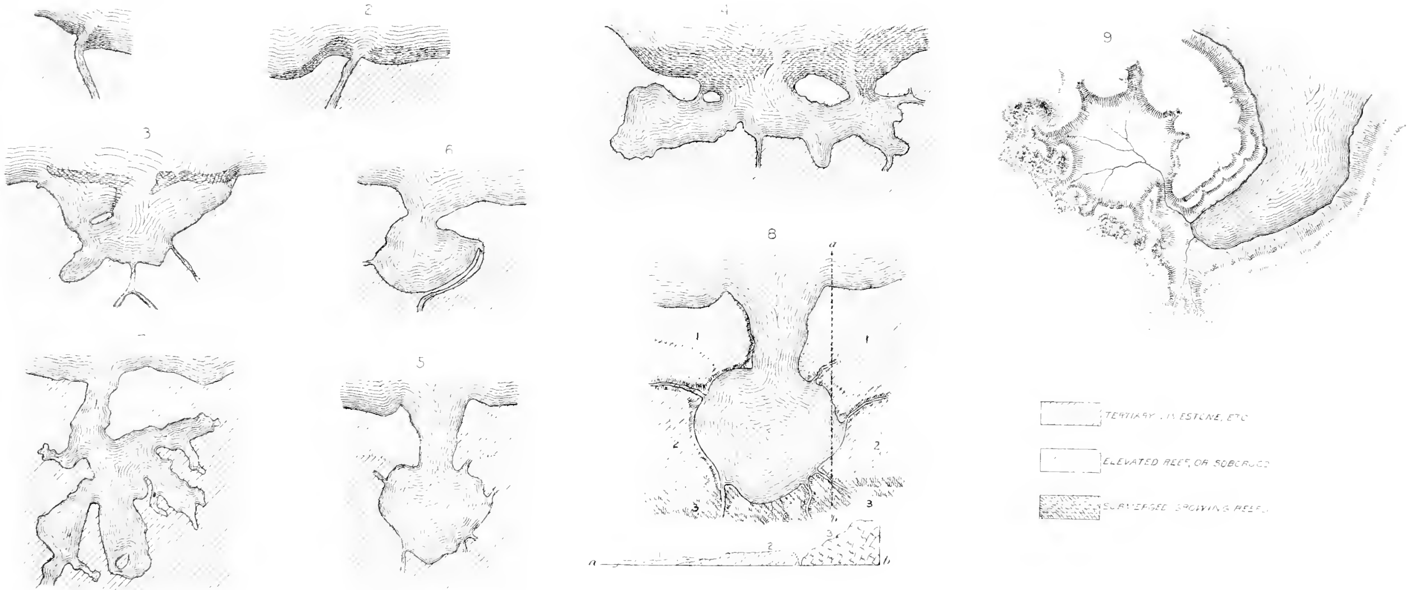
Yumuri River, Matanzas Bay.

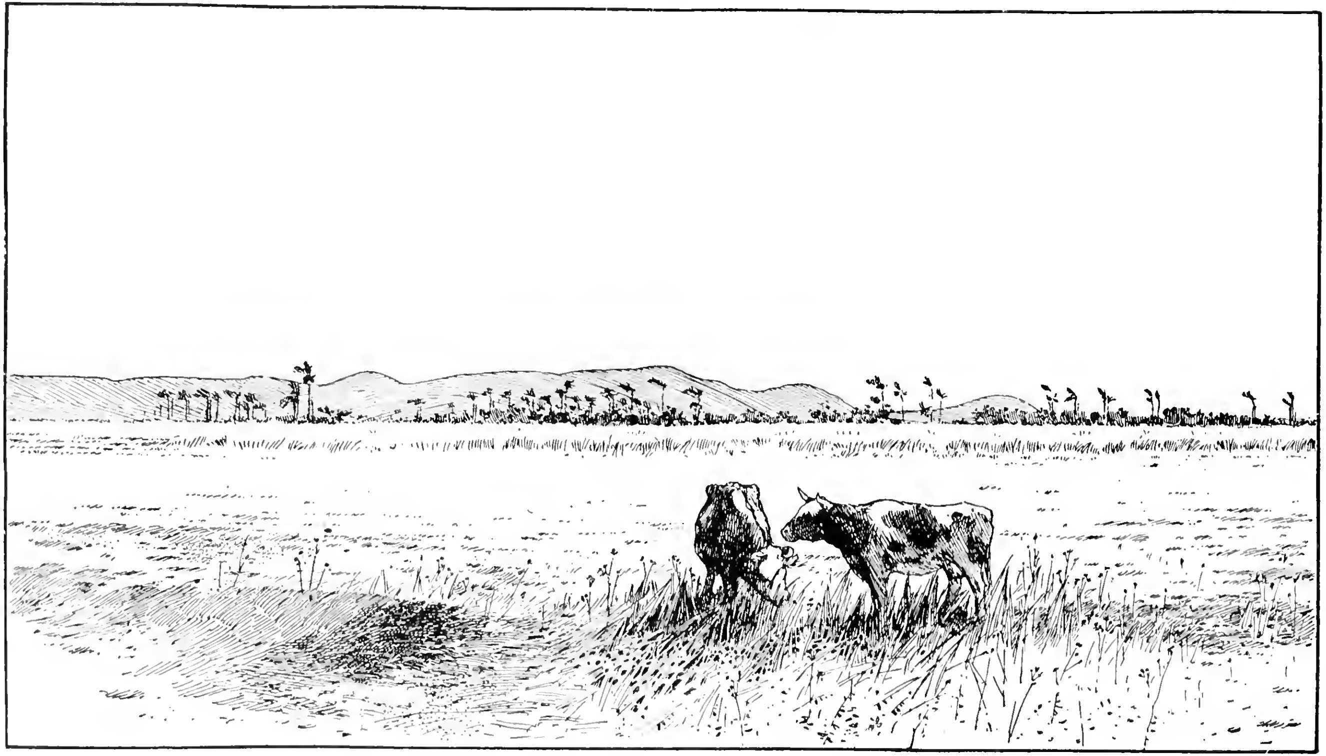
PLATE VIII.

Yumuri Valley and High Levels.

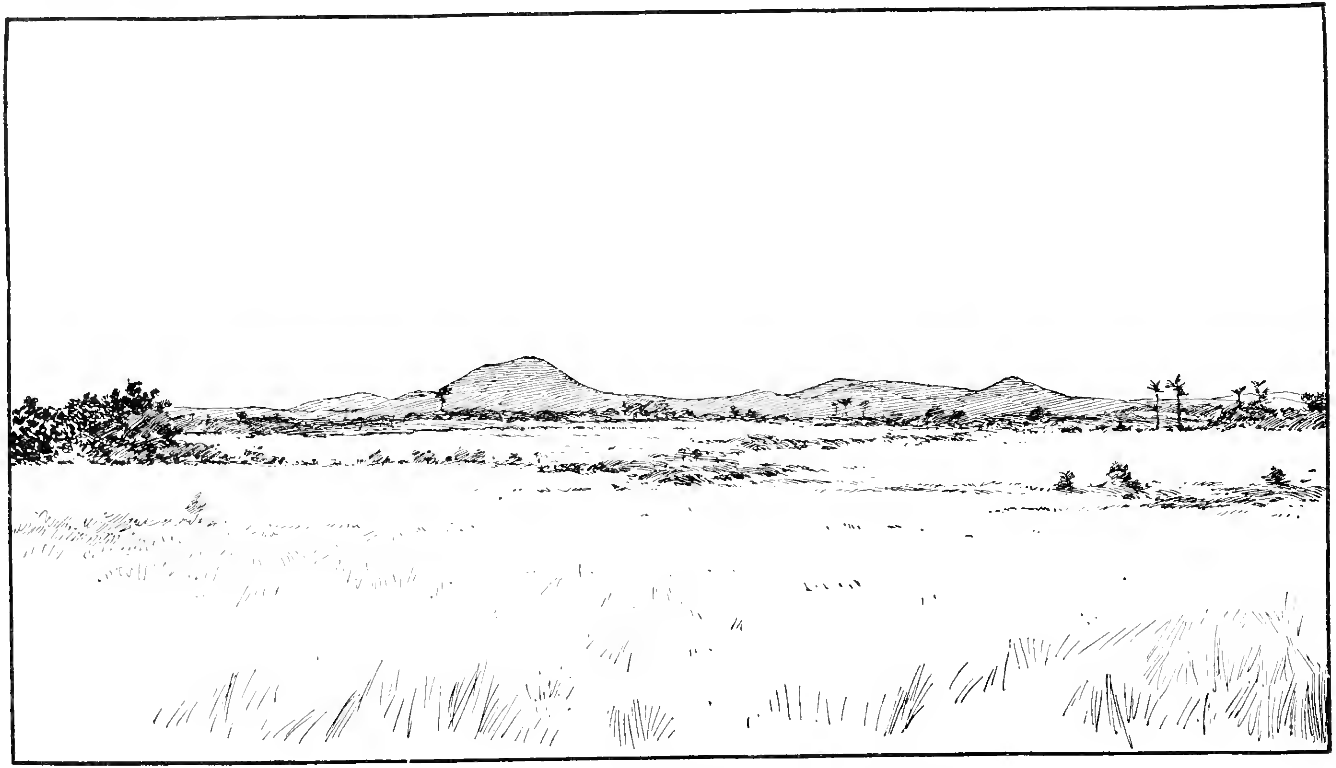
PLATE IX.

Yumuri River.


2
4
9
3
6
8
5
TERTIARY LIMESTONE, ETC
ELEVATED REEF, OR SOBORUCO
SUBMERGED GROWING REEF



LIMESTONE MOUNTAINS, SOUTH OF MATANZAS.



VILLA CLARA, METAMORPHIC MOUNTAINS.

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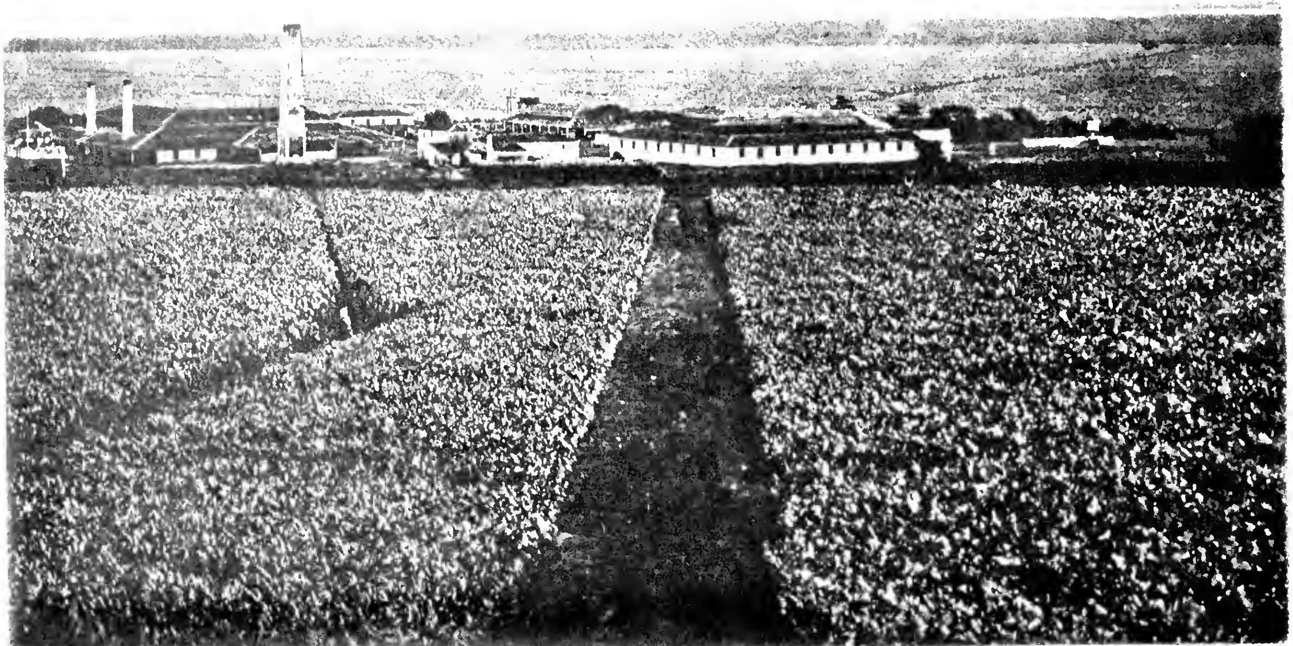
CONTACT OF UPLAND PLAIN WITH LIMESTONE HILLS.

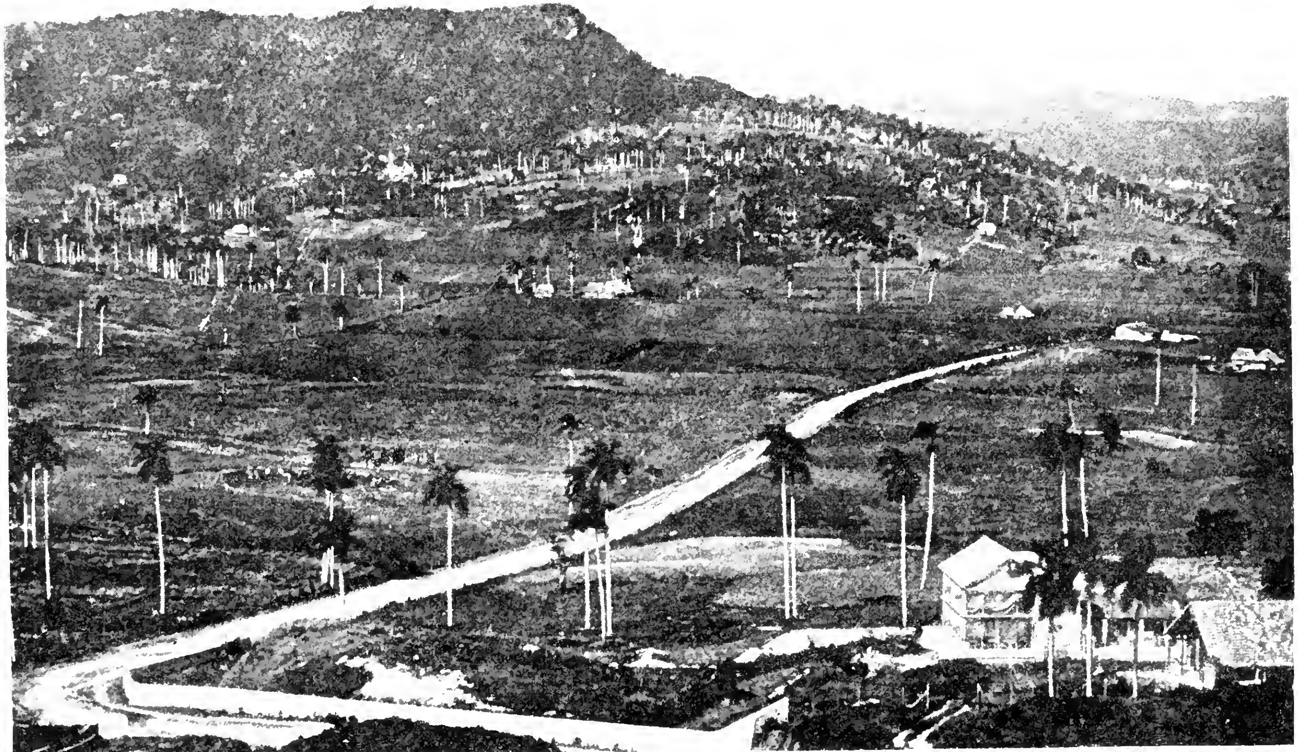


ARTOTYPE, E. BIERSTADT, N. Y.

TYPICAL PLAIN, CENTRAL CUBA.

ARTOTYPE E. BIERSTADT N.Y.

YUMURI RIVER, MATANZAS BAY



ARTOTYPE, E. BIERSTADT, N. Y.

YUMURI VALLEY AND HIGH LEVELS.

ARTOTYPE, E. BIERSTADT, N. Y.

YUMURI RIVER.